100,000 at age 65 (l_x column). These survivors will collectively live a total of 49,873 more years (sum of the last 5 values of L_x column), or an average of 7.9 years per person (49,873/6,324); therefore:

M4 = 1/7.9 = 0.126.

Since we are not concerned with the age structure within each of the four age levels, this assumption of exponential decay at a constant rate is within the computational accuracy we require.

The maturation rate MATN (N=1−3) from each population level to the next higher level is also formulated in the simplest possible way—as a first-order delay, with the delay time equal to the average number of years each person spends in the age level. The number of deaths each year is subtracted from the age level, so only survivors are moved into the next higher level.

```
5     R    MAT1.KL=(P1.K)(1-M1.K)/15
9     R    MAT2.KL=(P2.K)(1-M2.K)/30
13    R    MAT3.KL=(P3.K)(1-M3.K)/20
```

This formulation assumes that deaths within the level are evenly distributed by age. Such an assumption introduces a slight error into the calculation, the error being greater under conditions of high mortality. As we shall see in the comparative model runs in section 2.6, this small discrepancy does not seriously alter the dynamic behavior modes of the model system.

The total death rate in the four-level model is the sum of the deaths in each age level. The birth rate can now be expressed as a function of the size of the reproductive-age population P2. Thus the expression POP.K*FFW in the birth rate equation of the one-level model can be replaced by P2.K*0.5 in the four-level model. The factor 0.5 arises from the assumption that half the population in P2 is female.

```
17    A    D.K=D1.JK+D2.JK+D3.JK+D4.JK
18    S    CDR.K=1000*D.K/POP.K

30    R    B.KL=CLIP(D.K,(TF.K*P2.K*0.5/RLT),TIME.K,PET)
      C    RLT=30
      C    PET=4000
31    S    CBR.K=1000*B.JK/POP.K
```

This four-level population model is an improvement over the one-level model in that it recognizes the existence of a delay between the birth rate and the reproductive population. It also incorporates some of the known nonlinearities in human death rates as a function of age. However, the four-level model is still far from accurate, since it represents the proper *time lags* in the age structure but misrepresents the *order*, or response-shape, of the delay. (The dynamic distinction between various orders of delay is illustrated in Appendix F at the end of this book.) If there were a sudden rise in the birth rate, a real population would show a rise in the reproductive population only after a delay of about 15 years. The shape of that rise would probably be best represented with an intermediate-order delay (third- to sixth-order). The delay would not be infinite-order, since that would imply that all children reach sexual

maturity at exactly the same age. It would also not be first-order, since that would imply that some portion of the newborn children mature with no delay. The one-level population model assumes no delay at all between birth and sexual maturity. The four-level model assumes a 15-year, first-order delay. The more complex age disaggregation that follows represents a 15-year, fourth-order maturation delay between birth and reproduction; it also captures accurately the nonlinearities in the distribution of human deaths as a function of age.

Fifteen-Level Model The fifteen-level age-structure model is similar in concept to the four-level model, but the levels encompass an age span of five years or less. A partial DYNAMO flow diagram of this model is shown in Figure 2-81.

To represent the particularly high mortality risk characteristic of the first year of life, the first age level P1 contains only the population aged 0–1. The level P1 is increased by births B, decreased by deaths D, and decreased by maturation MAT1. The initial value of this level, as well as all succeeding levels, is taken from Figure 2-79. The number of deaths of 0- to 1-year olds D1 is calculated from the number of persons in the level P1 times the age-specific mortality M1 (derived from the variable life expectancy LE as described previously). The table values are taken directly from the m_x column of the model life table (U.N., 1956) and are illustrated in Figure 2-82. The maturation rate each year MAT1 from P1 to the next age level P2 simply equals the total number of 0- to 1-year-olds P1 minus the number that died D1.

```
NOTE  AGE 0-1
L     P1.K=P1.J+(DT)(B.JK-D1.JK-MAT1.JK)
N     P1=P1I
C     P1I=5.3E7
A     D1A.K=P1.K*M1.K
A     M1.K=TABHL(M1T,LE.K,20,70,10)
T     M1T=.40/.28/.20/.14/.07/.02
R     D1.KL=D1A.K
R     MAT1.KL=P1.K-D1A.K
```

The level of 1- to 4-year olds P2 is modeled similarly, except that it encompasses 4 years instead of 1 year. Therefore, the maturation rate MAT2 to the next level is 1/4 of the contents of level P2 minus the number of deaths that have taken place. This formulation of the maturation rate again assumes that within the four-year level the population is evenly distributed by age and that the deaths occur equally at all ages. This assumption is more accurate in the fifteen-level model than it was in the four-level model.

```
NOTE  AGE 1-4
L     P2.K=P2.J+(DT)(MAT1.JK-D2.JK-MAT2.JK)
N     P2=P2I
C     P2I=2.1E8
A     D2A.K=P2.K*M2.K
A     M2.K=TABHL(M2T,LE.K,20,70,10)
T     M2T=.08/.05/.03/.02/.008/.002
R     D2.KL=D2A.K
R     MAT2.KL=(P2.K-D2A.K)/4
```

The formulation of the P3 level is exactly analogous to that of P2, except that P3 is a five-year level, so the maturation rate MAT3 is divided by 5. All subsequent