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DEMOGC:
DEMOGRAPHY WITH DISTRIBUTED AGE COHORTS

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COMPUTER LIBRARY FOR AGRICULTURAL SYSTEMS SIMULATION

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July 1976

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DEMOGC Documentation

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July, 1976

George E. Rossmiller
Director
Agricultural Sector Analysis and
Simulation Projects

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1. *Symbolic Name*	2. *Name*	3. *Type*	4. *Version No. and Date*
DEMOGC	Demography with Distributed Age Cohorts	component	1A 5/1/74

DEMOGC Abstract

DEMOGC models the demographic cohort-survival processes of birth, death, migration and aging for a population disaggregated by age and sex. The length of a cohort is an average of the time individuals take to pass through the cohort; i.e., cohort staying times vary among individuals in the population. DEMOGC may be used, for example, for populations of trees, capital equipment, livestock, insects and humans --where "age" cohorts may be defined by such age-related characteristics as yield, reliability, fertility, instar and use of social services, respectively.

Age cohorts are modeled by distributed delays which assume individual staying times in a cohort are random variables following an Erlang distribution. The delays are non-conservative to handle storage losses due to deaths and migrations, and the means of the distributions, i.e., the average staying times, may be time varying. Finally, the user has the option of specifying whether births are to be endogenous (i.e., by natural reproduction) or treated as an input (e.g., overt plantings in the case of tree populations).

Inputs to DEMOGC are age-sex specific proportional fertility, death and net out-migration rates and mean delay times. DEMOGC computes population levels (total and by age and sex), births, deaths, migrations, the sex ratio, crude birth and death rates and the population's natural and net growth rates.

DEMOGC requires 429 decimal words of core storage and 6.0 milliseconds to execute (with three cohorts for each of two sexes) on a CDC 6500 computer.

I. Process Description

One of the components most commonly found in large-scale socioeconomic systems models is a population dynamics model. Population models, at one extreme, are often simple models in which a constant exponential growth rate is applied to an initial population level. At another extreme are found complex demographic systems in which the population is disaggregated by age, sex, income class, education level, geographic area, employment, etc.; fertility and death rates for each category are determined endogenously by socioeconomic conditions in the larger model; and migrations among categories are also linked to factors in the larger system.

DEMOGC takes a middle course in order to increase its general usefulness. Aggregated exponential growth models, for anything but very macro analyses, limit too greatly considerations of socioeconomic feedback effects on population growth and of population distribution effects on demographic outputs to the larger system. Demographic models which, on the other hand, disaggregate the population along several dimensions and compute fertility, death and migration rates endogenously have limited applications--limited to situations where the designated dimensions are applicable and where the chosen factors and functional forms determining fertility death and migration rates are appropriate. In addition, where the population model is but one component of a much larger model, the use of computer resources (i.e., execution time and core requirements) becomes a real constraint to the use of the more disaggregated models. DEMOGC is general enough, however, to be used, if desired in a particular application, as a subcomponent of a larger population component which

computes the feedback effects to and from a still larger socioeconomic model and thus passes endogenous fertility, death and migration rates to DEMOGC as inputs. In addition, such a larger population component can use DEMOGC repetitively to treat a multidimensional disaggregation of a single population as a collection of populations with possible migrations among them.

DEMOGC itself disaggregates a population by age and sex, and cohort-specific fertility, death and migration rates are treated as possibly time-varying inputs. The user has the flexibility to collapse either the sex dimension or the age dimension or both if greater aggregation is desired. For example, for capital equipment populations, the sex dimension may not be appropriate. Even for cases where disaggregation by sex is inappropriate, the "sex" dimension may be redefined and used for another classification, e.g., modern and traditional biological varieties of cocoa trees. Further, the user has the option of specifying that births are not to be generated within the population by natural reproduction but rather by external factors or decisions. Again, capital equipment populations serve as an example, where "births" are investment decisions.

Finally, age cohorts in DEMOGC are modeled as distributed delays (using CLASS component DELLVF) wherein the length of time spent in each cohort varies from individual to individual in the population, e.g., due to genetic or environmental differences. DELLVF also accounts for cohort population losses and additions due to factors other than aging, e.g., deaths and migrations. The average staying time in each cohort is treated as an input to DEMOGC and may change over time depending on conditions in a larger model. In this way, age cohorts may be defined

not by chronological age but by some other age-varying characteristic. Continuing the capital equipment example, if it can reasonably be assumed that reliability (or productivity) and maintenance requirements vary with age <u>in general</u> but that <u>individual</u> pieces of equipment of the same age may exhibit different degrees of reliability and maintenance requirements (i.e., individuals "mature" at different rates)--then the use of distributed delays is appropriate. If fixed age cohorts are desired, CLASS component DEMOGD may be used in place of DEMOGC.

The technical description of DEMOGC, which follows, is presented with reference to the illustrative use of DEMOGC as a simplified version of a demographic cattle model developed for a region of Colombia [1]. Three age cohorts are defined (Figure 1). For females, the three cohorts represent heifers, producing cows and old cows, respectively. For males, the output of the second cohort is considered finished males, all of which are sold for slaughter, so the third cohort remains empty.

