WORKING PAPER 389

FORECASTING THE POPULATION OF INDIA AND SUBNATIONAL AREAS WITH MINIMAL INFORMATION

PHILIP H. REES

Paper presented at a course at the Project Planning Centre, University of Bradford, Bradford, West Yorkshire.

School of Geography,
University of Leeds,
Leeds LS2 9JT.

May 1984

CONTENTS

ABSTRACT

The paper provides a pedagogic review of projection models that might be used to forecast the population of India and sub-national areas with minimal information to hand.

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

This paper provides a very brief review of the methods of population forecasting that could be used in India, with fairly minimal available data and with only a small microcomputer or electronic calculator available. The illustrations will be for the whole of India and for selected states, but the methods should be usable for smaller areas within states (principally cities). The discussion starts with the crudest models and works through to more sophisticated versions via a critique of each of their features.

2. EXTRAPOLATIVE MODELS

2.1 A compound growth model

Let us assume we only have available the total populations of our areas at the last two censuses in 1971 and 1981, as given in Table 1. The table also gives the percent growth between 1971-81.

If attention is first concentrated just on the 1971 and 1981 figures, we can see that

% intercensal growth

$$= 100\left[\frac{\text{Population 1981} - \text{Population 1971}}{\text{Population 1971}}\right]$$

e.g. % intercensal growth for all India

$$= 100\left[\frac{683{,}782 - 548{,}160}{548{,}160}\right] = 24.7$$

Assuming the rate of growth remains constant we would project the population using the following equation where P stands for population, t for a point in time

$$P(t + 10) = P(t)\ (1 + \%\ \text{growth}/100)$$
$$P(t + 20) = P(t + 10)\ (1 + \%\ \text{growth}/100)$$
$$\vdots$$
$$P(t + 10n) = P(t + 10(n-1))\ (I + \%\ \text{growth}/100)$$

or in general, using g to stand for the growth rate

$$P(t + 10n) = P(t)\ (1 + g)^n$$

TABLE 1. Population statistics for India and selected Indian states

Area	Population (1000s)		Intercensal growth (percent)
	1971	1981	1971-81
All India	548,160	683,782	24.7
Andhra Pradesh	43,503	53,404	22.8
Kerala	21,347	25,403	19.0
Uttar Pradesh	88,341	110,858	25.5
Rest of India	394,969	494,117	25.1

Source: Table 3 in Visaria and Visaria (1981)

For Uttar Pradesh, the most populous Indian state

$$g = .255$$

so that in 2001 the forecast population would be

$$\begin{aligned} P(2001) &= 110{,}858\ (1 + .255)^2 \\ &= 174{,}604 \end{aligned}$$

In 2021 it would be

$$\begin{aligned} P(2021) &= 110{,}858\ (1 + .255)^4 \\ &= 275{,}006 \end{aligned}$$

It will have more than doubled in our remaining lifetimes.

Now the problem with the method above is that it gives us figures only every ten years. What if we wanted figures for each year (on March 1 at the same time as the Census)? We would have to use an annual rate of growth.

2.2 Annual rates of growth

To compute the annual rate of growth we start with the model in the following form

$$P(t + 10) = P(t)\ (1 + g)^{10}$$

This needs to be manipulated to give us an expression for the growth rate

$$(1 + g)^{10} = P(t + 10)/P(t)$$

$$g = \sqrt[10]{P(t + 10)/P(t)} - 1$$

The average annual rate of growth between 1971 and 1981 for India was therefore

$$\begin{aligned} g &= \sqrt[10]{683{,}782/548{,}160} - 1 \\ &= .0223534 \end{aligned}$$

or in the usual units used in population work

22.4 per 1000.

However, is this figure correct? Visaria and Visaria (1981) give a figure of 2.23% per year. The reason for the difference is that we have assumed that the intercensal period is 10 years in length whereas, in fact, it was 1 month shorter since the 1971 Census was taken on April 1st and the 1981 Census on March 1st, so the growth rate is more correctly evaluated as

$$g = (683{,}782/548{,}160)^{\frac{1}{9.9167}} - 1$$

$$= .0225433 \doteq 22.5 \text{ per } 1000$$

There is still some disagreement with the Visaria and Visaria figure.

2.3 An exponential model

The reason may lie in the use of a slightly different extrapolative model, based on the exponential growth rather than the compound growth formula:

$$P(t+n) = P(t)\, e^{gn}$$

The exponential formula results from instaneous compounding.

The growth rate, g, in this case is given by

$$g = \ln\, (P(t+n)/P(t))/n$$

In the example

$$g = \ln\, (683{,}782/548{,}160)/9.9167$$

$$= .022293 \doteq 22.3 \text{ per } 1000$$

Does it matter which model, of these two, we use? No, as long as the growth rate being used has been computed, for an historical period, using the same model.

We can now compute the projected populations for years intermediate between censuses. Table 2 does this for India, our three states and the rest of India using the compound growth model for the rest of the 1980s. The 1981 population is the result of projecting forward the census population for 4 months. The perceptive arithmetician will immediately have noticed that the sum of the parts of India always exceeds the whole. This is always the case with spatially disaggregated projections as the population concentrates over time in the region growing faster than the average, in our case, the Rest of India.

2.4 Shifting from the constancy assumption

Clearly, it is not usually reasonable to suppose that the growth rate will continue unchanged into the future. The intercensal growth figures for our Indian regions since 1951 are given in Table 3. A wide variety of changes occurred. Between 1951-61 and 1961-71 the growth rates all went up. Between 1971 and 1981 those for Andhra Pradesh and Uttar Pradesh continued to increase, that for the Rest of India fell, that for India as a whole

TABLE 2. Projected populations for India and selected Indian states : compound growth results

Year	All India	Andhra Pradesh	Kerala	Uttar Pradesh	Rest of India
Growth rate 1971-71 * (per 1000 per annum)	22.5	20.9	17.7	23.2	22.8
Projected populations (mid-year)					
1981	688,872	53,773	25,552	111,709	497,844
1982	704,372	54,897	26,004	114,300	509,195
1983	720,220	56,045	26,465	116,952	520,805
1984	736,425	57,216	26,934	119,665	532,679
1985	752,995	58,412	27,410	122,442	544,824
1986	769,937	59,633	27,895	125,282	557,246
1987	787,261	60,879	28,389	128,189	569,951
1988	804,974	62,151	28,891	131,163	582,946
1989	823,086	63,450	29,402	134,206	596,237
1991	860,541	66,130	30,452	140,506	623,736
1996	961,808	73,335	33,245	157,578	698,159
2001	1,074,991	81,326	36,293	176,725	781,462
2006	1,201,494	90,187	39,620	198,199	874,704
2011	1,342,883	100,014	43,253	222,282	979,072
2016	1,500,910	110,911	47,219	249,291	1,095,894
2021	1,677,535	122,996	51,548	279,582	1,226,654

Source: Computed from Table 1 using compound growth models

TABLE 3. Intercensal growth (percent) for selected Indian states 1951-81

Area	1951-61	1961-71	1971-81
All India	21.6	24.8	24.7
Andhra Pradesh	15.6	20.9	22.8
Kerala	24.8	26.3	19.3
Uttar Pradesh	16.7	19.8	25.5
Rest of India	23.5	26.4	25.1

Source: Table 3 in Visaria and Visaria (1981 and computed from Table 1.1 in Government of India (1981)

TABLE 4. Shares of the India population for selected Indian states 1951-81 (in %)

Area	1951	1961	1971	1981	Δ1971-81	2021 (forecast)
Andra Pradesh	8.62	8.19	7.94	7.81	- 0.13	7.30
Kerala	3.75	3.85	3.89	3.72	- 0.17	3.04
Uttar Pradesh	17.51	16.79	16.12	16.21	+ 0.09	16.57
Rest of India	70.12	71.17	72.05	72.26	+ 0.21	73.10
All India	100.00	100.00	100.00	100.00		

Source: Computed from Table 1.1 in Government of India (1981) declined slightly while that for Kerala fell substantially.

It is clear from the figures that linear extrapolation of the growth rates would be unwise. The underlying reason is that the growth rate is itself a function of two other rates, those of birth and death, which change substantially over time. We move to a components view of population change in Section 3 of the paper.

However, extrapolation may play a useful role when it comes to sharing out population in a projection to subnational units. Table 4 sets out the percentage shares that each area has of the Indian population at the last four censuses. Assuming the shifts in shares in the last intercensal decade persist, we would share out the 2021 All India projected population of 1,653 millions thus

Andhra Pradesh	121 millions
Kerala	50 millions
Uttar Pradesh	274 millions
Rest of India	1209 millions

3. COMPONENTS MODELS

3.1 The components equation

Population growth can be divided into a number of components. At the simplest level

population change = natural increase + net migration,

assuming no change in the boundaries of the areal units involved. This can be further decomposed into

population change = (births - deaths)
plus
(in-migration - out-migration)

Adopting the symbols P for population, B for births, D for deaths, I for in-migration and O for out-migration as numbers and their lower case equivalents for rates, the components of change equation can be written *

$$P(t+n) - P(t) = (B(t,t+n) - D(t,t+n)) + (I(t,t+n) - O(t,t+n))$$

or

$$P(t+n) = P(t) + B(t,t+n) - D(t,t+n) + I(t,t+n) - O(t,t+n)$$

Can all these components be measured accurately for subnational areas of India?

* The postscript (t,t+n) means "occurring in the time interval between time t and time t+n."

Unfortunately not. The Sample Registration System provides an estimate of births and deaths but both are underestimated (Casson, 1978). Migration is measured in the Census but only for a short period prior to the census, not over the whole inter-censal period. In developed countries, the components equation is used to estimate net migration over the inter-censal period

$$N(t,t+n) = I(t, t+n) - O(t, t+n)$$
$$= P(t,+n) - P(t) - B(t,t+n) + D(t,t+n)$$

but for Indian states and other subnational areas it is likely that the possible errors in the births and deaths figures exceed the level of net migration. Woods (1981, p.74) gives a map of intercensal net migration rates for Indian states, 1961-71, which implies that they vary between +2% and -2%, compared with intercensal growth percentages varying between 20% and 40% in the same decade (Visaria and Visaria, 1981, Table 3).

So the assumption can reasonably be made that population growth is largely attributable to natural increase and that the population components equation can be reduced to

$$P(t+n) = P(t) + B(t,t+n) - D(t,t+n)$$

We will proceed on this basis for the numerical forecasts presented in the paper, but will later present projection models incorporating migration which should be used if census migration information is available. For projections of the population of urban areas it is essential to incorporate migration into the projection model.

3.2 A projection model based on crude birth and death rates

The natural components equation above can be converted into a projection model by first defining the rates of birth and death, dropping the period labels as understood,

$$b = B/\tfrac{1}{2}(P(t) + P(t+n))$$
$$d = D/\tfrac{1}{2}(P(t) + P(t+n))$$

where the denominator, the average population in the period, is the population at risk of experiencing the event of giving birth or of death.

