WORKING PAPER

DDMSLT:
A Computer Program for Estimating the Duration-Dependent Multistate Life Table Model

Charles A. Calhoun

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IIASA
International Institute
for Applied Systems Analysis

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Foreword

Demographic transitions from one state to another - such as from married to divorced or from working to not-working - are often considered to depend not only on age but also on the duration in the status. Yet the traditional life table methodology to describe these phenomena can only account for one demographic time dimension (mostly age).

This paper is in line with recent IIASA efforts to generalize the life table approach to account for at least two relevant demographic time dimensions (age and duration). It presents a computer program that conveniently estimates the duration-dependent multistate life table model which was suggested in earlier papers by Douglas Wolf.

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1. INTRODUCTION

DDMSLT is a micro-computer program for estimating the duration-dependent multistate life table model that was originally developed at IIASA by Douglas Wolf (1988). DDMSLT is for general applications to multistate problems with n_1 states from which transitions are age-dependent and n_2 states from which transitions are dependent on both age and duration. The program allows for duration-preserving transitions and for an open-ended duration category. DDMSLT was written using the GAUSS Mathematical and Statistical System (Edlefsen and Jones, 1986), which is also required for running the program.

DDMSLT accepts input data based on (1) totals, (2) rates, or (3) transition probabilities estimated by other programs. The program also allows for mortality data that are organized by (a) age, (b) state and age, or (c) state, age, and duration. Most of the work involved in rearranging the data and computing rates is done by the program. The output from the program is a vector of survival proportions (life table $l(x)$ values), and a collection of GAUSS procedures (memory resident subroutines), that can be used to compute person years of exposure (life table $L(x)$ values) and life expectancies (life table $T(x)$ values). The first time the program is run, the vector of survival proportions is computed and saved to disk. Auxillary programs for computing and tabulating life tables from the vector of survivors are also provided.

Section 2 summarizes the general model and presents the formulas upon which the calculations in the program are based. This section draws heavily on the paper by Wolf (1988), with some modification of the notation to simplify the presentation of the general model including both age and duration-dependent states, duration-preserving transitions, and an open- ended duration category. Section 3 describes the parameters that must be provided before running the program. Instructions on how to prepare the data for input into DDMSLT are given in section 4. Section 5 summarizes the outputs from the program, and section 6 discusses future developments.

2. THE DURATION-DEPENDENT MULTISTATE LIFE TABLE MODEL

The notation employed in this section generalizes that used by Wolf (1988) in order to present the DDMSLT model that simultaneously includes a mixture of age-dependent and duration-dependent states, duration-preserving transitions, and an open-ended duration category. For clarity, one-year age groups and duration categories are used except where noted explicitly. The DDMSLT model uses transition rates or probabilities that are conditioned on the "duration category occupied at the last birthday." Thus, an individual in duration-dependent state i at age x can be in duration category d, where $0 \leq d \leq x$. The number of individuals in n_1 age-dependent states and n_2 duration-dependent states at exact age x is given by the $(n_1 + n_2(x+1))$-element column vector $l(x)$, arranged by states and durations according to:

$$l(x) = [l_a(x)' \; l_d(x,0)' \; l_d(x,1)' \; l_d(x,2)' \cdots l_d(x,x)']' \quad . \tag{1}$$

The elements of $l(x)$ include the $(n_1 \times 1)$ vector $l_a(x)$ for the number of individuals in each of the age-dependent states, and a sequence of $(n_2 \times 1)$ vectors, $l_d(x,d)$, $d = 0,1,2,...,x$, for the numbers of individuals in each of the duration-dependent states for durations 0 up to and including current age x.[1] When there is an open-ended duration category u, and $u < x$, then the last element of $l(x)$ is $l_d(x,u)$.