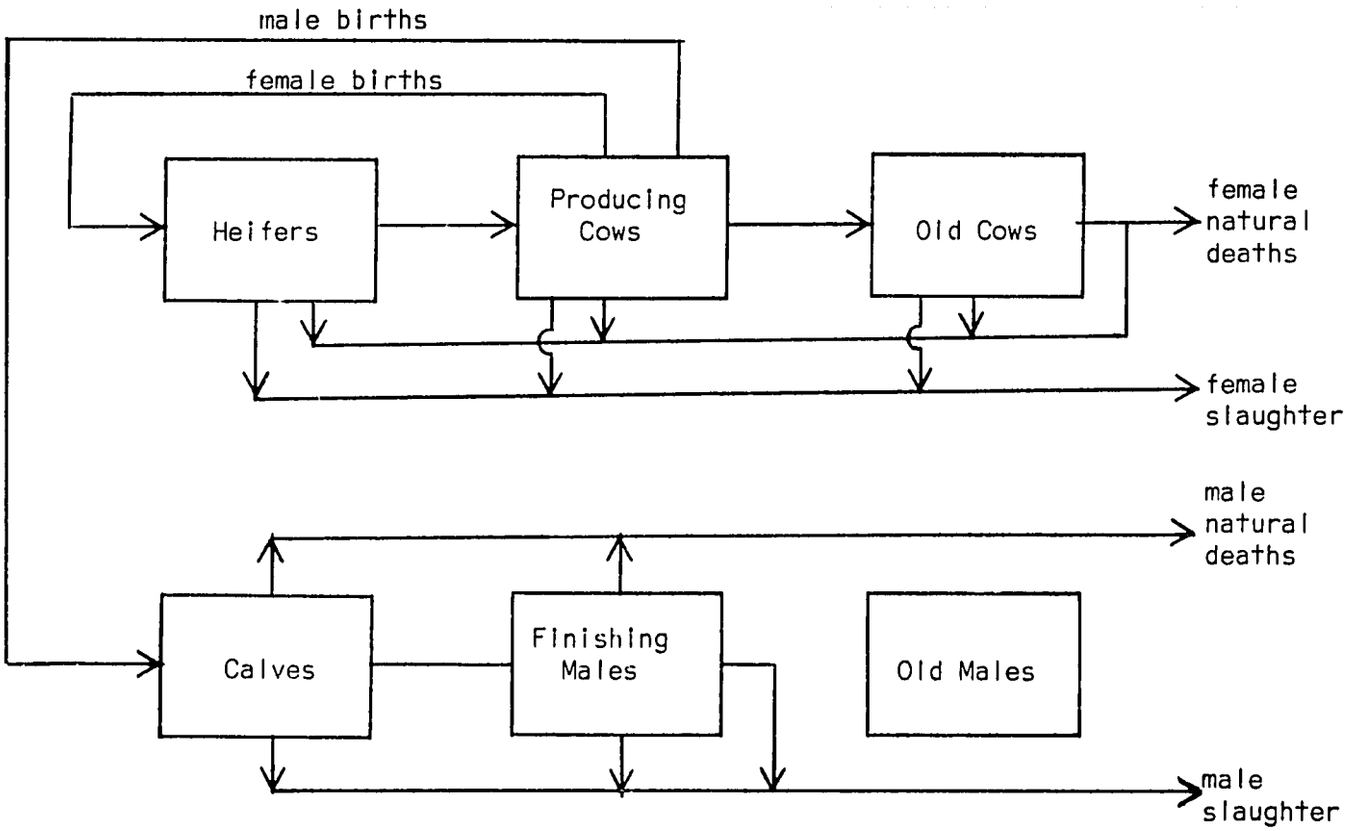

Figure 1

DEMOGC Cattle Demography Illustration

II. Technical Description

A. Mathematical model

DEMOGC is modeled in two parts. The first part uses CLASS component DELLVF to simulate the maturation process of individual animals aging through the distributed delay cohorts, and it computes the population for each age-sex cohort, for each sex, and the total. The delay for each cohort, e.g., of age j and sex k, is of order KC_{jk}. See the DELLVF documentation for derivations of equations (1) and (2). (The simulation model uses Euler integration to solve the differential equations.)

$$(1)\quad \frac{dRP_{ijk}(t)}{dt} = \frac{KC_{jk}}{DEL_{jk}(t)}\left[RP_{(i+1)jk}(t) - RP_{ijk}(t)\left(1 + \frac{1}{KC_{jk}}\frac{dDEL_{jk}(t)}{dt} + \frac{DEL_{jk}(t)}{KC_{jk}} \cdot PLR_{jk}(t)\right)\right], \quad i=1, \ldots, KC_{jk}$$

$$RP_{(KC+1)jk}(t) = RIN_{jk}(t)$$

$$ROUT_{jk}(t) = RP_{1jk}(t)$$

$$(2)\quad POP_{jk}(t) = \frac{DEL_{jk}(t)}{KC_{jk}} \sum_{i=1}^{KC_{jk}} RP_{ijk}(t)$$

$$(3)\quad POPS_k(t) = \sum_{j=1}^{NC} POP_{jk}(t)$$

$$(4)\quad TPOP(t) = \sum_{k=1}^{NSEX} POPS_k(t)$$

where:

RP -- intermediate rates of the delay

RIN -- population entering the cohort (animals/year)

ROUT -- rate at which population matures out of the cohort (animals/year)

POP -- population level in the cohort (animals)

PLR -- proportional loss rate due to deaths and migration[1/] (proportion/year) (equation (6))

DEL -- the average time for an individual to mature through the cohort--input to DEMOGC (years)

KC -- the order of the delay

POPS -- population by sex (animals)

TPOP -- total population (animals)

j -- indexes cohorts, j=1, ..., NC

k -- indexes sexes, k=1, ..., NSEX

NC -- the number of cohorts

NSEX -- the number of sexes (NSEX = 1 or 2).