The projection model is therefore

$$P(t+n) = P(t) + b\,\tfrac{1}{2}(P(t) + P(t+n)) - d\,\tfrac{1}{2}(P(t) + P(t+n))$$

which must be manipulated to yield a model with all P(t) terms on the right hand side and P(t + n) terms on the left hand side

$$P(t+n) = P(t) + \tfrac{1}{2} b\, P(t) + \tfrac{1}{2} P(t+n) - \tfrac{1}{2} d\, P(t) - \tfrac{1}{2} d\, P(t+n)$$

$$P(t+n) - \tfrac{1}{2} b\, P(t+n) + \tfrac{1}{2} d\, P(t+n)$$

$$= P(t) + \tfrac{1}{2} b\, P(t) - \tfrac{1}{2} d\, P(t)$$

$$P(t+n)(1 - \tfrac{1}{2} b + \tfrac{1}{2} d) = P(t)(1 + \tfrac{1}{2} b - \tfrac{1}{2} d)$$

$$P(t+n) = \frac{1 + \frac{1}{2} b - \frac{1}{2} d}{1 - \frac{1}{2} b + \frac{1}{2} d}\; P(t)$$

Adding back the time period notation the model rolls forward thus

$$P(t+1) = \frac{1 + \frac{1}{2} b(t,t+1) - \frac{1}{2} d\,(t,t+1)}{1 - \frac{1}{2} b(t,t+1) + \frac{1}{2} d\,(t,t+1)}\; P(t)$$

$$P(t+2) = \frac{1 + \frac{1}{2} b(t+1,t+2) - \frac{1}{2} d(t+1,t+2)}{1 - \frac{1}{2} b(t+1,t+2) + \frac{1}{2} d(t+1,t+2)}\; p(t+1)$$

$$\vdots$$

$$P(t+n) = \frac{1 + \frac{1}{2} b(t+n-1,t+n) - \frac{1}{2} d(t+n-1,t+n)}{1 - \frac{1}{2} b(t+n-1,t+n) + \frac{1}{2} d(t+n-1,t+n)}\; P(t+n-1)$$

To implement the model we need a sequence of forecast birth and death rates.

3.3 Crude birth and death rates, past and future

Figure 1 and Table 5 present the estimated birth rate, death rate and natural increase rates for the All India population over the three decades prior to 1981 and the four decades thereafter. Both Cassen (1978) and Visaria and Visaria (1981) suggest that birth and death rates may be underenumerated by up to 10%. If both birth and death rate estimates for 1971-81 are increased by 10% then the resulting natural increase rate estimate approaches closely the observed rate of intercensal population change.

Variation across the states of India in vital rates is considerable, as Table 6 reveals. Birth rates in 1976-78 vary by a factor of 2 from 21 per 1000 population (Nagaland, Goa) to 40 per 1000 (Uttar Pradesh) according to the Sample Registration System (Visaria and Visaria, 1981, Table 6, p.24). Our selected states - Andhra Pradesh, Kerala and Uttar Pradesh - are located at the mid, low and high points of the distribution.

The graph of the vital rates (Figure 1) show that death rates have been declining overall (though not in every year) since the early 1950s but birth rates only from the early 1960s (and again not in every year). Fairly

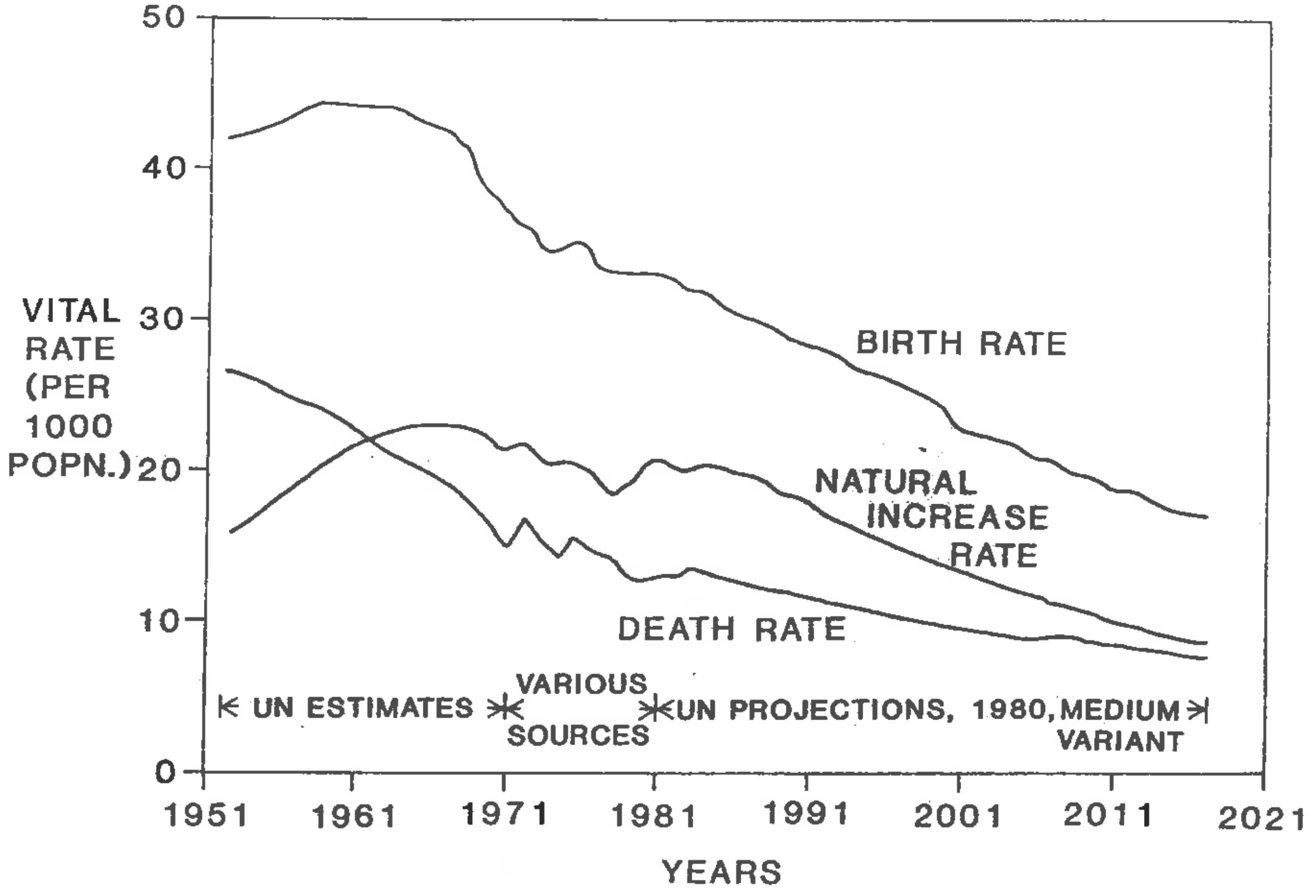

FIGURE 1. Vital rates for India, 1950-2020

TABLE 5. Vital rates for India 1950-2020

	Estimated				Projected		
Year(s)	CBR	CDR	NIR	Year(s)	CBR	CDR	NIR
1950-55	42.0	26.6	15.4	1980-85	32.6	11.8	20.8
1955-60	44.4	24.6	19.8	1985-90	29.5	10.1	19.4
1960-65	44.0	21.5	22.5	1990.95	27.8	11.2	16.6
1965-70	42.0	18.8	23.2	1995-00	25.1	10.2	14.9
1970	36.8	15.17	21.1	2000-05	22.0	9.3	12.7
1971	36.9	14.9	22.0	2005-10	20.2	8.9	11.3
1972	36.6	16.9	19.7	2010-15	18.3	8.6	9.7
1973	34.6	15.5	19.1	2015-20	17.4	8.5	8.9
1974	34.5	14.5	20.0	results of linear regression of 1970-80 values			
1975	35.2	15.9	19.3				
1976	34.4	15.0	19.4				
1977	33.0	14.7	18.3	intercept	36.9	16.3	20.4
1978	33.3	14.2	19.1	slope	-0.405	-0.305	-0.099
1979	33.2	12.8	20.4	correlation	-0.909	-0.784	-0.303
1980	33.5	12.5	21.0	value in 2020	16.5	1.0	15.5

Notes

CBR = crude birth rate per 1000 population

CDR = crude death rate per 1000 population

NIR = natural increase rate per 1000 population

Source: 1950-55 to 1965-70 : UN (1981a), Tables A-6, A-9
1970 : Visaria and Visaria (1981), Table 5
1971-80 : UN (1981b)
1980-85 to 2015-20 : UN (1981b), Tables A-6, A-9

TABLE 6. Vital rates for selected India states, 1970-72 and 1976-78

Area	1970-72			1976-78		
	CBR	CDR	NIR	CBR	CDR	NIR
All India	37.2	16.1	21.1	33.3	14.5	18.8
Andhra Pradesh	35.4	15.5	19.9	33.2	14.0	19.8
Kerala	31.3	9.1	22.2	26.4	7.5	18.9
Uttar Pradesh	44.5	22.5	22.0	40.3	20.0	20.3
Rest of India	36.1	15.1	21.0	32.1	13.7	18.4

Source: Visaria and Visaria (1981), Table 6 rapid decline in the birth rate from 1975 to 1977 probably reflects the effects of the Emergency Drive for family planning lead by Sanjay Gandhi. When the Janata Government took power in 1977 the element of coercion in the programme was removed and the birth rate remained fairly constant in the period 1977-80.

How can we use this information to forecast the likely future trend in birth and death rates for the national and subnational populations? The history of family planning in India suggests it is unwise to extrapolate the 1970-72 to 1976-78 changes for the states. Instead it is better to use a longer run of data for All India and assume that the average rates of decline apply to the states. Over the 1970-80 period the average rates of decline for the All India population, measured by linear regression, were 0.405 per 1000 per year for the birth rate, 0.305 per 1000 per year for the death rate and 0.099 per 1000 per year for the natural rate. The faster fall in the birth rate than the death rate produces the natural increase rate decline. However, the declines in the death rate are unlikely to continue indefinitely. The UN suggests that the death rate will hit a lower limit of around 8.5 per 1000. However, Kerala has already achieved a death rate of 7.5/1000, and other countries with young population have death rates in the range 5 to 7.

3.4 A components projection

A simple projection model for the states of India can now be put forward, which consists of the following steps:

(1) 1976-78 birth and death rates are raised by 10% and trended forward to 1981 at the 1970-80 observed rates of decline (-0.405/1000 for births, -0.305/1000 for deaths).

(2) The base populations are interpolated for Jan.1, 1981 from the 1971 and 1981 Censuses.

(3) Birth and death rates are trended over the 1981-2021 period using the 1970-80 rates of decline until limits of 12 per 1000 (birth rate) and 7 per 1000 (death rate) are reached.

(4) The projection model equations described in Section 3.2 are used.

A BASIC program to implement this projection is given in Figure 2. Figure 3 summarizes the results for all selected states for every fifth year. Results for every year can be obtained by changing the third data item on line 110 from 5 to 1.