$l(x+1)$ is computed from $l(x)$ by first multiplying $l(x)$ by a matrix $A(x)$ that inserts an $(n_2 \times 1)$ column vector of zeros, call it $l_d(x,\Delta)$, after the age-dependent vector $l_a(x)$.[2] The transformed version of $l(x)$, call it $l^*(x)$, is then multiplied by an $(n_1 + n_2(x+2) \times n_1 + n_2(x+2))$ square matrix of transition probabilities, $P^*(x)$, rearranged to account for age-dependent, duration-dependent, and duration-preserving states. The general form of $P^*(x)$ is given by (2).

$$P^*(x) = \begin{bmatrix} P_{aa}(x) & P_{ad}(x,\Delta) & P_{ad}(x,0) & P_{ad}(x,1) & P_{ad}(x,2) & \cdots & P_{ad}(x,x) \\ P_{da}(x) & P_{dd}(x,\Delta) & CP(x,0) & CP(x,1) & CP(x,2) & \cdots & CP(x,x) \\ 0 & 0 & DP(x,0) & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & DP(x,1) & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & DP(x,2) & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & DP(x,x) \end{bmatrix} \tag{2}$$

[1]Strictly speaking, an individual can be in duration category x at exact age x only if they were born into a duration-dependent state. States for which duration is equivalent to age for all individuals (e.g., never-

$P_{aa}(x)$ is an $(n_1 \times n_1)$ matrix of probabilities for transitions between age-dependent states. $P_{da}(x)$ is an $(n_2 \times n_1)$ matrix of probabilities for transitions from age-dependent states to duration-dependent states. The sequence of $(n_1 \times n_2)$ matrices $P_{ad}(x,d)$ for $d = \Delta, 0,1,...,x$ account for transitions from duration-dependent states to age-dependent states.[3] A corresponding sequence of matrices $P_{dd}(x,d)$ for $d = \Delta, 0,1,...,x$ for transitions among duration-dependent states is represented in $P^*(x)$ by $P_{dd}(x,\Delta)$, $DP(x,0),..., DP(x,x)$, $CP(x,0),..., CP(x,x)$, where $P_{dd}(x,d) = CP(x,d)+DP(x,d)$ for $d = 0,1,2,...,x$. When a transition from state j to state i is duration-preserving, then the ij-th element of $P_{dd}(x,d)$ appears as the ij-th element of $DP(x,d)$ and the corresponding element of $CP(x,d)$ is assigned a zero value. Otherwise, the ij-th element of $P_{dd}(x,d)$ appears as the ij-th element of $CP(x,d)$. Making no transition or a transition to the same duration-dependent state are always treated as duration-preserving. In the absence of any other duration-preserving transitions $DP(x,d)$ will be an $(n_2 \times n_2)$ matrix with diagonal elements corresponding to the main diagonal of $P_{dd}(x,d)$ and zeros elsewhere, while $CP(x,d)$ is $P_{dd}(x,d)$ with the main diagonal replaced by zeros.

Multiplication of $l^*(x)$ by $P^*(x)$ results in the $(n_1 + n_2(x+2))$-element column vector $l(x+1)$, also arranged by states and durations, but with an additional n_2 elements to account for the individuals who now occupy duration category $x+1$. This procedure continues until the maximum age, or until age exceeds the open-ended duration category u, at which point the matrix $A(x+1)$ is altered so as to result in the addition of the numbers of individuals in the last two duration categories of $l(x+1)$ into one category. For all subsequent ages the vector $l(x+1)$ contains $(n_1 + n_2(u+1))$ elements. Calculation of $l(x+1)$ is summarized in matrix notation by (3).

$$l(x+1) = P^*(x)A(x)l(x) \tag{3}$$

married, never-worked, etc.) should be classified as age-dependent states.

[2]These "place-saving" zeros, are included to account for transitions that place individuals in duration category 0 at age $x+1$. See the discussion of duration category Δ in Wolf (1988) and footnote 3 below.

[3]Duration category Δ is included to account for individuals who enter a duration-dependent state during the interval $[x,x+1)$, and must therefore be assigned to a special duration category until exact age $x+1$ is reached and they can be assigned to duration category zero. Note that one cannot occupy duration category Δ on one's birthday (Wolf, 1987, p. 13), so that in the life table calculations $l_d(x,\Delta) \equiv 0$. This restriction is imposed at each step of the calculations when $l(x)$ is transformed to $l^*(x)$ through multiplication by the matrix $A(x)$.