Population entering cohort j of sex k, RIN, is defined as:

$$(5) \quad RIN_{jk}(t) = \begin{cases} BTH_k(t) \text{ for } j=1 \\ ROUT_{(j-1)k}(t) \text{ for } j=2, \ldots, NC \end{cases}$$

where:

BTH -- births by sex (animals/year) (equation (11)).

The DELLVF routine (refer to its CLASS documentation) simulates a distributed delay with time-varying mean delay time DEL (an input to DEMOGC) and storage losses PLR (equation (6)). The order of the delay KC is a measure of the variance σ^2 of the delay times of individual

---

[1/] Migrations are interpreted as slaughter in this illustration.

animals about the mean--the larger KC, the smaller the variance, where $\sigma^2 = DEL^2/KC$ and where individual delay times follow an Erlang distribution. In certain cases, KC and DEL may be estimated from observed or experimental data [2].

The second part of DEMOGC computes births, deaths and migrations from fertility, death and migration rates (inputs to DEMOGC). It also computes growth rate statistics.

The total proportional rate at which animals leave cohort jk for reasons other than aging, i.e., due to deaths and migrations, is PLR.

$$(6) \quad PLR_{jk}(t) = PMR_{jk}(t) + DR_{jk}(t)$$

where:

PMR -- proportional migration rate--input to DEMOGC (proportion/year)

DR -- proportional death rate--input to DEMOGC (proportion/year).

Deaths, then, are computed for each cohort and summed across cohorts, and total migration is calculated.

$$(7) \quad DTH_{jk}(t) = \begin{cases} DR_{jk}(t) \cdot POP_{jk}(t), & j=1, \ldots, NC-1 \\ DR_{NCk}(t) \cdot POP_{NCk}(t) + ROUT_{NCk}(t) & \end{cases}$$

$$(8) \quad TDTH(t) = \sum_{k=1}^{NSEX} \sum_{j=1}^{NC} DTH_{jk}(t)$$

$$(9) \quad TMR(t) = \sum_{k=1}^{NSEX} \sum_{j=1}^{NC} PMR_{jk}(t) \cdot POP_{jk}(t)$$

where:

DTH -- deaths from a cohort (animals/year)

TDTH -- total deaths (animals/year)

TMR -- total migration (animals/year).

Notice that animals aging out of the last, oldest cohort of the population are accounted as deaths (equation (7)).

Equations (10) and (11) compute total births and births by sex.

$$(10) \quad TBTH(t) = \sum_{j=1}^{NC} FR_j(t) \cdot POP_{j=1}(t)$$

$$(11) \quad BTH_1(t) = PBF \cdot TBTH(t)$$

$$BTH_2(t) = TBTH(t) - BTH_1(t)$$

where:

TBTH -- total births (animals/year)

BTH -- births by sex (animals/year)

FR -- fertility rate--input to DEMOGC (proportion/year)

PBF -- proportion of births which are female.

If DEMOGC is used to model a population which does not reproduce itself naturally (or for which it is not desired to model reproduction), and births are determined exogenously to DEMOGC, e.g., the planting of trees, then equation (10) is not executed and TBTH is considered an input to DEMOGC. It is also possible to use DEMOGC for populations not disaggregated by sex.

Finally, DEMOGC generates a number of population statistics.

$$(12) \quad SR(t) = POPS_2(t)/POPS_1(t)$$

$$(13) \quad CBR(t) = TBTH(t)/TPOP(t)$$

(14) CDR(t) = TDTH(t)/TPOP(t)

(15) PGRN(t) = 100(CBR(t) - CDR(t))

(16) PGRT(t) = PGRN(t) - 100•TMR(t)/TPOP(t)

where:

SR -- sex ratio (not computed if the population is not disaggregated by sex)

CBR -- crude birth rate (proportion/year)

CDR -- crude death rate (proportion/year)

PGRN -- natural growth rate (percent/year)

PGRT -- net growth rate (percent/year).

Initial conditions must be specified exogenously for the inputs FR_j, DR_{jk} and PMR_{jk} and for the cohort populations POP_{jk}. Outputs and internal variables (e.g., RP_{ijk}, RIN_{jk}) are initialized by DEMOGC. Parameters which must be given values are PBF, KC_{jk}, NC, NSEX, and the simulation step size DT.