Compared with the extrapolative projections of Table 2 the projected populations produced by this model in which both birth and death rates decline

```
10 REM PROGRAM INDIA2
20 REM COMPONENTS OF GROWTH PROJECTION
30 REM FOR ALL INDIA AND SELECTED STATES
40 DATA "ALL INDIA","ANDHRA PRADESH","KERALA","UTTAR PRADESH","       INDIA"
50 REM POPULATION IN MILLIONS AS ESTIMATED ON JAN 1 1981
60 DATA 701.9,55.120,25.232,110.224,491.442
70 REM CRUDE BIRTH RATES PER 100 POPULATION - 1976-78 AVERAGED
80 DATA 33.3,30.2,26.4,40.3,32.1
90 REM CRUDE DEATH RATES PER 1000 POPULATION - 1976-78 AVERAGED
100 DATA 14.7,14.4,7.5,20.0,13.2
110 DATA 11.7,5
120 DIM N$(5),P1(5),P2(5),B(5),D(5)
130 F$="####         ##.#           ##.#          ##.#             ####.###"
140 FOR K=1 TO 5
150 FOR I=1 TO 5: READ N$(I) :NEXT I
160 FOR I=1 TO 5: READ P1(I) : NEXT I
170 FOR I=1 TO 5: READ B(I):B(I)=B(I)*1     NEXT I
180 FOR I=1 TO 5: READ D(I):D(I)=D(I)*1     NEXT I
190 READ BL,DL,YP
200 REM BL=LOWER BIRTH RATE LIMIT
210 REM DL=LOWER DEATH RATE LIMIT
220 REM YP=PRINTING YEAR INTERVAL
230 PRINT#-2,"COMPONENTS OF GROWTH FORECASTS FOR ";N$(K) :PRINT#-2
240 PRINT#-2,"ESTIMATED POPULATION AT JAN 1 1981 = ";P1(K);" MILLIONS"
250 GOSUB 510
260 PRINT#-2,"YEAR      CRUDE BIRTH  CRUDE DEATH  NATURAL INCREASE   POPULATION"
270 PRINT#-2,"             RATE          RATE          RATE           (END OF YEAR)

280 PRINT#-2,"           (PER 1000     (PER 1000    (PER 1000         (MILLIONS)"
290 PRINT#-2,"           POPULATION)   POPULATION) POPULATION)"
300 GOSUB 510
310 FOR T=1 TO 4
320 B(K)=B(K)-0.405:IF B(K)<BL THEN B(K)=BL
330 D(K)=D(K)-0.305:IF D(K)<DL THEN D(K)=DL
340 Y=1976+T
350 NEXT T
360 Q=0
370 FOR T=5 TO 45
380 Q=Q+1:Y=1976+T
390 P2(K)=((1+0.5*B(K)/1000-0.5*D(K)/1000)/(1-0.5*B(K)/1000+0.5*D(K)/1000))*P1(K
)
400 N(K)=B(K)-D(K)
410 IF Q<>YP THEN 430
420 PRINT#-2,USING F$;Y,B(K),D(K),N(K),P2(K):Q=0
430 B(K)=B(K)-0.405:IF B(K)<BL THEN B(K)=BL
440 D(K)=D(K)-0.305:IF D(K)<DL THEN D(K)=DL
450 P1(K)=P2(K)
460 NEXT T
470 GOSUB 510
480 RESTORE
490 NEXT K
500 GOTO 540
510 REM LINE PRINT SUBROUTINE
520 FOR Z=1 TO 66:PRINT#-2,"-";:NEXT Z:PRINT#-2," "
530 RETURN
540 END
```

FIGURE 2. A program to project the population of India and selected states using a simple components of growth model

COMPONENTS [illegible] GROWTH FORECASTS [illegible] ALL INDIA

ESTIMATED POPULATION AT JAN 1 1981 = 679.989 MILLIONS

YEAR	CRUDE BIRTH RATE (PER 1000 POPULATION)	CRUDE DEATH RATE (PER 1000 POPULATION)	NATURAL INCREASE RATE (PER 1000 POPULATION)	POPULATION (END OF YEAR) (MILLIONS)
1985	33.4	[illegible]	19.[illegible]	751.387
1990	31.4	12.0	19.4	928.135
1995	29.3	10.5	18.9	912.133
2000	27.3	8.9	19.4	1000.934
2005	25.[illegible]	7.4	17.9	1095.637
2010	23.3	7.2	16.[illegible]	1193.163
2015	21.2	7.0	14.2	1286.415
2020	19.2	7.0	12.2	1372.982

COMPONENTS OF GROWTH FORECASTS FOR ANDHRA PRADESH

ESTIMATED POPULATION AT JAN 1 1981 = 53.129 MILLIONS

YEAR	CRUDE BIRTH RATE (PER 1000 POPULATION)	CRUDE DEATH RATE (PER 1000 POPULATION)	NATURAL INCREASE RATE (PER 1000 POPULATION)	POPULATION (END OF YEAR) (MILLIONS)
1985	33.3	14.0	19.3	58.579
1990	31.3	12.4	18.8	64.427
1995	29.2	10.9	18.3	70.681
2000	27.2	9.4	17.8	77.349
2005	25.2	7.9	17.3	84.435
2010	23.2	7.0	16.2	91.938
2015	21.1	7.0	14.1	98.961
2020	19.1	7.0	12.1	105.563

FIGURE 3. Results of the components of growth projections for India and selected states

COMPONENTS OF GROWTH FORECASTS FOR KERALA

ESTIMATED POPULATION AT JAN 1 [illegible]

YEAR	CRUDE BIRTH RATE (PER 1000 POPULATION)	CRUDE DEATH RATE (PER 1000 POPULATION)	NATURAL INCREASE RATE (PER 1000 POPULATION)	POPULATION (END OF YEAR) (MILLIONS)
1985	25.8	7.0	[illegible]	27.3[illegible]7
1990	23.8	7.0	16.9	30.461
1995	21.7	7.0	14.7	32.[illegible]25
2000	19.7	7.0	12.7	35.231
2005	17.7	7.0	10.7	37.318
2010	15.7	7.0	8.7	39.130
2015	13.6	7.0	6.6	40.617
2020	12.0	7.0	5.0	41.752

COMPONENTS OF GROWTH FORECASTS FOR UTTAR PRADESH

ESTIMATED POPULATION AT JAN 1 1981 = 110.224 MILLIONS

YEAR	CRUDE BIRTH RATE (PER 1000 POPULATION)	CRUDE DEATH RATE (PER 1000 POPULATION)	NATURAL INCREASE RATE (PER 1000 POPULATION)	POPULATION (END OF YEAR) (MILLIONS)
1985	41.1	19.6	21.5	122.875
1990	39.1	18.0	21.0	136.636
1995	37.0	16.5	20.5	151.559
2000	35.0	15.0	20.0	167.692
2005	33.0	13.5	19.5	185.079
2010	31.0	11.9	19.0	203.759
2015	28.9	10.4	18.5	223.763
2020	26.9	8.9	18.0	245.118

COMPONENTS OF GROWTH FORECASTS FOR REST OF INDIA

ESTIMATED POPULATION AT JAN 1 1981 = 491.34 MILLIONS

YEAR	CRUDE BIRTH RATE (PER 1000 POPULATION)	CRUDE DEATH RATE (PER 1000 POPULATION)	NATURAL INCREASE RATE (PER 1000 POPULATION)	POPULATION (END OF YEAR) (MILLIONS)
1985	32.1	12.6	19.4	542.040
1990	30.0	11.1	19.9	596.478
1995	28.0	9.6	18.4	654.745
2000	26.0	8.1	17.9	716.908
2005	24.0	7.0	17.0	782.516
2010	21.9	7.0	14.9	846.653
2015	19.9	7.0	12.9	906.919
2020	17.9	7.0	10.9	961.425

FIGURE 3. Continued

are substantially lower. The All India population is only 1,373 millions in 2021 compared with 1,678 millions; Andhra Pradesh's population is only 106 millions compared with 123; Kerala's population only reaches 42 millions as opposed to 52; Uttar Pradesh's population keeps to 245 millions compared with 280; and the Rest of India is limited to below 1 billion at 961 millions compared with 1.227 billion.

In 40 years time India's birth rate is projected to reach the level of the United Kingdom's birth and death rates in the early 1960s, while Kerala's will have reached the UK level in the late 1970s and early 1980s. Crude death rates will, however, be much lower than those of the UK because of the youthful age structure of the population.

Several major criticisms must, however, be levelled at these projections. Firstly, it is well known that all age population projections may under-estimate the amount of population growth. Secondly, we may wish to know, for many planning purposes, the future numbers by age and sex. Thirdly, it is difficult to relate rates such as the crude birth rate or crude death rate to the likely fertility behaviour or survival chances of families, the more immediate concerns of the population. Fourthly, the projection model should be flexible enough to enable us to test out the consequences of differing rates of fertility and mortality decline, and to vary those rates for each regional population. These criticisms lead us to the cohort survival model.

4. A COHORT SURVIVAL MODEL

4.1 An age disaggregated projection model

To implement a cohort survival model it is necessary to define the cohorts (groups of persons born in the same set of years) or age groups. These must be equal, regular groupings of age. For the India projections we use the following age groups.

Number	Age range at last birthday	Number	Age range at last birthday
1	0- 4	9	40-44
2	5- 9	10	45-49
3	10-14	11	50-54
4	15-19	12	55-59
5	20-24	13	60-64
6	25-29	14	65-69
7	30-34	15	70-74
8	35-39	16	75 +

Because the age groups have age ranges of five years, therefore the model must operate with a five year time interval. Populations will be projected every five years. If populations are required more frequently or for smaller age groups, interpolation from the results of a five year cohort survival model will usually be satisfactory.

Verbally, the model can be expressed as follows:

survived population in age group a + 1 at time t + 5	=	survival rate from age group a to age group a + 1	x	population in age group a at time t
population in last age group 75 + at time t + 5	=	survived population in age group 80 + at time t + 5	+	survived population in age group 75-79 at time t + 5

Then births are forecast by

births	=	sum over all ages of potential mother	of	fertility rates of age group a	x	population at risk of potential mothers in age group a

and the first age group population is given by

population in first age group 1	=	survival rate from birth to age group 1	x	sex proportion	x	births

The left hand side projected populations are then used as the initial populations for the next period.

Formally, let us adopt the following definitions

$P_a^x(t)$	=	population of sex x in age group a at time t
$s^x_{aa+1}(t,t+5)$	=	survival rate of sex x from age group a to age group a+1 over period time t to time t+5
$P^x_{a+1}(t+5)$	=	survived population of sex x in age group a+1 at time t+5
Ba	=	births to mothers in age group a
fa	=	fertility rate in age group a of potential mothers
z^x	=	proportion of births in sex x

There are two sexes: X = M (males), x = F (females). The age groups range from 1 through a to A (the last) but 0 is used for birth and A+1 for the age group into which the oldest group survives.

So, formally, the model can be written as follows

$$P^x_{a+1}(t+5) = s^x_{aa+1}\, P^x_a(t) \quad \text{for } a = 1, \ldots, A-1$$

$$P^x_A(t+5) = s^x_{A-1A}\, P^x_{A-1}(t) + s^x_{AA}\, P^x_A(t) \quad \text{for } a = A, \text{ the last age group}$$

$$B_a(t, t+5) = f_a\, \tfrac{1}{2}\,(P^F_a(t) + P^F_{a+1}(t+5))$$

$$P^x_1(t+5) = s^x_{01}\, z^x \sum_{a=4}^{10} B_a(t, t+5)$$

The task is now to seek out or estimate suitable values for India and the selected state for the population broken down by age and sex, survival rates by age and sex, fertility rates by age and sex proportions at birth, and to establish trends in the component rates.

4.2 Survival rate and fertility rate derivation

The estimation of the required rates for the Indian population is not a straightforward task because India lacks a complete birth and death registration system. Demographers have developed fairly elaborate techniques for estimating death rates and birth rates by age using a combination of census populations and synthetic sets of rates contained in collections of model life tables and model fertility schedules (see Coale and Demeny, 1966 and Woods, 1982 for an introduction). Ideally these should be used to establish starting values for rates for the inter-censal decade 1971-81, but the requisite census volumes were not at hand.