2.1. Calculating Transition Probabilities

If the input data are observed numbers of deaths, transitions, and population totals tabulated by age and duration defined by year of birth and year of last event, then the program computes the age-duration-specific rates required for the DDMSLT model according to the formula:

$$R(x,d) = \begin{cases} E(x,0)/N(x,0) & \text{if } d = \Delta \\ (1/2)E(x,d)/N(x,d) + (1/2)E(x,d+1)/N(x,d+1) & \text{if } 0 \leq d < min(u,x) \\ E(x,d)/N(x,d) & \text{if } d = min(u,x) \end{cases} \quad (4)$$

where $E(x,d)$ and $N(x,d)$ are numbers of events and population totals, respectively, and $R(x,d)$ is the resulting age-duration-specific transition or death rate. This entails the assumption that the underlying transition intensities are constant over the square subregions defined by age-at-last-birthday and duration-at-last-anniversary. When the input data are already in the form of transition rates, it is assumed that these correspond to $E(x,d)/N(x,d)$ and the program automatically computes the appropriate $R(x,d)$ values. The transition rates for age x are arranged in an $(n_1 + n_2(x+2) \times n_1 + n_2(x+2))$ transition matrix $M^*(x)$ and used to compute $P^*(x)$ under the linear-integration formula given by (5).

$$P^*(x) = [I + (1/2)M^*(x)]^{-1} \, [I - (1/2)M^*(x)] \quad (5)$$

Wolf (1988) should be consulted for further details on the construction of $M^*(x)$.

When the input data are age-duration-specific transition probabilities, such as those which might be computed from the estimated parameters of a regression model for discrete transition probabilities or continuous intensities (hazard functions), the program assumes that age and duration are measured exactly and proceeds to tabulate the vector of life table $l(x)$ values. It is assumed that no information is available on multiple transitions within an age interval, so that $P_{dd}(x,\Delta)$ is an $(n_2 \times n_2)$ identity matrix, and $P_{ad}(x,\Delta)$ is an $(n_2 \times n_1)$ zero matrix. This is equivalent to assuming that multiple moves among duration-dependent states between exact ages x and $x+1$ are always to the same state, so that no observed transitions are recorded. This results in no loss of information about the tabulated $l(x)$ vector, given that $l_d(x,\Delta) \equiv 0$.

3. INPUT PARAMETERS

The following parameters must be provided before running the program:

n_1 – The number of states from which transitions are age-dependent. Examples are the state "never-married" in a marital-status life table, or the state "never-worked" in a table of working life.

n_2 – The number of states from which transitions are duration-dependent. Examples are the states "married," "divorced," or "widowed" in the marital status life table, or "employed" and "non-employed" in the table of working life.

n_3 – The number of duration-preserving transitions, that is, those which can occur between duration-dependent states that do not result in the duration value being reset to zero. An example would be the working life table model with employment statuses defined by "part-time" and "full-time" employment, and duration defined by "length of current employment." Transitions from part-time to full-time work and vice versa are duration-preserving since there is no interruption in current employment. See the definition of mask below.

a_1 – The minimum age used in the life table calculations.

a_2 – The maximum age used in the life table calculations. This corresponds to the final $x+1$ value. The program assumes that data are provided for intervals beginning with exact ages a_1, a_1+1, ..., a_2-1. The values of $l(x)$ will be computed for a_1 to a_2.

u – The open-ended duration category u. All individuals with duration greater than or equal to u are allocated to this category. When there is no open-ended category then use $u = a_2$.