B. Sample Run

The sample computer run using the cattle demography illustration (Figure 1) assumes constant proportional annual fertility, death and migration rates, where "migration" is interpreted to be slaughter. The fertility rate for the producing cows is .75. The death rates are, for the three female cohorts, .03, .02 and .02; and, for the two male cohorts, .03 and .02, respectively. Slaughter rates are .13, .02 and .5 for the three female cohorts, and .11 and .1 for the male cohorts. The mean lengths of the cohorts, also assumed constant for this illustration, are 2.5, 10 and 5 years respectively for the female cohorts, and 2.5 and 3 years for the male cohorts. Initial population levels are (in thousands of animals) 118, 242, and 43 for female cohorts, and 117 and 94 for male

cohorts. The output of a ten-year simulation appears in Figure 2.

The results of sensitivity tests changing parameters by +10% and DT by -50% (the latter to test integration accuracy) are tabulated in Table I.

```
TIME        TOT. POP.  FEM. POP.  MALE POP.  DEATHS     BIRTHS
 0.          .6140E+06  .4030E+06  .2110E+06  .2323E+05  .1815E+06

SEX RATIO  CRUDE BR   CRUDE DR   NAT. GRTH. NET GRTH.  MIGRN.
  .5336E+00  .2956E+00  .3783E-01  .2578E+02  .1026E+02  .9528E+05

    FEMALE POPULATION COHORTS          MALE POPULATION COHORTS
  .1180E+06  .2420E+06  .4300E+05  .1170E+06  .9400E+05 0.


TIME        TOT. POP.  FEM. POP.  MALE POP.  DEATHS     BIRTHS
  .2000E+01  .7508E+06  .4725E+06  .2783E+06  .2243E+05  .1944E+06

SEX RATIO  CRUDE BR   CRUDE DR   NAT. GRTH. NET GRTH.  MIGRN.
  .5890E+00  .2590E+00  .2988E-01  .2291E+02  .9145E+01  .1033E+06

    FEMALE POPULATION COHORTS          MALE POPULATION COHORTS
  .1761E+06  .2592E+06  .3718E+05  .1796E+06  .9868E+05 0.


TIME        TOT. POP.  FEM. POP.  MALE POP.  DEATHS     BIRTHS
  .4000E+01  .8932E+06  .5485E+06  .3447E+06  .2552E+05  .2290E+06

SEX RATIO  CRUDE BR   CRUDE DR   NAT. GRTH. NET GRTH.  MIGRN.
  .6283E+00  .2564E+00  .2857E-01  .2279E+02  .9624E+01  .1176E+06

    FEMALE POPULATION COHORTS          MALE POPULATION COHORTS
  .2077E+06  .3054E+06  .3543E+05  .2128E+06  .1319E+06 0.


            TOT. POP.  FEM. POP.  MALE POP.  DEATHS     BIRTHS
    000E+01  .1078E+07  .6560E+06  .4224E+06  .2991E+05  .2793E+06

SEX RATIO  CRUDE BR   CRUDE DR   NAT. GRTH. NET GRTH.  MIGRN.
  .6438E+00  .2590E+00  .2773E-01  .2313E+02  .9758E+01  .1442E+06

    FEMALE POPULATION COHORTS          MALE POPULATION COHORTS
  .2491E+06  .3724E+06  .3451E+05  .2550E+06  .1673E+06 0.


TIME        TOT. POP.  FEM. POP.  MALE POP.  DEATHS     BIRTHS
  .8000E+01  .1308E+07  .7967E+06  .5108E+06  .3561E+05  .3420E+06

SEX RATIO  CRUDE BR   CRUDE DR   NAT. GRTH. NET GRTH.  MIGRN.
  .6412E+00  .2616E+00  .2724E-01  .2343E+02  .1025E+02  .1723E+06

    FEMALE POPULATION COHORTS          MALE POPULATION COHORTS
  .3040E+06  .4560E+06  .3668E+05  .3113E+06  .1996E+06 0.


TIME        TOT. POP.  FEM. POP.  MALE POP.  DEATHS     BIRTHS
  .1000E+02  .1599E+07  .9748E+06  .6238E+06  .4317E+05  .4194E+06

SEX RATIO  CRUDE BR   CRUDE DR   NAT. GRTH. NET GRTH.  MIGRN.
  .6399E+00  .2624E+00  .2701E-01  .2351E+02  .1049E+02  .2086E+06

    FEMALE POPULATION COHORTS          MALE POPULATION COHORTS
  .3726E+06  .5592E+06  .4296E+05  .3914E+06  .2423E+06 0.
```

Figure 2
Sample Run Output

Table 1

DEMOGC Sensitivity Test Results at Year 10

ın Definition	Standard Value Coh. 1	Standard Value Coh. 2	Standard Value Coh. 3	Test Run Value	Female Population	Male Population	Sex Ratio	Natural Growth Rates	Sales--Culls and Slaughters
					1000 animals	1000 animals	--	%/year	1000 animals/yr.
.. Standard run					974.8	623.8	.6399	23.54	208.6
					% deviation from standard run				
. Female initial cohort populations	118.0	242.0	43.0	+10%	+10.1	+10.0	0	0	+10.0
. Male initial cohort populations	117.0	94.0	0	+10%	0	0	0	0	0
. Female cohort maturation times	2.5	10.0	5.0	+10%	-3.10	-4.64	-1.60	-1.70	-4.02
. Male cohort maturation times	2.5	3.0	--	+10%	0	+4.91	+4.92	-2.13	-1.44
. Female cohort death rates	.03	.02	.02	+10%	-2.25	-1.72	+.5	-.8	-1.73
. Male cohort death rates	.03	.02	--	+10%	0	-.609	-.594	-.170	-.527
. Female cohort sales rates	.13	.02	.5	+10%	-5.73	-3.98	+1.86	-.212	-.911
. Male cohort sales rates	.11	.1	--	+10%	0	-2.32	-2.31	+.9	+.8
. Fertility rate		.75		+10%	+15.7	+19.7	+3.50	+6.37	+16.7
. Proportion of births female		.5		+10%	+15.7	-2.02	-15.3	-3.99	+3.64
. Simulation time increment DT		.25		-50%	+1.09	+1.47	+.391	-3.823	+1.39