A simpler strategy was therefore adopted. Survival rates were estimated by interpolation between two model schedules in the Coale and Demeny (1966) tables. These are listed in Table 7. The North model life table set was chosen because work by Woods (1982, Chapter 2, Table 2.9, p.77) indicated that the North model was the one that fitted state data best most frequently. The two schedules bracket, in terms of life expectancy, current Indian experience and that likely in the long term. Interpolation was accomplished thus.

(1) A forecast life expectancy value for the projection period was determined (see later).

(2) Survival rates were computed as

TABLE 7. Survival rates derived from the North model life tables of Coale and Demeny (1966)

Age transition	Male level 14	Male level 23	Female level 13	Female level 21
Birth to 0-4	.86165	.97468	.86486	.96292
0-4 to 5-9	.93471	.99472	.92878	.98894
5-9 to 10-14	.97392	.99685	.97125	.99490
10-14 to 15-19	.97958	.99564	.97860	.99478
15-19 to 20-24	.97265	.99273	.97558	.99275
20-24 to 25-29	.96704	.99132	.97148	.99098
25-29 to 30-34	.96515	.99075	.96714	.98979
30-34 to 35-39	.96174	.98957	.96235	.98839
35-39 to 40-44	.95539	.98733	.95727	.98524
40-44 to 45-49	.94617	.98312	.95235	.98092
45-49 to 50-54	.93214	.97430	.94345	.97383
50-54 to 55-59	.91193	.96231	.92638	.96339
55-59 to 60-64	.88077	.94323	.89706	.94592
60-64 to 65.69	.83102	.90936	.84825	.91294
65-69 to 70-74	.75634	.85809	.77469	.85865
70-74 to 75-79	.65266	.77851	.67498	.77536
75+ to 80+	.40199	.51240	.41680	.50883
Life expectancy (e_0)	49.1	71.6	50.0	70.0

Source: Coale and Demeny (1966), pp. 232-3, 240, 242

$$\text{survival rate at lower life expectancy} + \frac{(\text{forecast life expectancy} - \text{lower life expectancy})}{(\text{higher life expectancy} - \text{lower life expectancy})}(\text{higher survival rate} - \text{lower survival rate})$$

For example, assume female life expectancy was forecast to be 60 years at some point in the future. The survival rate for age group 30-34 surviving into age group 35-39 would be

$$.96235 + \frac{(60 - 50)}{(70 - 50)}(.98839 - .96235)$$

$$= .96235 + \tfrac{1}{2}(.02604) = .97537$$

A similar technique was used to interpolate fertility rates using age specific fertility rates for India in 1972 estimated from Sample Registration System data reported in Visaria and Visaria (1981) as the high fertility level, and a schedule for the United Kingdom in 1975 to represent the lowest likely level of fertility (below replacement). These schedules are listed in Table 8. The total fertility rate per woman was forecast and then the following interpolation was carried out

$$\text{fertility rate at higher total fertility} + \frac{(\text{forecast total fertility} - \text{higher total fertility})}{(\text{lower total fertility} - \text{higher total fertility})}\left(\text{fertility rate at lower total fertility} - \text{fertility rate at higher total fertility}\right)$$

So if total fertility for a state population was forecast as 3 children per woman the fertility rate for women aged 25-29 would be estimated as

$$275.9 + \frac{(3 - 5.387)}{(1.822 - 5.387)}(124.9 - 275.5)$$

$$= 275.9 + (.66957)(-150.6) = 175.1$$

The method of forecasting life expectancy or total fertility is described in the next section. This method has the conceptual drawback that the waterbuffalo (the summary measure) has been assigned to pushing the cart (the disaggregated rates). When good time series of deaths by cause and by age are available these are projected forward and the life expectancy is simply a summary measure of the consequences of these individual age group projections. However, such time series are not available for Indian populations.

4.3 Life expectancy trends and regional differences

Table 9 gathers together historical and projected statistics on life expectancy in India. Substantial improvement has been made in the past three

TABLE 8. Age specific fertility rates, India 1972 and United Kingdom, 1975

Age group	India 1972	United Kingdom 1975
15-19	87.5	36.8
20-24	261.9	116.5
25-29	275.5	124.9
30-34	215.4	59.8
35-39	141.7	20.9
40-49	74.0	5.2
45-49	21.3	0.3
Total fertility rate per woman	5.387	1.822

Rates are in births per 1000 women per year

Sources:

India, 1972 : Visaria and Visaria, 1981, see footnote to TABLE 13
UK, 1975 : Rees, 1979, Table 13, p.42

TABLE 9. Life expectancy trends, past and future, India

Years	UN estimates[a]		Other sources				
	Male	Female		Male	Female		
1950-55	39.4	38.0	1961-70[b]				
1955-60	41.4	40.0	1961-70[b]	46.4	44.7		
1960-65	44.3	43.0	1961-70[c]	47.1	45.6		
1965-70	46.8	45.5	1966-70[d]	48	46		
1970-75	49.0	47.7					
1975-80	50.0	48.7	1976-77[e]	50.8	50.0		
				M1	M3	M1	M3
1980-85	52.0	51.0	1981-85[f]	51.2	58.4	49.6	57.6
1985-90	54.1	53.4	1986-90	52.3	61.6	50.8	61.2
1990-95	56.4	55.8	1991-95	53.4	64.6	52.0	64.5
1995-00	58.8	58.0	1996-00	54.4	67.4	53.2	67.4
2000-05	61.0	61.0	2001105	55.5	70.0	54.4	70.0
2005-10	62.9	63.1	2006-10	56.5	70.0	55.5	70.0
2010-15	64.6	65.3	2011-15	57.5	70.0	56.6	70.0
2015-20	66.1	67.3	2016-20	58.5	70.0	57.6	70.0
2020-25	67.3	69.1					

Notes: Life expectancy is life expectancy at birth, e_0.

Sources:

[a]UN (1981a), Table A-15, pp. 84-95

[b]UN (1983), Table 16

[c]Government of India quoted in Cassen (1978, Table 2.11, p. 116)

[d]Cassen and Dyson (1976) quoted in Cassen (1978), Table 2.1, p.116

[e]UN (1981b), Table 4, p.184

[f]Cassen (1978), Table 2.18, p.133. M1-least decline, M3-most decline in mortality

decades: 10.6 years have been added to male life expectancy at birth and 10.7 to female; an average per year of 0.42 and 0.43 years per year respectively. One unusual feature of the Indian mortality regime is the higher mortality suffered by women.

The table (Table 9) also reports two views as to the future trends. The UN sees in its 1980 based medium variant projections (UN, 1981) the rate of improvement increasing through the 1990s and then decreasing to the 2020s. The rate of improvement in female life expectancies is greater than that of males and women's life expectancy overtakes than of men in 2005-10. The average rates of improvement for the 1980-2020 period are 0.38 years per year for men and 0.45 years per year for women, quite close to the experience of the previous 30 years.

Other authorities are move pessimistic about the rate of improvement. Casson (1978) includes a series of projections (labelled M_1) that assume an improvement rate of only 0.2 years per year. He also carried out a set of forecasts that assume a much faster improvement of 0.7 years per year, up to a limit of 70 years (labelled M_3 in Table 9).

Table 9 reports life expectancy trends for All India only. The equivalent information was not to hand for the states of India. Woods (1982, Chapter 2) has, however, made some estimates of average life expectancy at birth for the intercensal decade 1961-71, for 13 Indian states (or groupings of states). His results for our selected states are gathered together in Table 10. Compared with the Government of India and Cassen and Dyson estimates for the same decade for India as a whole, the weighted average for Woods' 13 states gives higher life expectancies for males and lower for females. Because of this disagreement Woods' estimates are not used directly : rather the ratios of regional life expectancies to the national mean are computed and applied to the national figure. Andhra Pradesh has lower life expectancy values for both men and women than All India and Kerala has higher. Uttar Pradesh has marginally higher life expectancies for men but much lower for women. The Rest of India values, which are fairly approximate, are close to the All India average. The last column of Table 10 gives the inverse of the ratio of state crude death to national for 1976-78. This ratio agrees with the life expectancy ratio in direction (above or below 100) though not in magnitude, for Kerala, Uttar Pradesh and the Rest of India, though not for Andhra Pradesh.

TABLE 10. Life expectancy estimates for selected Indian states, 1961-71

State	Male		Female		CDR
	e_0	ratio to nation	e_0	ratio to nation	1976-78 inverse ratio to nation
Andhra Pradesh	44.3	92	40.0	97	103
Kerala	56.3	117	50.0	122	192
Uttar Pradesh	49.1	102	35.0	85	72
Rest of India (est)	48.2	100	43.8	107	106
India (13 states)	48.2	100	41.1	100	100

Source: Woods (1982), Table 2.10, p.78
Rest of India figures are an unweighted average of the remaining states in the table
The India figures are weighted average for 13 states
The CDR ratios are computed from Table 6

Thus, the life expectancy for a state population for a projection period is computed as follows:

(1) The All India life expectancy values for the first period are set at 52 for males, 51 for females (following the UN estimates).

(2) The following ratios to the national average life expectancy are used:

	Males	Females
All India	1.00	1.00
Andhra Pradesh	0.92	0.97
Kerala	1.17	1.22
Uttar Pradesh	1.02	0.85
Rest of India	1.00	1.07

(3) The state life expectancies are computed by multiplying the state ratios:

	Males	Females
All India	52.0	51.0
Andhra Pradesh	47.8	49.5
Kerala	60.8	62.2
Uttar Pradesh	53.0	43.4
Rest of India	52.0	54.6

(4) In each period these life expectancies are increased by the rates of increase adopted for the particular projection

e.g. In 1996-2001 Kerala's female life expectancy climbs to $62.2 + 0.4 \times 15 = 68.2$

assuming an improvement of 0.4 years per year.

4.4 Total fertility trends and regional differences

Similar difficulties are involved in forecasting total fertility rates for the selected states. Table 11 gathers together some estimates of All India total fertility for various years during the 1970s together with UN estimates from 1950-55 onwards. Table 12 gives age specific fertility rates associated with one set of estimates. For the early 1970s the concensus of estimates based on the Sample Registration System is that the total fertility rate was 5.3-5.4 children per family with the UN estimates about 5% higher to allow for underreporting. In the late 1970s the rate had dropped to 4.3-4.6 with the UN suggesting about 5.05 (a 10% underreporting).

