economic-technological systems are not capable of handling the competitive demands of an increasing population, the result in the model is an input to the death rate through the lifetime multiplier from food LMF or through the lifetime multiplier from health services LMHS, or a change in the birth rate. Thus it is not necessary to include an explicit influence from crowding to express the effect of the conflict of individuals for decreasing resources.

It is also possible that population pressure on resources might result not in individual competition but in socially sanctioned war and thus in an increased death rate through international conflict. Studies of past international conflicts seem to indicate that, historically at least, there is little correlation between population density per se and participation in wars, although population density may be involved in a complicated interaction with many other factors (Bremer, Singer, and Luterbacher 1971; Choucri and North 1972). Since causal theories of social conflict and technology of international warfare are both evolving rapidly, we omitted this complex conflict factor from our representation of crowding in this preliminary model. It is a sociopolitical factor that may well stop growth below the physical limits we represent, and it may be directly dependent on pressures from those limits. It is an important subject for future research.

2. Increased exposure to infectious disease. The role of population density in the transmission of infectious diseases has been recognized by epidemiologists for decades (see, for example, Taylor and Knowelden 1957, p. 199). It has been vaguely sensed by the general populace for centuries. Until this century, cities were widely known as unhealthy places to live in because of crowding and pestilence. Life expectancy in London in 1841 was 35 years, in Liverpool and Manchester it was only 26 years, while for England as a whole it was 41 years (Glass 1964). In Stockholm in the eighteenth century, life expectancy was 16 years; for all of Sweden it was 35 years. In the United States in 1830 one-half of a cohort of age 5 would survive to age 65 in rural areas, to age 56 in small cities, and to age 41 in large cities (U. N. 1953, p. 52). The spread of the last plague epidemic in France was highly associated with the pattern of population concentrations (Biraben 1968).

These statistics pertained before medical control of infectious diseases eliminated those diseases as the major cause of human deaths. As public health techniques and medical knowledge improved, the rural-urban differential in life expectancies gradually decreased. In the United States in 1901, the average life expectancy for city dwellers was 10 years lower than that of the rural population; in 1910 it was 7.8 years lower; in 1939, 2.6 years lower (U. N. 1953, p. 62). There is some evidence that in several developing countries today urban life expectancy is actually higher than rural life expectancy because sanitary improvements and medical services are available only in cities (Arriaga 1967).

The relation between population density and the death rate from infectious diseases is clear; all else being equal, as the density increases, the death rate from infectious diseases would be expected to increase. The relation between density and overall life expectancy, however, must also take into account the relative contribution of infectious diseases to the total death rate. This contribution is high only in areas

where effective health services per capita (defined previously) are low. Although crowding may have a significant effect on life expectancy in these areas, in most of the world today health services are more than adequate to control infectious disease.

A dynamic representation of the dependency of life expectancy on crowding as modified by the prevailing level of health care is shown in Figure 2-41. The influence of density on life expectancy is altered by the degree of control of infectious diseases, more control resulting in a smaller influence. "Living space" could be defined in terms of total land area or, more specifically, in terms of urban land area or actual housing space per person. Health service expenditures would be generated by the economy, as indicated in the discussion of the lifetime multiplier from health services in section 2.5.

3. Local pollution. Densely settled populations in industrialized areas create and consequently are exposed to local pollution. This pollution is dynamically different from the persistent global pollution modeled in the pollution sector of World3. Persistent global pollution includes long-lived, globally distributed pollutants that are incorporated widely in the biosphere and affect human health after a relatively long delay. They act by permeating the entire ecosystem, usually entering the human body through food or water. Examples are mercury, lead, many pesticides, polychlorobiphenyls, and radioactive wastes. Local pollution, on the other hand, consists of pollutants that are not of concern on a long-term global scale but are important to human health in industrialized, urban environments. Typically, local pollutants are absorbed by the human body with little delay after their generation, often through the lungs. Most of them are included in the designation "air pollution": sulfur and nitrogen oxides, carbon monoxide, complex hydrocarbons, asbestos, and airborne particles of some materials that are later dispersed to become global pollutants (mercury, lead, cadmium). Other important local pollutants may include contaminants of local water supplies and noise.

The relation between local pollution and human mortality has been documented in several large cities. Only a few examples from the growing epidemiological literature on air pollution will be cited here. During a two-week period in New York in 1963 an unusual increase in the concentration of sulfur dioxide (SO_2) to about twice its normal value resulted in an increase in overall mortality by a factor of about 1.2. There were statistically significant increases in deaths due to influenza-pneumonia,

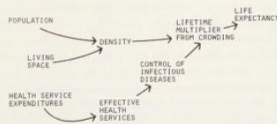

Figure 2-41 Influence of crowding on life expectancy through infectious diseases