III. Program Information

A. Program Description

DEMOGC was programmed and tested in the following operating environment:

Machine: CDC 6500
Operating system: MSU Hustler 2 L239 LSD 32--an extension of CDC Scope 3.2
Compiler: CDC FTN V3.0-P357
Core requirements: 429 decimal words
CP compile time: 2.5 seconds
CP execution time (for sample run): 6.0 milliseconds
Tapes: none
Direct access files: none
FORTRAN library subprograms used: FLOAT, AMAX1

DEMOGC is structured as two subroutines, DEMOGC and DELLVF, the former containing two calls to the latter, the second call being inside a DO-loop. No COMMON blocks are used.

DEMOGC models the cohort-survival process of a population disaggregated by age and sex, given fertility, death and migration rates. DELLVF models the flow of population through the cohorts as distributed delays. (See DELLVF Documentation.)

DEMOGC is divided in two parts which may be executed separately by specifying ICALL = 1 or ICALL = 2 in the argument list. This is significant only if fertility rates (FR), death rates (DR), or migration rates (PMR) depend on current population levels, which are computed in the first part of DEMOGC. If this is the case, two calls to DEMOGC (the first with ICALL = 1, the second with ICALL = 2) should be used, with FR, DR, and PMR calculated between the two calls. If this is not the case, i.e., if FR, DR and PMR are constant or depend only on past values of variables, a single call to DEMOGC (with ICALL = 0) will suffice. (Although in the sample program one call with ICALL = 0 rather than two calls would work

because FR, DR and PMR are constant, two calls are used for illustrative purposes as if FR, DR and PMR depended on current population levels.)

B. Program implementation

All inputs and outputs are transmitted through the argument list, and no logical units are used by DEMOGC. See the list of the sample run executive program for an example of the call statement.

The program will <u>not</u> execute properly if NSEX has a value other than 1 or 2, or NOBTH has a value other than 0 or 1. If NSEX = 1, PBF need not be defined. If NOBTH = 1, TBTH must be defined outside of DEMOGC, and FR need not be defined. Finally, the following conditions must hold:

$DT > 0$

$NC \geq 1$ and integer

$DEL_{jk}(t) > 0$ for all t, $j=1, \ldots, NC$; $k=1, \ldots, NSEX$

$KC_{jk} \geq 1$ and integer, $j=1, \ldots, NC$; $k=1, \ldots, NSEX$.

C. Program lists

The computer programs for the sample run and for DEMOGC, including subroutines DEMOGC and DELLVF, are listed below:

```
      PROGRAM DEMTST(OUTPUT)
      DIMENSION BR(3), BTH(2), DEL(3,2), DELP(3,2), DR(3,2), DTH(3,2)
      DIMENSION KC(3,2), PLR(3,2), PMR(3,2), POP(3,2), POPS(2)
      DIMENSION ROUT(3,2), RP(10,3,2)
      DATA POP / 118000., 242000., 43000., 117000., 94000., 0. /
      DATA DEL / 2.5, 10., 5., 2.5, 3., 1. /
      DATA DR / .03, .02, .02, .03, .02, 0. /
      DATA PMR / .13, .02, .5, .11, .1, 0. /
      DATA IDTU / 1 /
      DATA KC / 10, 6, 3, 10, 6, 2 /
      DATA BR / 0., .75, 0. /
      DATA NK,NC,NSEX / 10, 3, 2 /
      DATA NOBTH,BCP,PBF / 0, 1., .5 /
      DATA DT / .25 /
      T = -DT
      DO 40 I=1,41
        T = T + DT
        ROUT(2,2) = 0.
        CALL DEMOGC(POP, ROUT, RP, DEL, DELP, KC, POPS, TPOP, SR, DR,
     +              CDR, DTH, TDTH, NOBTH, PBF, BR, CBR, BTH, TBTH,
     +              TMR, PMR, PLR, PGRN, PGRT, NK, NC, NSEX, DT, IDTU,
     +              T, 1)
        CALL DEMOGC(POP, ROUT, RP, DEL, DELP, KC, POPS, TPOP, SR, DR,
     +              CDR, DTH, TDTH, NOBTH, PBF, BR, CBR, BTH, TBTH,
     +              TMR, PMR, PLR, PGRN, PGRT, NK, NC, NSEX, DT, IDTU,
     +              T, 2)
        TMR = TMR + ROUT(2,2)
        PGRT = PGRN - 100.*TMR/TPOP
        IF(MOD(I-1,8) .NE. 0) GO TO 40
        PRINT90,T,TPOP,POPT,TDTH,TBTH
        PRINT91,SR,CBR,CDR,PGRN,PGRT,TMR
        PRINT92,POP
40    CONTINUE
      STOP
90    FORMAT(5H1TIME,7X,9HTOT. POP.,3X,6HFEM. POP.,2X,9HMALE POP.,2X,
     +       6HDEATHS,5X,6HBIRTHS/1H ,6E11.4)
91    FORMAT(10HUSEX RATIO,2X,8HCRUDE BR,3X,8HCRUDE DR,3X,10HNAT. GRTH.
     +       1X,9HNET GRTH.,3X,6HMIGRN./1H ,6E11.4)
92    FORMAT(30H0    FEMALE POPULATION COHORTS,9X,15HMALE POPULATION,
     +       8H COHORTS/1H ,6E11.4)
      END
```

```
 SUBROUTINE DEMOGC(POP, ROUT, RP, DEL, DELP, KC, POPS, TPOP, SR,
+                  DR, CDR, DTH, TDTH, NOBTH, PBF, BR, CBR,
+                  BTH, TBTH, TMR, PMR, PLR, PGRN, PGRT, NK, NC,
+                  NSEX, DT, IDTU, T, ICALL)
```