A variety of future forecasts are put forward by Casson (1978) ranging from a decline of 0.060 of a child per year to .122 of a child per year. The UN medium variant forecasts begin with an annual decline of 0.124 children per woman per year between the first and second half of the 1980s falling steadily to a rate of 0.02 children per woman per year in the

TABLE 11. Total fertility in India, past and future

Year		Total fertility rate	Years	GRR	GRR x $^{1}/_{.485}$
Other estimates			UN estimates		
1971-72[a]		5.345	1950-55	3.11	6.41
1976[a]		4.685	1955-60	3.15	6.49
1972[b] urban		4.290	1960-65	3.07	6.33
rural		5.696	1965-70	2.93	6.04
total		5.387			
1978[b] urban		3.294	1970-75	2.75	5.67
rural		4.556	1975-80	2.45	5.05
total		4.278			
1980[c]		4.900	1980-85	2.20	4.54
	F1	F6			
1981-85[d]	4.879	3.203	1985-90	1.90	3.92
1986-90	4.530	2.500			
1991-95	4.206	2.500	1990-95	1.70	3.51
1996-00	3.904	2.500	1995-00	1.50	3.09
2001-05	3.624	2.500	2000-05	1.30	2.68
2006-10	3.364	2.500	2005-10	1.20	2.47
2011-15	3.123	2.500	2010-15	1.10	2.27
2016-20	2.899	2.500	2015-20	1.05	2.16
			2020-25	1.00	2.06

Notes: GRR = Gross Reproduction Rate .485 proportion of births assumed to be female

Sources:

[a]Population Reference Bureau (1981)

[b]Visaria and Visaria (1981), Table 7, p.26
Total computed as a weighted average : urban % (1980) = 22 rural = 78

[c]World Bank (1982), Table 18, p.144

[d]Casson (1978), Table 2.18, p.133. F1 - least decline
F6 - most decline in fertility

2015-20 to 2020-25 time interval. Over the late 1960s and 1970s the decline rate averaged about 0.1 child per woman per year, although there were substantial variations from year to year reflecting the state of the family planning programme (Visaria and Visaria, 1981, pp. 35-43).

With no regional figures for total fertility to hand, the best that can be done to estimate fertility levels for the selected states is to use the ratio of the estimated crude birth rate to the national average, which are given in Table 13.

Thus, the total fertility rate for a state population for a projection period is computed as follows:

(1) The UN estimate for All India for 1980-85 of 4.54 children per woman is adopted for the base period.

(2) The state values are computed by applying the 1976-78 ratios of Table 14 (in decimal fraction form):

	TFR
All India	4.54
Andhra Pradesh	4.54
Kerala	3.59
Uttar Pradesh	5.49
Rest of India	4.36

(3) In each period these total fertility rates are decreased by the rate of decline adopted for the particular projection

e.g. In 1996-2001 Kerala's total fertility rate is projected to be 3.58 - 0.06 x 15 = 2.69, assuming a decline 0.06 children per woman per year.

4.5 A computer program and some sample results

A computer program in BASIC (Microsoft Extended Basic on the Tandy Color Computer) has been written to implement the projection model outlined above. The program is listed in Figure 4. No guarantee is given that it will run when typed in on any computer but someone with a modicum of programming experience should get it working and be able to improve it! The statements that will probably need alteration are those involved in printing in the last third of the program. If difficulty is experienced fitting the program in your computer, (1) omit all rem statements, (2) omit all unnecessary spaces between the statement number and the statement and within the statement, (3) reduce the number of regions to be processed to 2 (All India, One Other) and re-run the program with fresh data, (4) omit the long printout routine. If all those drastic steps don't work, write your own program!

```
10 REM INDIA3 COHORT SURVIVAL PROJECTION MODEL
20 REM FOR ALL INDIA AND SELECTED STATES
30 DATA "ALL INDIA","ANDHRA PRADESH","KERALA","UTTAR PRADESH","REST OF INDIA"
40 DIM RN$(5),SN$(2)
50 FOR I=1 TO 5:READ RN$(I):NEXT I
60 DATA "FEMALES"," MALES "
70 FOR X=1 TO 2:READ SN$(X):NEXT X
80 REM INFORMATION ON POPULATIONS
90 REM AGE-SEX POPULATIONS FOR ALL INDIA,1.6.80
100 REM FEMALES FIRST,THEN MALES, POPULATIONS IN MILLIONS
110 REM AGES 0-4,5-9,...,70-74,75+,TOTAL
120 DATA 45.318,42.576,39.585,34.589,29.240,24.565
130 DATA 21.138,18.319,15.661,13.035,10.441,8.295
140 DATA 6.341,4.612,3.187,3.186,320.268
150 DATA 47.757,45.285,41.955,37.354,31.483,25.921
160 DATA 22.007,19.192,16.823,14.591,12.188,9.716
170 DATA 7.279,5.116,3.331,3.330,343.328
180 DIM PN(2,17)
190 FOR X=1 TO 2:FOR A=1 TO 17:READ PN(X,A):NEXT A:NEXT X
200 REM ALL INDIA AND STATE POPULATIONS - TOTAL 1971,FEMALE 1981,MALE 1981
210 DATA 548.160,43.503,21.347,88.341,394.969
220 DATA 330.463,26.368,12.915,52.077,239.103
230 DATA 353.347,27.036,12.488,58.781,255.042
240 DIM P71(5),P81(3,5),G2(5),PT(2,5)
250 FOR I=1 TO 5:READ P71(I):NEXT I
260 FOR X=1 TO 2:FOR I=1 TO 5:READ P81(X,I):NEXT I:NEXT X
270 DIM P1(2,17),P2(2,18)
280 REM SURVIVAL RATE DATA
290 REM SOURCE - NORTH MODEL LIFE TABLE COALE AND DEMENY 1966
300 REM VARIABLES - LEVEL,E(0),S(-5),S(0),...,S(70),S(75+)
310 REM FEMALES FIRST,THEN MALES
320 DATA 13,50.0,.86486,.92878,.97125,.97860,.97558
330 DATA .97148,.96714,.96235,.95727,.95235,.94345
340 DATA .92638,.89706,.84825,.77469,.67498,.41680
350 DATA 21,70.0,.96292,.98894,.99490,.99478,.99275
360 DATA .99098,.98979,.98839,.98524,.98092,.97383
370 DATA .96339,.94592,.91294,.85865,.77536,.50883
380 DATA 14,49.1,.86165,.93471,.97392,.97958,.97265
390 DATA .96704,.96515,.96714,.95539,.94617,.93214
400 DATA .91193,.88077,.83012,.75634,.65266,.40199
410 DATA 23,71.6,.97468,.99472,.99685,.99564,.99273
420 DATA .99132,.99075,.98957,.98733,.98312,.97430
430 DATA .96231,.94323,.90936,.85809,.77851,.51240
440 DIM L1(2),L2(2),E1(2),E2(2),S1(2,17),S2(2,17),S(2,17)
450 REM E1=LOWER LE LEVEL (L1)
460 REM E2=HIGHER LE LEVEL (L2)
470 REM S1=LOWER SURVIVAL RATE LEVEL
480 REM S2=HIGHER SURVIVAL RATE LEVEL
490 FOR X=1 TO 2
500 READ L1(X),E1(X):FOR A=1 TO 17:READ S1(X,A):NEXT A
510 READ L2(X),E2(X):FOR A=1 TO 17:READ S2(X,A):NEXT A
520 NEXT X
530 REM LIFE EXPECTANCY VALUES FOR BASE QUINQUENNIUM 1981-86
540 REM INDIA LE,STATE RATIOS
550 REM FEMALES FIRST,THEN MALES
560 DATA 51.0,1.00,.97,1.22,.85,1.07
570 DATA 52.0,1.00,.92,1.17,1.02,1.00
580 DIM E(2,5),DE(2),R(2,5)
590 FOR X=1 TO 2
600 READ E(X,1):FOR I=1 TO 5:READ R(X,I):E(X,I)=E(X,1)*R(X,I):NEXT I
610 NEXT X
620 REM -- FERTILITY RATE ESTIMATION ROUTINE ----
630 REM FERTILITY RATE LIMITS AKEN FOM VISARIA AND VISARIA, 1981
640 REM AND REES, 1979 M&S1 UK
650 REM DATE,TFR,F(15-19),F(20-24),...,F(45-49) PER 1000 WOMEN
660 DATA 5.387,87.5,261.9,275.5,215.4,141.7,74.0,21.3
670 DATA 1.822,36.8,116.5,124.9,59.8,20.9,5.2,0.3
680 DIM F1(7),F2(7),F(7),B1(8)
690 REM F1=HIGHER FERTILITY LEVEL F2=LOWER FERTILITY LEVEL
700 REM T1=HIGHER TFR T2=LOWER TFR B1=BIRTHS
710 READ T1:FOR B=1 TO 7:READ F1(B):NEXT B
720 READ T2:FOR B=1 TO 7:READ F2(B):NEXT B
730 REM FERTILITY VALUES FOR BASE YEAR,STATE RATIOS
740 DATA 4.54,1.0,1.0,.79,1.21,.96
750 DIM RF(5),T(5)
```

FIGURE 4. A program to project the population of India and selected states using a cohort survival model

```
760 READ T3:FOR I=1 TO 5:READ RF(I):NEXT I
770 FOR I=1 TO 5:T(I)=T3*RF(I):NEXT I
780 REM ---- SEX PROPORTIONS AT BIRTH ---
790 DIM SX(2)
800 SX(1)=.485:SX(2)=.515
810 REM ----- INITIAL PARAMETERS FOR PROJECTION SET ---
820 PRINT "PLEASE SUPPLY A TITLE FOR THIS PROJECTION RUN"
830 INPUT TITLE$
840 PRINT "DESCRIBE THE SCENARIO INVOLVED (SUCCINCTLY)"
850 INPUT SCEN$
860 PRINT "INPUT LIFE EXPECTANCY INCREASE RATE FOR FEMALES, THEN MALES IN DECIMA
L FRACTIONS OF A YEAR PER YEAR"
870 INPUT DE(1),DE(2):FOR X=1 TO 2:DE(X)=DE(X)*5:NEXT X
880 PRINT "INPUT TOTAL FERTILITY DECLINE RATE IN DECIMAL FRACTION OF A CHILD PER
 WOMAN PER YEAR"
890 INPUT DT:DT=DT*5
900 REM *** START OF REGION LOOP ***
910 PRINT "WHICH REGIONAL POPULATION DO YOU WISH TO PROJECT?"
920 PRINT "1 = ALL INDIA"
930 PRINT "2 = ANDHRA PRADESH"
940 PRINT "3 = KERALA"
950 PRINT "4 = UTTAR PRADESH"
960 PRINT "5 = REST OF INDIA"
970 PRINT "TYPE IN NUMBER BETWEEN 1 AND 5 OR 0 TO QUIT"
980 INPUT NR
990 IF NR=0 THEN 2250
1000 PRINT "HOW MANY PERIODS FOR THE PROJECTION?":INPUT NT
1010 PRINT#-2,"PROJECTION RUN = ";TITLE$
1020 PRINT#-2,"SCENARIO        = ";SCEN$
1030 PRINT#-2,"LIFE EXPECTANCY INCREASE RATES (PER 5 YEARS)= "
1040 PRINT#-2,"FEMALE ";DE(1);" MALE ";DE(2)
1050 PRINT#-2,"TOTAL FERTILITY DECLINE RATE (PER 5 YEARS)= ";DT
1060 PRINT#-2,"NUMBER OF REGION                     = ";NR
1070 PRINT#-2,"NUMBER OF PERIODS                    = ";NT
1080 PRINT#-2
1090 PRINT"SHORT (TYPE 0) OR LONG (TYPE 1) PRINTOUT?":INPUT NP
1100 IF NP=1 THEN 1190
1110 IF NP=0 THEN 1130
1120 GOTO 1090
1130 PRINT#-2,"FORECASTS FOR ";RN$(NR)
1135 GOSUB 2220
1140 PRINT#-2,"YEAR      CRUDE BIRTH  CRUDE DEATH  NATURAL INCREASE  POPULATION
YEAR"
1150 PRINT#-2,"START";TAB(12)"RATE           RATE            RATE";TAB(53)"(END OF PE
RIOD) END"
1160 PRINT#-2,TAB(12)"(PER 1000";TAB(23)"(PER 1000";TAB(36)"PER 1000";TAB(53)"(M
ILLIONS)"
1170 PRINT#-2,TAB(10)"POPULATION)";TAB(23)"POPULATION)";TAB(36)"POPULATION)"
1180 GOSUB 2220
1190 I=NR
1200 REM BASE POPULATIONS ESTIMATED
1210 P81(3,I)=P81(1,I)+P81(2,I)
1220 G2(I)=(P81(3,I)/P71(I))^(1/(10-31/365))-1
1230 FOR X=1 TO 2
1240 PT(X,I)=(P71(I)*(1+G2(I))^(3+9/12))*(P81(X,I)/P81(3,I))
1250 NEXT X
1260 REM BASE POPULATIONS DISAGGREGATED BY AGE
1270 FOR X=1 TO 2:FOR A =1 TO 17
1280 P1(X,A)=PT(X,I)*(PN(X,A)/PN(X,17))
1290 NEXT A:NEXT X
```