width – The width of the age groups and duration categories in years, usually 1 or 5. The program automatically adjusts for the width of the age groups and duration categories. The values of a_1, a_2, and u should represent years and not numbers of categories. For example, the model that uses data on 5-year age groups starting with exact ages 0, 5, ..., 85, and duration categories 0–4, 5–9, 10–14, and 15 or more years, the correct parameter values are $a_1 = 0$, $a_2 = 90$, $u = 15$, and width $= 5$.

data – The type of input data: $= 1$ if totals, $= 2$ if rates, $= 3$ if probabilities.

last – Last age group open or closed: $= 0$ if last age group is open, $= 1$ if last age group is closed (everyone dies between age a_2-1 and age a_2). When *last* $= 1$ and the data are totals or rates, person-years lived in the last interval are computed using the product of the inverse of the matrix of transition rates and the vector of survivors to exact age a_2-1. When the data are based on probabilities no adjustment to the last age group is taken.

deaths – The type of mortality data: $= 1$ if age-specific, $= 2$ if age- and state-specific, $= 3$ if age-state-duration-specific.

radix – The radix for the DDMSLT model is a column vector with the n_1 radix elements of the age-dependent states listed first, followed by the n_2 radix elements of the duration-dependent states. When $n1$ or n_2 are zero, no radix elements are given for those states. When n_1 or n_2 are positive, but no one originates in a particular age- or duration-dependent state, then the radix value for that state is zero.

mask – An ($n_3 \times 2$) matrix of ordered-pairs corresponding to the duration-preserving transitions. It is assumed that the states are numbered $1,2,...,n_1,n_1+1,...,n_1+n_2$. If the duration-preserving transitions are $3 \rightarrow 4$, $3 \rightarrow 5$, $4 \rightarrow 3$, $4 \rightarrow 5$, $5 \rightarrow 3$, $5 \rightarrow 4$, then mask is defined by the matrix:

$$\begin{bmatrix} 3 & 4 \\ 3 & 5 \\ 4 & 3 \\ 4 & 5 \\ 5 & 3 \\ 5 & 4 \end{bmatrix}$$

In this example, the value n_3 for the number of duration-preserving transitions would be set to 6. Transitions to the same state are always duration-preserving and are not listed in mask or counted in n_3.

4. INPUT DATA

Once the input parameters have been specified, the input data need only be organized in a simple pattern. Input data for the life table computations will be read from the following GAUSS data files:

If data = 1:

m.dat – observed transitions
p.dat – observed population totals
d.dat – observed death totals

If data = 2:

mr.dat – transition rates
dr.dat – death rates

If data = 3:

mp.dat – transition probabilities
dp.dat – death probabilities

The files must be GAUSS data files. Only those that will be used need to exist before running the program. Each file should consist of a single variable, with any name the user selects. The CONVERT and ATOG utilities provided with GAUSS can be used to convert ASCII files to GAUSS data files.

4.1. Transition Data

DDMSLT is designed to used state-age-duration-specific transition data organized as follows: Data for transitions between age-dependent states are given first, following the pattern: $1 \rightarrow 2$, $1 \rightarrow 3$, ..., $1 \rightarrow n_1$, $2 \rightarrow 1$, $2 \rightarrow 3$, ..., $2 \rightarrow n_1$, ..., $n_1 \rightarrow 1$, ..., $n_1 \rightarrow n_1 - 1$. Here $i \rightarrow j$ represents the vector of age-specific transitions from state i to state j. This results in the first $n_1\ (n_1 - 1)A$ terms, where A is the number of age groups. Note that no accounting is made of transitions to the same state, so that if there is only one age-dependent state there will be no entries made at this point.

Next come the data for transitions from age-dependent states to duration-dependent states. These are organized in a similar manner, following the pattern: $1 \rightarrow n_1+1$, $1 \rightarrow n_1+2$, ..., $1 \rightarrow n_1+n_2$, ..., $2 \rightarrow n_1+1$, $2 \rightarrow n_1+2$, $2 \rightarrow n_1+n_2$, ..., $n_1 \rightarrow n_1+1$, ..., $n_1 \rightarrow n_1+n_2$. This results in an additional $n_1 n_2 A$ terms.