TITLE - DEMOGRAPHY WITH DISTRIBUTED AGE COHORTS

VERSION - 1A

DATE - 1 MAY 1975

PURPOSE - DEMOGC MODELS THE COHORT-SURVIVAL DEMOGRAPHIC PROCESSES OF BIRTH, DEATH, MIGRATION AND AGING FOR A POPULATION DISAGGREGATED BY AGE AND SEX, WHERE AGE COHORTS ARE MODELED BY DISTRIBUTED DELAYS

INPUT REQUIREMENTS

VALUES TRANSMITTED THROUGH THE ARGUMENT LIST -- ALL INPUT VARIABLES

VARIABLES REQUIRING VALUES WHICH WILL NOT CHANGE DURING A RUN -- DT, IDTU, KC(I,J), NC, NOBTH, NSEX

VARIABLES REQUIRING VALUES WHICH MAY CHANGE DURING A RUN -- BR(I), DEL(I,J), DR(I,J), ICALL, PBF, PMR(I,J), T

VARIABLES COMPUTED BY THIS ROUTINE REQUIRING INITIAL VALUES -- POP(I,J)

OUTPUT VARIABLES

VALUES TRANSMITTED THROUGH THE ARGUMENT LIST -- BTH(J), CBR, CDR, DELP(I,J), DTH(I,J), PGRN, PGRT, PLR(I,J), POPS(J), ROUT(I,J), RP(K,I,J), SR, TBTH, TDTH, TMR, TPOP

VARIABLE DEFINITIONS

BR(I) - FERTILITY RATE IN PROPORTION/UNIT TIME. (AGE)

BTH(J) - BIRTHS IN INDIVIDUALS/UNIT TIME. (SEX)

CBR - CRUDE BIRTH RATE IN PROPORTION/UNIT TIME.

CDR - CRUDE DEATH RATE IN PROPORTION/UNIT TIME.

DEL(I,J) - LENGTH OF DELAY IN TIME UNITS. (AGE,SEX)

DELP(I,J) - LENGTH OF DELAY AT PREVIOUS TIME PERIOD IN TIME UNITS. (AGE,SEX)

DR(I,J) - DEATH RATE IN PROPORTION/UNIT TIME. (AGE,SEX)

DT - SIMULATION TIME INCREMENT IN TIME UNITS.

DTH(I,J) - DEATHS IN INDIVIDUALS/UNIT TIME. (AGE,SEX)

ICALL - MODE OF OPERATION OF THE COMPONENT. UNITLESS.

IDTU - NUMBER OF INTERVALS INTO WHICH DT IS DIVIDED FOR USE IN THE DELAY ROUTINE. UNITLESS.

KC(I,J) - ORDER OF COHORT DELAY. UNITLESS. (AGE,SEX)

NC - NUMBER OF AGE COHORTS. UNITLESS.

NOBTH - INDICATES WHETHER BIRTHS ARE GENERATED BY THE POPULATION OR NOT. UNITLESS.

NSEX - NUMBER OF SEXES (OR SUBPOPULATIONS). UNITLESS.

PBF - PROPORTION OF BIRTHS WHICH ARE FEMALE (OR FIRST SUBPOPULATION).

PGRN - NATURAL GROWTH RATE OF THE POPULATION IN PERCENT/ UNIT TIME.

PGRT - ACTUAL GROWTH RATE OF THE POPULATION IN PERCENT/ UNIT TIME.

PLR(I,J) - PROPORTIONAL LOSS RATE (MIGRATION AND DEATHS) IN PROPORTION/UNIT TIME. (AGE,SEX)

PMR(I,J) - PROPORTIONAL MIGRATION RATE IN PROPORTION/UNIT TIME. (AGE,SEX)

POP(I,J) - POPULATION IN INDIVIDUALS. (AGE,SEX)

POPS(J) - TOTAL POPULATION BY SEX IN INDIVIDUALS. (AGE,SEX)

ROUT(I,J) - COHORT OUTPUT RATE IN INDIVIDUALS/UNIT TIME. (AGE,SEX)

RP(K,I,J) - SET OF INTERMEDIATE RATES FOR EACH COHORT IN INDIVIDUALS/UNIT TIME. (STAGE OF DELAY,AGE,SEX)

SR - SEX RATIO. UNITLESS.