FIGURE 4. **Continued**

```
1300 Y=1981
1310 REM *** START OF TIME LOOP ***
1320 FOR Q=1 TO NI
1330 REM PERIOD SURVIVORSHIP RATES ARE COMPUTED
1340 FOR X=1 TO 2
1350 FOR A=1 TO 17
1360 S(X,A)=S1(X,A)+((E(X,I)-E1(X))/(E2(X)-E1(X)))*(S2(X,A)-S1(X,A))
1370 NEXT A:NEXT X
1380 REM PERIOD FERTILITY RATES ARE COMPUTED
1390 FOR B=1 TO 7
1400 F(B)=F1(B)+((T(I)-T1)/(T2-T1))*(F2(B)-F1(B))
1410 F(B)=(F(B)/1000)*5
1420 NEXT B
1430 REM *** START OF MAIN SEX LOOP ***
1440 FOR X=1 TO 2
1450 REM *** START OF AGE LOOP ***
1460 FOR A=1 TO 16:A1=A+1
1470 P2(X,A1)=P1(X,A)*S(X,A)
1480 NEXT A
1490 FOR B=1 TO 7:A=B+3
1500 B1(B)=F(B)*((P1(1,A)+P2(1,A))/2)
1510 NEXT B
1520 B1(8)=0
1530 FOR B=1 TO 7:B1(8)=B1(8)+B1(B):NEXT B
1540 P2(X,1)=B1(8)*SX(X)*S(X,1)
1550 P1(X,17)=0:P2(X,18)=0:P3=0
1560 FOR A=1 TO 16:P1(X,17)=P1(X,17)+P1(X,A):NEXT A
1570 FOR A=1 TO 17:P2(X,18)=P2(X,18)+P2(X,A):NEXT A
1580 FOR B=1 TO 7:A1=B+3:P3=P3+0.5*(P1(1,A1)+P2(1,A1)):NEXT B
1590 IF NP=0 THEN 1980
1600 REM --- TABLE PRINTING ROUTINE ---
1610 Y1=Y+4
1620 PRINT#-2,"PROJECTION FOR PERIOD JAN.1";Y;" TO DEC.31";Y1;" REGION = ";RN$(I
)
1630 PRINT#-2,"LIFE EXPECTANCY (YEARS) = ";
1640 PRINT#-2,USING "##.#";E(X,I);
1650 PRINT#-2," TOTAL FERTILITY RATE = ";
1660 PRINT#-2,USING "#.###";T(I);
1670 PRINT#-2," CHILD.PER WOMAN"
1680 IF NP<>1 THEN 1980
1690 GOSUB 2220
1700 PRINT#-2,"INITIAL",TAB(31)"**** ";SN$(X);" ****";TAB(75)"FINAL"
1710 PRINT#-2,"AGE           INITIAL    SURVIVAL SURVIVORS  FERTILE  FERTILITY  BIRT
HS       AGE"
1720 PRINT#-2,"GROUP       POPULATION  RATE",TAB(40)"POPULATION RATE",TAB(75)"GROU
P"
1730 PRINT#-2,TAB(10)"(MILLIONS)";TAB(27)"(MILLIONS)(MILLIONS)(PER 1000)(MILLION
S)"
1740 GOSUB 2220
1750 F1$="BIRTH                     .#####    ####.###                          ####.###
     ## ##"
1760 F2$="##-##          ####.###   .#####    ####.###
     ##-##"
1770 F3$="##-##          ####.###   .#####    ####.###   ####.###  ####.#   ####.###
     ##-##"
1780 F4$="##+            ####.###   .#####    ####.###
     ##+"
1790 F5$="TOTALS         ####.###             ####.###   ####.###           ####.###
    TOTALS"
```

FIGURE 4. Continued

```
1800 A1=0:A2=4
1810 PRINT#-2,USING F1$;S(X,1),P2(X,1),B1(8),A1,A2
1820 FOR A=1 TO 3:B=A+1:A1=(A-1)*5:A2=A1+4:A3=(B-1)*5:A4=A3+4
1830 PRINT#-2,USING F2$;A1,A2,P1(X,A),S(X,B),P2(X,B),A3,A4
1840 NEXT A
1850 FOR A=4 TO 10:B=A+1:A1=(A-1)*5:A2=A1+4:A3=(B-1)*5:A4=A3+4
1860 FF=0.5*(P1(1,A)+P2(1,A)):FR=F(A-3)*1000
1870 PRINT#-2,USING F3$;A1,A2,P1(X,A),S(X,B),P2(X,B),FR,B1(A-3),A3,A4
1880 NEXT A
1890 FOR A=11 TO 15:B=A+1:A1=(A-1)*5:A2=A1+4:A3=(B-1)*5:A4=A3+4
1900 PRINT#-2,USING F2$;A1,A2,P1(X,A),S(X,B),P2(X,B),A3,A4
1910 NEXT A
1920 A=16:B=A+1:A1=(A-1)*5:A3=(B-1)*5
1930 PRINT#-2,USING F4$;A1,P1(X,A),S(X,B),P2(X,B),A3
1940 GOSUB 2220
1950 A=17:B=A+1
1960 PRINT#-2,USING F5$;P1(X,A),P2(X,B),P3,B1(8)
1970 GOSUB 2220
1980 NEXT X: REM END OF SEX LOOP
1990 REM COMPONENT RATES ARE COMPUTED AND PRINTED
2000 P4=0.5*(P1(1,17)+P2(1,18)+P1(2,17)+P2(2,18))
2010 P5=P2(1,18)+P2(2,18)
2020 CBR=(B1(8)/P4)*1000:CBR=CBR/5
2030 REM DEATHS TOTAL COMPUTED
2040 D=P1(1,17)+P1(2,17)+B1(8)-P2(1,18)-P2(2,18)
2050 CDR=(D/P4)*1000:CDR=CDR/5
2060 NIR=CBR-CDR
2070 IF NP<>0 THEN 2100
2080 F6$="####          ##.#          ##.#          ##.#                ####.###  ####"
2085 Y2=Y+4
2090 PRINT#-2,USING F6$;Y,CBR,CDR,NIR,P5,Y2
2100 REM LES, TFRS AND POPNS UPDATED
2110 FOR X=1 TO 2:E(X,I)=E(X,I)+DE(X):NEXT X
2120 T(I)=T(I)-DT
2130 FOR X=1 TO 2:FOR A =1 TO 15
2140 P1(X,A)=P2(X,A)
2150 NEXT A
2160 P1(X,16)=P2(X,16)+P2(X,17)
2170 NEXT X
2180 Y=Y+5
2190 NEXT Q:REM END OF TIME LOOP
2195 GOSUB 2220
2200 GOTO 910:REM END OF REGION LOOP
2210 GOTO 2250
2220 REM LINE PRINTING ROUTINE
2230 FOR K=1 TO 79:PRINT#-2,"-";:NEXT K:PRINT#-2," "
2240 RETURN
2250 END
```

FIGURE 4 (Continued)

Lines 30 - 800 contain the data required throughout the projection. Lines 80 - 190 contain and read in the All India national populations by age and sex. Lines 200 - 260 contain regional populations from the 1971 and 1981 censuses of Table 1 and Government of India (1981). Lines 280 - 520 contain and read in the model life table survival rates of Table 8. Lines 530 - 610 contain the life expectancy data for regions described in the text (Section 4.3). Lines 620 - 720 contain the national fertility schedules (Table 9) and lines 730 - 770 the regional data. Lines 780 - 800 fix the proportions of each sex at birth.

The structure of the remainder of the program is shown in Figure 5. The user initially inputs a title for the projection, a description of the scenario involved, and then the life expectancy increase rates for females and males and the total fertility rate decrease rate. These govern the projections of all regions. If it is wished to apply different change rates to each region alter line 2200 to

```
2200 goto 820 : rem end of region loop
```

At line 910 the region loop begins and the user selects a region for projection, and then the type of printout desired. The projection model proper starts with a time loop at line 1320, a sex loop at 1430, an age loop at 1450. Populations, life expectancies and total fertilities are updated after each period's computations.

Figures 6 and 7 give examples of projections for All India and Kerala respectively in which full details of the projection are printed out. Female results precede male for each period. The initial population in age groups 0 - 4 to 75+ is multiplied by the survival rate shown to produce survivors in the final age groups listed on the right hand side. The fertile population is for females in both the female and male table since the model is used is female dominant. The fertile populations are multiplied by the fertility rates to yield births by age of mother, which are summed, sexed and survived in the top row of the table.

If full details of the projection calculations are not required, a short printout can be requested as shown in Figure 8. Compared with the earlier forecasts using the component model, the projections are a good deal lower. The reason is that the improvement rate in life expectancy (.2 of a year per year) results in a much slower lowering of the death rate than was assumed in the components model, and the total fertility decline assumed (0.6 child per year) produces a slightly faster decrease in the birth rate than assumed earlier. A projection of more current experience would

810 initial parameters

TITLES ETC INPUT
LIFE EXPECTANCY INCREASE RATE INPUT
TOTAL FERTILITY DECLINE RATE INPUT

910 Start of region loop

REGION SELECTED
TYPE OF PRINTOUT SELECTED

1320 Start of time loop

SURVIVAL RATES COMPUTED
FERTILITY RATES COMPUTED

1430 Start of main sex loop

1450 Start of age loop

MODEL COMPUTATIONS

1590 End of age loop

PRINTOUT OF AGE-SEX TABLE

1980 End of sex loop

PRINTOUT OF AGGREGATE TABLE
UPDATING OF POPULATIONS, LIFE EXPECTANCIES,
TOTAL FERTILITIES

2190 End of time loop

2200 End of region loop

FIGURE 5. The loop structure of the program for implementing the cohort survival model

PROJECTION RUN = THIRD TRIAL RUN
SCENARIO = F1 M1 SLOW CHANGE
LIFE EXPECTANCY INCREASE RATES (PER 5 YEARS)=
FEMALE 1 MALE 1
TOTAL FERTILITY DECLINE RATE (PER 5 YEARS)= .3
NUMBER OF REGION = 1
NUMBER OF PERIODS = 3

PROJECTION FOR PERIOD JAN.1 1981 TO DEC.31 1985 REGION = ALL INDIA
LIFE EXPECTANCY (YEARS) = 51.0 TOTAL FERTILITY RATE = 4.540 CHILD.PER WOMAN