The data on transitions among duration-dependent states follow the same general pattern, except that for each age x there are additional terms specific to durations up to and including the minimum of x and the open-ended duration category u. Thus, transitions between duration-dependent states i and j at age x are given for durations categories 0, 1, 2, ..., $min(x,u)$. Again, there is no accounting for transitions to the same state, so if there is not more than one duration-dependent state no entries will be made. This results in another $n_2(n_2-1)[D(D+1)/2 + D(A-D)]$ terms where D is the number of duration categories.

Finally, we have the data for transitions from duration-dependent origin states to age-dependent states. These are organized in the same manner as transitions among duration-dependent states and result in an additional $n_1 n_2[D(D+1)/2 + D(A-D)]$ terms. Note that in the case of one duration-dependent state, entries will still be made here if there are any age-dependent states.

4.2. Population Data

The data on population totals are given by state, age, and where relevant duration. Again, the data on age-dependent states should precede those for duration-dependent states. In the case of more than one age- or duration-dependent state it is not necessary to repeat the population at risk of transition for each possible destination state. The program will automatically expand the vector of population totals to match the dimensions of the vector of transitions. The vector of population totals should have $n_1 A + n_2[D(D+1)/2 + D(A-D)]$ terms.

4.3. Mortality Data

If only age-specific mortality data are available (deaths = 1) then the totals, rates, or probabilities should be listed by age in the appropriate GAUSS data file. If state-age-specific mortality data are used (deaths = 2), the data for age-dependent states should be given first, followed by those for the duration-dependent states. When state-age-duration-specific mortality data are used (deaths = 3), the program will expect the data to be in the same format as was indicated for the population totals (see above). The program will expand the vector of death totals to match the vector of population totals to compute death rates, and again to match the dimensions of the vector of transition rates or probabilities.

5. OUTPUTS AND AUXILLARY PROGRAMS

Running the program DDMSLT produces a vector of state-age-duration-specific $l(x)$ values that are automatically save to disk. These can be recalled to memory, along with a set of GAUSS procedures for tabulating life table values. Procedures for computing specific entries of the $l(x)$, $L(x)$, and $T(x)$ columns of the duration-dependent multistate life table are included, along with instructions on how to modify the utilities to generate alternative tabulations.

6. FUTURE DEVELOPMENTS

6.1. Multistate/Multiregional Life Tables

The current version of the program has been designed for the estimation and tabulation of multistate life tables, and will not produce all of the summary measures associated with the more general multistate/multiregional life table model of Willekens and Rogers (1978). While it is possible to compute many of the same summary measures for persons originating in different states (places of birth) by running DDMSLT with different radix values, one cannot, for example, compute life expectancy by current state (place of residence). Future developments will include auxillary programs for tabulation of the duration-dependent multistate/multiregional model.

6.2. Maximum Problem Size

The maximum size of the model that can be estimated depends on the number of states, duration categories, and age groups according to the following formula:

$$n_1(n_1+n_2-1)A \ + \ n_2(n_1+n_2-1)[D(D+1)/2 + D(A-D)] \leq 8190$$

where D is the number of duration categories and A is the number of age groups. Thus, if the number of duration categories is small, models with a large number of states and age groups can be estimated. This makes the possibility of specifying an open-ended duration category quite useful. In principle it would be possible to make the limit correspond only to the number of states, but this would require sacrificing the advantages of speed offered by the use of matrix operations in GAUSS. Aptech Systems, the distributors of GAUSS, have announced that the current maximum array size of 8190 cells (approximately 64K) will be increased with the release of an 80386/80387 version of GAUSS in 1989. At that time this restriction will no longer hold, and the maximum problem size will depend only on available memory. Through the use of partitioned inverses, the dimension of the largest matrix that must inverted directly has already been limited to n_1+n_2. For problems with no duration-dependent states ($n_2 = 0$) the largest problem is limited to 9 states and 113 single-year age groups, or 20 states and 21 five-year age groups (e.g., 0, 5, ..., 100).

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