T - SIMULATION TIME IN TIME UNITS.

TBTH - TOTAL BIRTHS IN INDIVIDUALS/UNIT TIME.

TDTH - TOTAL DEATHS IN INDIVIDUALS/UNIT TIME.

TMR - TOTAL MIGRATION RATE IN INDIVIDUALS/UNIT TIME.

TPOP - TOTAL POPULATION IN INDIVIDUALS.

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      DIMENSION BR(NC), BTH(NSEX), DEL(NC,NSEX), DELP(NC,NSEX)
      DIMENSION DR(NC,NSEX), DTH(NC,NSEX), KC(NC,NSEX), PLR(NC,NSEX)
      DIMENSION PMR(NC,NSEX), POP(NC,NSEX), POPS(NSEX)
      DIMENSION ROUT(NC,NSEX), RP(NK,NC,NSEX)
C
C         DEMOGC IS DIVIDED IN TWO PARTS WHICH MAY BE CALLED SEPARATELY
C             IF ICALL=0 THE ENTIRE ROUTINE IS EXECUTED
C             IF ICALL=1 THE CURRENT POPULATION IS CALCULATED
C             IF ICALL=2 BIRTHS, DEATHS, MIGRATION, ETC. ARE CALCULATED
C
      IF(ICALL .GT. 1) GO TO 32
      TPOP = 0.
      DO 50 K=1,NSEX
        IF(T .NE. 0.) GO TO 20
C
C         SET INITIAL VALUES FOR DELAY ROUTINE
C
        DO 15 J=1,NC
          DELP(J,K) = DEL(J,K)
          IKC = KC(J,K)
          DO 10 I=1,IKC
            RP(I,J,K) = POP(J,K)/DEL(J,K)
10        CONTINUE
          ROUT(J,K) = RP(1,J,K)
15      CONTINUE
        GO TO 30
C
C         UPDATE POPULATION COHORTS
C
20      JNC = NC-1
        DO 25 JJ=1,JNC
          J = NC + 1 - JJ
          CALL DELLVF(ROUT(J-1,K), ROUT(J,K), RP(1,J,K), POP(J,K),
     +                PLR(J,K), DEL(J,K), DELP(J,K), DT, IDTU, KC(J,K))
25      CONTINUE
        CALL DELLVF(BTH(K), ROUT(1,K), RP(1,1,K), POP(1,K), PLR(1,K),
     +              DEL(1,K), DELP(1,K), DT, IDTU, KC(1,K))
C
C         POPULATION TOTALS
C
30      POPS(K) = 0.
        DO 40 J=1,NC
          POPS(K) = POPS(K) + POP(J,K)
40      CONTINUE
        TPOP = TPOP + POPS(K)
50    CONTINUE
      IF(ICALL .EQ. 1) RETURN
C
C         IF ICALL=1 EXECUTION ENDS HERE
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          IF ICALL=2 EXECUTION BEGINS HERE

          MIGRATION AND DEATHS

52      TMR = 0.
        TDTH = 0.
        DO 54 K=1,NSEX
          DO 53 J=1,NC
            PLR(J,K) = PMR(J,K) + DR(J,K)
            DTH(J,K) = DR(J,K)*POP(J,K)

            THE OUTPUT OF THE LAST AGE COHORT IS CONSIDERED TO BE DEATHS

            IF(J .EQ. NC) DTH(J,K) = DTH(J,K) + ROUT(J,K)
            TDTH = TDTH + DTH(J,K)
            TMR = TMR + PMR(J,K)*POP(J,K)
53        CONTINUE
54      CONTINUE

            BIRTHS

            IF BIRTHS ARE NOT COMPUTED FROM THE POPULATION (NOBTH=1)
                THEN THE CALLING PROGRAM MUST SET TBTH TO THE DESIRED
                NUMBER OF BIRTHS

        IF(NOBTH .EQ. 1) GO TO 65
        TBTH = 0.
        DO 55 J=1,NC
          TBTH = TBTH + BR(J)*POP(J,1)
55      CONTINUE
65      IF(NSEX .NE. 2) GO TO 68

            FOR TWO SEXES BIRTHS ARE APPORTIONED BETWEEN THEM ACCORDING
                TO VARIABLE PBF

        BTH(1) = PBF*TBTH
        BTH(2) = TBTH - BTH(1)
        IF(POPS(1) .EQ. 0.) GO TO 70
        SR = POPS(2)/POPS(1)
        GO TO 75