INITIAL AGE GROUP	INITIAL POPULATION (MILLIONS)	SURVIVAL RATE	**** FEMALES **** SURVIVORS (MILLIONS)	FERTILE POPULATION (MILLIONS)	FERTILITY RATE (PER 1000)	BIRTHS (MILLIONS)	FINAL AGE GROUP
BIRTH		.86976	51.381			121.803	0 4
0 4	46.589	.93179	40.521				5 9
5 9	43.720	.97243	40.784				10 14
10 14	40.695	.97941	39.573				15 19
15 19	35.559	.97644	34.827	37.566	377.3	14.173	20 24
20 24	30.060	.97246	29.352	32.443	1136.8	36.881	25 29
25 29	25.254	.96827	24.558	27.303	1198.6	32.725	30 34
30 34	21.731	.96365	21.041	23.144	892.2	20.649	35 39
35 39	18.833	.95867	18.148	19.937	565.0	11.264	40 44
40 44	16.100	.95378	15.435	17.124	288.3	4.936	45 49
45 49	13.401	.94497	12.781	14.418	81.6	1.176	50 54
50 54	10.734	.92823	10.143				55 59
55 59	8.528	.89950	7.916				60 64
60 64	6.519	.85148	5.864				65 69
65 69	4.741	.77889	4.037				70 74
70 74	3.276	.68000	2.552				75 79
75+	3.275	.42140	2.227				80+
TOTALS	329.064		361.140	171.935		121.803	TOTALS

PROJECTION FOR PERIOD JAN.1 1981 TO DEC.31 1985 REGION = ALL INDIA
LIFE EXPECTANCY (YEARS) = 52.0 TOTAL FERTILITY RATE = 4.540 CHILD.PER WOMAN

INITIAL AGE GROUP	INITIAL POPULATION (MILLIONS)	SURVIVAL RATE	**** MALES **** SURVIVORS (MILLIONS)	FERTILE POPULATION (MILLIONS)	FERTILITY RATE (PER 1000)	BIRTHS (MILLIONS)	FINAL AGE GROUP
BIRTH		.87622	54.964			121.803	0 4
0 4	48.970	.94244	42.908				5 9
5 9	46.435	.97688	43.763				10 14
10 14	43.021	.98165	42.026				15 19
15 19	38.303	.97524	37.600	37.566	377.3	14.173	20 24
20 24	32.283	.97017	31.483	32.443	1136.8	36.881	25 29
25 29	26.579	.96845	25.787	27.303	1198.6	32.725	30 34
30 34	22.568	.97003	21.854	23.144	892.2	20.649	35 39
35 39	19.679	.95951	19.090	19.937	565.0	11.264	40 44
40 44	17.250	.95093	16.552	17.124	288.3	4.936	45 49
45 49	14.962	.93757	14.227	14.418	81.6	1.176	50 54
50 54	12.498	.91842	11.717				55 59
55 59	9.963	.88882	9.150				60 64
60 64	7.464	.84033	6.634				65 69
65 69	5.246	.76945	4.408				70 74
70 74	3.416	.66888	2.626				75 79
75+	3.415	.41622	2.284				80+
TOTALS	352.049		387.076	171.935		121.803	TOTALS

FIGURE 6. A projection of India's population 1981-1996: age-sex disaggregated populations forecast by a cohort survival model

PROJECTION FOR PERIOD JAN.1 1991 TO DEC.31 1995 REGION = ALL INDIA
LIFE EXPECTANCY (YEARS) = 53.[illegible] TOTAL FERTILITY RATE = 3.940 CHILD.PER WOMAN

INITIAL AGE GROUP	INITIAL POPULATION (MILLIONS)	SURVIVAL RATE	**** FEMALES **** SURVIVORS	FERTILE POPULATION (MILLIONS)	FERTILITY RATE (MILLIONS)(PER 1000)	BIRTHS (MILLIONS)	FINAL AGE GROUP
BIRTH		.87957	56.496			132.435	0 4
0 4	54.873	.93780	48.264				5 9
5 9	44.941	.92480	42.146				10 14
10 14	37.879	.98103	36.924				15 19
15 19	39.708	.97810	38.355	38.316	334.6	12.821	20 24
20 24	38.730	.97441	37.943	36.873	1014.4	39.433	25 29
25 29	34.036	.97054	33.165	35.990	1071.9	38.576	30 34
30 34	28.572	.96626	27.730	30.868	761.2	23.498	35 39
35 39	23.807	.96147	23.004	25.768	463.3	11.940	40 44
40 44	20.304	.95664	19.521	21.654	230.4	4.988	45 49
45 49	17.423	.94801	16.668	18.472	63.9	1.180	50 54
50 54	14.743	.93193	13.977				55 59
55 59	12.097	.90439	11.274				60 64
60 64	9.404	.85795	8.532				65 69
65 69	7.139	.78728	6.125				70 74
70 74	5.012	.69004	3.946				75 79
75+	6.435	.43060	4.441				80+
TOTALS	395.194		429.110	209.941		132.435	TOTALS

PROJECTION FOR PERIOD JAN.1 1991 TO DEC.31 1995 REGION = ALL INDIA
LIFE EXPECTANCY (YEARS) = 54.0 TOTAL FERTILITY RATE = 3.940 CHILD.PER WOMAN

INITIAL AGE GROUP	INITIAL POPULATION (MILLIONS)	SURVIVAL RATE	**** MALES **** SURVIVORS	FERTILE POPULATION (MILLIONS)	FERTILITY RATE (MILLIONS)(PER 1000)	BIRTHS (MILLIONS)	FINAL AGE GROUP
BIRTH		.88627	60.447			132.435	0 4
0 4	58.705	.94778	52.028				5 9
5 9	48.437	.97891	45.907				10 14
10 14	40.553	.98308	39.698				15 19
15 19	42.795	.97702	42.071	38.316	334.6	12.821	20 24
20 24	41.265	.97233	40.336	38.873	1014.4	39.433	25 29
25 29	36.702	.97073	35.687	35.990	1071.9	38.576	30 34
30 34	30.578	.97202	29.683	30.868	761.2	23.498	35 39
35 39	25.002	.96235	24.303	25.766	463.3	11.940	40 44
40 44	21.221	.95422	20.422	21.654	230.4	4.988	45 49
45 49	19.344	.94132	17.504	18.472	63.9	1.180	50 54
50 54	15.767	.92290	14.842				55 59
55 59	13.366	.89437	12.[illegible]				60 64
60 64	10.788	.84738	9.[illegible]				65 69
65 69	8.158	.77850	6.[illegible]				70 74
70 74	5.598	.68007	4.[illegible]				75 79
75+	6.725	.42603	4.[illegible]				80+
TOTALS	424.024		460.756	209.941		132.435	TOTALS

FIGURE 6. Continued

PROJECTION RUN = FOURTH TRIAL RUN
SCENARIO = F1 M1
LIFE EXPECTANCY INCREASE RATE (PER 5 YEARS)=
FEMALE 1 MALE 1
TOTAL FERTILITY DECLINE RATE (PER 5 YEARS)= .3
NUMBER OF REGION = 1
NUMBER OF PERIODS = 2

PROJECTION FOR PERIOD JAN.1 1981 TO DEC.31 1985 REGION = KERALA
LIFE EXPECTANCY (YEARS) = 62.2 TOTAL FERTILITY RATE = 3.587 CHILD.PER WOMAN

INITIAL AGE GROUP	INITIAL POPULATION (MILLIONS)	**** FEMALES **** SURVIVAL RATE	SURVIVORS (MILLIONS)	FERTILE POPULATION (MILLIONS)	FERTILITY RATE (PER 1000)	BIRTHS (MILLIONS)	FINAL AGE GROUP
BIRTH		.92477	1.719			3.833	0 4
0 4	1.822	.96554	1.685				5 9
5 9	1.712	.98570	1.653				10 14
10 14	1.592	.98849	1.560				15 19
15 19	1.391	.98607	1.375	1.480	309.5	0.458	20 24
20 24	1.176	.98339	1.159	1.275	942.3	1.202	25 29
25 29	0.998	.98098	0.971	1.074	997.2	1.071	30 34
30 34	0.850	.97826	0.834	0.911	684.1	0.623	35 39
35 39	0.737	.97436	0.721	0.785	403.5	0.317	40 44
40 44	0.630	.96981	0.614	0.675	196.3	0.133	45 49
45 49	0.524	.96201	0.506	0.569	53.5	0.030	50 54
50 54	0.420	.94899	0.404				55 59
55 59	0.334	.92691	0.317				60 64
60 64	0.255	.88778	0.236				65 69
65 69	0.185	.82599	0.165				70 74
70 74	0.128	.73631	0.106				75 79
75+	0.128	.47303	0.094				80+
TOTALS	12.870		14.129	6.768		3.833	TOTALS

PROJECTION FOR PERIOD JAN.1 1981 TO DEC.31 1985 REGION = KERALA
LIFE EXPECTANCY (YEARS) = 60.8 TOTAL FERTILITY RATE = 3.587 CHILD.PER WOMAN

INITIAL AGE GROUP	INITIAL POPULATION (MILLIONS)	**** MALES **** SURVIVAL RATE	SURVIVORS (MILLIONS)	FERTILE POPULATION (MILLIONS)	FERTILITY RATE (PER 1000)	BIRTHS (MILLIONS)	FINAL AGE GROUP
BIRTH		.92063	1.817			3.833	0 4
0 4	1.732	.96602	1.595				5 9
5 9	1.642	.98588	1.587				10 14
10 14	1.522	.98796	1.500				15 19
15 19	1.355	.98313	1.338	1.480	309.5	0.458	20 24
20 24	1.142	.97971	1.123	1.275	942.3	1.202	25 29
25 29	0.940	.97851	0.921	1.074	997.2	1.071	30 34
30 34	0.798	.97884	0.781	0.911	684.1	0.623	35 39
35 39	0.696	.97206	0.681	0.785	403.5	0.317	40 44
40 44	0.610	.96545	0.593	0.675	196.3	0.133	45 49
45 49	0.529	.95414	0.511	0.569	53.5	0.030	50 54
50 54	0.442	.93822	0.422				55 59
55 59	0.352	.91336	0.331				60 64
60 64	0.264	.87147	0.241				65 69
65 69	0.186	.80943	0.162				70 74
70 74	0.121	.71833	0.098				75 79
75+	0.121	.45960	0.087				80+
TOTALS	12.452		13.787	6.768		3.833	TOTALS

FIGURE 7.