            FOR ONE SEX ALL BIRTHS GO TO THAT SEX AND SEX RATIO IS ZERO

68      BTH(1) = TBTH
70      SR = 0.

            CRUDE BIRTH RATE, DEATH RATE, AND GROWTH RATES

75      IF(TPOP .EQ. 0.) GO TO 80
        CBR = TBTH/TPOP
        CDR = TDTH/TPOP
        PGRN = 100.*(CBR - CDR)
        PGRT = PGRN - 100.*TMR/TPOP
        RETURN
80      CBR = 0.
        CDR = 0.
        PGRN = 0.
        PGRT = 0.
        RETURN
        END
```

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SUBROUTINE DELLVF(RIN,ROUT,R,STRG,PLR,DEL,DELP,DT,IDTU,K)

TITLE - DISTRIBUTED DELAY WITH VARIABLE DELAY TIME AND STORAGE
        LOSSES

VERSION - 1A

DATE - 1 NOV 1974

PURPOSE - SIMULATION OF A DISTRIBUTED TIME DELAY PROCESS WITH
          VARIABLE DELAY TIME AND STORAGE LOSSES

INPUT REQUIREMENTS

    VALUES TRANSMITTED THROUGH THE ARGUMENT LIST -- DEL, DELP,
                DT, IDTU, K, PLR, R(I), RIN, STRG

    VARIABLES REQUIRING VALUES WHICH WILL NOT CHANGE DURING A RUN
              -- DT, IDTU, K
    VARIABLES REQUIRING VALUES WHICH MAY CHANGE DURING A RUN
              -- DEL, PLR, RIN
    VARIABLES COMPUTED BY THIS ROUTINE REQUIRING INITIAL VALUES
              -- DELP, R(I), STRG

OUTPUT VARIABLES

    VALUES TRANSMITTED THROUGH THE ARGUMENT LIST -- R(I), ROUT,
              STRG

VARIABLE DEFINITIONS

    DEL - CURRENT LENGTH OF DELAY IN TIME UNITS.

    DELP - PREVIOUS LENGTH OF DELAY IN TIME UNITS.

    DT - SIMULATION TIME INCREMENT IN TIME UNITS.

    IDT - NUMBER OF SUBDIVISIONS OF DT REQUIRED. UNITLESS.

    IDTU - USER-SPECIFIED NUMBER OF SUBDIVISIONS OF DT. UNITLESS.

    K - ORDER OF DELAY. UNITLESS.

    PLR - PROPORTIONATE LOSS RATE IN PROPORTION/UNIT TIME.

    R(I) - INTERMEDIATE RATES IN UNITS/UNIT TIME.(STAGE OF DELAY)

    RIN - INPUT RATE IN UNITS/UNIT TIME.

    ROUT - OUTPUT RATE IN UNITS/UNIT TIME.

    STRG - STORAGE IN UNITS.
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      DIMENSION R(1)
      FK = FLOAT(K)
      B = 1. + (DEL-DELP)/(FK*DT) + PLR*DELP/FK
      IDT = 1. + 2.*B*DT*FK/DELP
      IF(IDT .LT. IDTU) IDT = IDTU
      A = FK*DT/(DELP*FLOAT(IDT))
      DELP = DEL
      KM1 = K-1
      DO 20 J=1,IDT
        IF(K .EQ. 1) GO TO 15
        DO 10 I=1,KM1
          R(I) = R(I) + A*(R(I+1)-B*R(I))
10      CONTINUE
15      R(K) = R(K) + A*(RIN-B*R(K))
20    CONTINUE
      STRG = 0.
      DO 30 I=1,K
        STRG = STRG + R(I)*DEL/FK
30    CONTINUE
      ROUT = R(1)
      RETURN
      END
```

References

[1] Posada, Alvaro, A Simulation Analysis of Policies for the Northern Colombia Beef Cattle Industry, unpublished Ph.D. dissertation, Michigan State University, 1974.

[2] Manetsch, Thomas J. and Gerald L. Park, Systems Analysis and Simulation with Applications to Economic and Social Systems, Part II, Preliminary Edition (East Lansing: Division of Engineering Research, Michigan State University, 1973), Chapter 12.

CLASS Documents

Number	Title
1	"Computer Library for Agricultural Systems Simulation: A Progress Report," Michael H. Abkin and Tom W. Carroll. (July 1976)
2	"Software Standards Manual." (July 1976)
3	"Policy Analysis Language, Version 2.3, Programmer's Guide for CDC Cyber Computers," Claudia S. Winer and Chris Wolf. (July 1976)
4	"Policy Analysis Language, Version 2.3, Reference Manual," Claudia S. Winer anc Chris Wolf. (July 1976).
5	"Policy Analysis Language, Version 2.3, Guide to Using a PAL Program," Claudia S. Winer and Chris Wolf. (July 1976)
6	"DEMOGC: Demography with Distributed Age Cohorts," Michael H. Abkin and Chris Wolf. (July 1976)
7	"DEMOGD: Demography with Discrete Age Cohorts," Michael H. Abkin and Chris Wolf. (July 1976)
8	"Distributed Delay Routines: DEL, DELS, DELF, DELLF, DELVF, DELLVF," Michael H. Abkin and Chris Wolf. (July 1976)
9	"Table Functions: TABEL, TABEX, TABUL, TABUX," Michael H. Abkin, Chris Wolf, and Tom W. Carroll. (July 1976)
10	"AGACC: Accounting Routine for the Agricultural Sector," Dennis Pervis and Chris Wolf. (July 1976)
11	"User's Guide for the Beef Cattle Enterprise Simulation Model," Michael R. Jaske. (July 1976)
12	"User's Guide to SYSOPT: An Interactive System Optimization Computer Program," Marcus Buchner. (August 1976)