A projection of Kerala's population 1981-91: age-sex disaggregated populations forecast by a cohort survival model

PROJECTION FOR PERIOD JAN.1 1986 TO DEC.31 1990 REGION = KERALA
LIFE EXPECTANCY (YEARS) = 63.2 TOTAL FERTILITY RATE = 3.287 CHILD.PER WOMAN

INITIAL AGE GROUP	INITIAL POPULATION (MILLIONS)	SURVIVAL RATE	**** FEMALES **** SURVIVORS (MILLIONS)	FERTILE POPULATION (MILLIONS)	FERTILITY RATE (PER 1000)	BIRTHS (MILLIONS)	FINAL AGE GROUP
BIRTH		.92968	1.827			4.052	0 4
0 4	1.719	.96855	1.538				5 9
5 9	1.685	.98688	1.632				10 14
10 14	1.653	.99929	1.631				15 19
15 19	1.569	.98693	1.552	1.000	288.1	0.481	20 24
20 24	1.375	.98437	1.357	1.463	881.2	1.290	25 29
25 29	1.159	.98211	1.141	1.256	933.9	1.175	30 34
30 34	0.971	.97956	0.954	1.056	618.6	0.653	35 39
35 39	0.834	.97576	0.817	0.894	352.6	0.315	40 44
40 44	0.721	.97123	0.703	0.763	167.3	0.129	45 49
45 49	0.614	.96353	0.596	0.658	44.6	0.029	50 54
50 54	0.508	.95084	0.490				55 59
55 59	0.404	.92936	0.384				60 64
60 64	0.317	.89101	0.294				65 69
65 69	0.236	.83019	0.211				70 74
70 74	0.165	.74133	0.137				75 79
75+	0.200	.47763	0.148				80+
TOTALS	14.129		15.472	7.699		4.052	TOTALS

PROJECTION FOR PERIOD JAN.1 1996 TO DEC.31 1990 REGION = KERALA
LIFE EXPECTANCY (YEARS) = 61.8 TOTAL FERTILITY RATE = 3.287 CHILD.PER WOMAN

INITIAL AGE GROUP	INITIAL POPULATION (MILLIONS)	SURVIVAL RATE	**** MALES **** SURVIVORS (MILLIONS)	FERTILE POPULATION (MILLIONS)	FERTILITY RATE (PER 1000)	BIRTHS (MILLIONS)	FINAL AGE GROUP
BIRTH		.92565	1.932			4.052	0 4
0 4	1.817	.96863	1.682				5 9
5 9	1.595	.98690	1.545				10 14
10 14	1.587	.98867	1.566				15 19
15 19	1.500	.98402	1.483	1.000	288.1	0.481	20 24
20 24	1.338	.98079	1.317	1.463	881.2	1.290	25 29
25 29	1.123	.97965	1.101	1.258	933.9	1.175	30 34
30 34	0.921	.97984	0.902	1.056	618.6	0.653	35 39
35 39	0.781	.97346	0.765	0.894	352.6	0.315	40 44
40 44	0.681	.96709	0.663	0.763	167.3	0.129	45 49
45 49	0.593	.95601	0.574	0.658	44.6	0.029	50 54
50 54	0.511	.94046	0.488				55 59
55 59	0.422	.91614	0.397				60 64
60 64	0.331	.87499	0.303				65 69
65 69	0.241	.81395	0.211				70 74
70 74	0.162	.72392	0.132				75 79
75+	0.185	.46451	0.134				80+
TOTALS	13.787		15.194	7.699		4.052	TOTALS

FIGURE 7. Continued

PROJECTION RUN = SIXTH TRIAL RUN
SCENARIO = F1 M1 SLOW CHANGE
LIFE EXPECTANCY INCREASE RATE (PER [illegible] YEARS) =
FEMALE 1 MALE 1
TOTAL FERTILITY DECLINE RATE (PER 5 YEARS)= .3
NUMBER OF REGION = 1
NUMBER OF PERIODS = 8

FORECASTS FOR ALL INDIA

YEAR START	CRUDE BIRTH RATE (PER 1000 POPULATION)	CRUDE DEATH RATE (PER 1000 POPULATION)	NATURAL INCREASE RATE PER 1000 POPULATION)	POPULATION (END OF PERIOD) (MILLIONS)	YEAR END
1981	34.1	15.3	18.8	748.216	1985
1986	33.0	14.9	18.1	819.219	1990
1991	31.0	14.5	16.5	883.866	1995
1996	28.0	13.9	14.2	955.164	2000
2001	25.1	13.3	11.8	1013.173	2005
2006	22.6	12.7	9.9	1064.620	2010
2011	20.6	12.3	8.2	1109.409	2015
2016	18.4	12.0	6.4	1145.493	2020

FORECASTS FOR ANDHRA PRADESH

YEAR START	CRUDE BIRTH RATE (PER 1000 POPULATION)	CRUDE DEATH RATE (PER 1000 POPULATION)	NATURAL INCREASE RATE PER 1000 POPULATION)	POPULATION (END OF PERIOD) (MILLIONS)	YEAR END
1981	34.9	17.1	17.8	58.173	1985
1986	33.9	16.6	17.3	63.418	1990
1991	31.9	16.2	15.7	68.597	1995
1996	28.8	15.5	13.3	73.312	2000
2001	25.7	14.9	10.9	77.413	2005
2006	23.2	14.2	9.0	80.965	2010
2011	21.1	13.8	7.3	83.977	2015
2016	18.9	13.4	5.5	86.305	2020

FIGURE 8. A projection of the populations of India and selected states 1981-2021 using a cohort survival model

FORECASTS FOR KERALA

YEAR START	CRUDE BIRTH RATE (PER 1000 POPULATION)	CRUDE DEATH RATE (PER 1000 POPULATION)	NATURAL INCREASE RATE PER 1000 POPULATION)	POPULATION YEAR (END OF PERIOD) (MILLIONS)	END
1981	28.8	9.3	19.5	27.916	1985
1986	27.7	8.9	18.8	30.666	1990
1991	25.8	8.6	17.2	33.427	1995
1996	23.1	8.3	14.8	35.992	2000
2001	19.8	7.9	11.9	38.200	2005
2006	16.7	7.7	9.0	39.968	2010
2011	14.1	7.5	6.6	41.305	2015
2016	11.7	7.5	4.2	42.129	2020

FORECASTS FOR UTTAR PRADESH

YEAR START	CRUDE BIRTH RATE (PER 1000 POPULATION)	CRUDE DEATH RATE (PER 1000 POPULATION)	NATURAL INCREASE RATE PER 1000 POPULATION)	POPULATION YEAR (END OF PERIOD) (MILLIONS)	END
1981	39.3	17.7	21.6	123.040	1985
1986	37.7	17.4	20.3	136.185	1990
1991	35.1	16.9	18.2	149.198	1995
1996	31.7	16.1	15.7	161.351	2000
2001	28.9	15.2	13.6	172.737	2005
2006	27.0	14.6	12.4	183.797	2010
2011	25.4	14.1	11.3	194.459	2015
2016	23.5	13.7	9.8	204.233	2020

FORECASTS FOR REST OF INDIA

YEAR START	CRUDE BIRTH RATE (PER 1000 POPULATION)	CRUDE DEATH RATE (PER 1000 POPULATION)	NATURAL INCREASE RATE PER 1000 POPULATION)	POPULATION YEAR (END OF PERIOD) (MILLIONS)	END
1981	32.9	14.2	18.7	540.417	1985
1986	31.9	13.8	18.1	591.732	1990
1991	30.0	13.4	16.6	643.125	1995
1996	27.2	12.9	14.4	691.048	2000
2001	24.3	12.3	12.0	733.836	2005
2006	21.9	11.8	10.1	771.664	2010
2011	19.8	11.5	8.3	804.340	2015
2016	17.6	11.2	6.4	830.378	2020

FIGURE 8. Continued

need a life expectancy improvement rate of .4 year per year and a total fertility decline rate of .1 child per year.

The projections for Kerala indicate, however, that we should set limits on the change in life expectancies and total fertility rates. Otherwise they become unrealistically low.

5. PROJECTION MODELS INCORPORATING MIGRATION

5.1 Introduction

The cohort survical model takes us to the usual limit of conventional demographic practice in population projection for India's population. However, a major assumption underlies its use : that the population is not influenced by migration. For the All India population and for states such as Andhra Pradesh and Uttar Pradesh this may be a reasonable assumption. But if the population of a major urban agglomeration were being projected, the assumption would not be reasonable.

In what ways can migration be incorporated into a population projection model? The simplest method is to use rates of net in-migration and add these to the cohort survival model. The second method is to use a bi-regional cohort survival model: the two regions are the area of interest and rest of the country. The third method is to construct population accounts for the area of interest, the rest of the country and the outside world and use a projection model based on these accounts. Each method has additional data requirements compared with the one earlier in the list.

In the rest of the section brief notes on each model are given and suggestions made about the projection of migration rates. Unfortunately, insufficient data were to hand to develop the models in practice.

5.2 Incorporating net migration into the cohort survival model

For urban areas it is possible, because a large part of their growth, at least initially, derives from net in-migration, to measure net migration, N, by the survived population method over a ten year intercensal period:

$$N^x_{aa+2}(t,t+10) = P^x_{a+2}(t+10) - s^x_{a+1a+2}\, s^x_{aa+1}\, P^x_a(t)$$

for initial age cohorts a = 3 to A-3

$$N^x_{02}(t,t+10) = P^x_2(t+10) - s^x_{12}\, s^x_{01}\, B^x(t,t+5)$$

for the second age cohort

$$N^x_{01}(t,t+5) = P^x_1(t+10) - s^x_{01}\, B^x(t+5,t+10)$$

for the first age cohort

$$N^x_{A-2A}(t,t+10) + N^x_{A-1A}(t,t+10) + N^x_{AA}(t,t+10) = P^x_A(t+10) - s^x_{A-1A}\, s_{A-2A-1}\, P^x_{A-2}(t) - s^x_{AA}\, s_{A-1A}\, P^x_{A-1}(t) - s^x_{AA}\, s_{AA}\, P^x_A(t)$$

for intial age cohorts A-2, A-1 and A.

These equations measure net migration over a ten year period. This migration needs to be distributed over five year periods for the cohort survival model. One estimate would be

$$N^x_{aa+1} = \tfrac{1}{2}\,(\tfrac{1}{2}\, N^x_{aa+2} + \tfrac{1}{2}\, N^x_{a-1a+1})$$

assuming net migration to be evenly distributed over the period.

There are then two possible rate definitions that could be adopted

$$n^{(1)}_{aa+1} = N_{aa+1} \,/\, P_a(t)$$

or

$$n^{(2)}_{aa+1} = N_{aa+1} \,/\, (P_{a+1}(t+10) \,/\, s_{aa+1})$$

which could be averaged.

The principal cohort survival model equation would then be modified to read

$$P^x_{a+1}(t+5) = (s^x_{aa+1} + n^x_{aa+1})\, P^x_a(t)$$

with suitable modifications to the other equations.
That is, net migration rates are added to the survival rates throughout. The net migration rates would be positive for Indian metropolitan areas and negative for rural. They might be either negative or positive for state populations.

How would the net migration rates be forecast? As with the survival and fertility rates, a standard schedule would be established and an overall parameter, such as the overall net migration rate, forecast into the future. Cassen (1978) argues that net migration rates into Indian urban areas will tend to fall over time as they lose their attraction with growth. This he suggests has already happened to Calcutta and is happening to Bombay. At first net migration is a very important contributor to urban population growth but then natural increase becomes relatively more important. The level of both components will tend to fall in the future then.

5.3 A bi-regional cohort survival model

If migration data are available via a retrospective question in a decadal census it is possible to develop a model that incorporates rates of migration from an area to the rest of the country and to an area from the rest of the country. These rates can be defined very approximately as

$$m^{ij}_{aa+1} = M^{ij}_{aa+1}(t,t+5) \,/\, (P_{a+1}(t+5) \,/\, s_{aa+1})$$

where M^{ij}_{aa+1} is the migration flow from region i to region j over a five year period from age group a to a+1. The end of period census population must be back-survived to provide an estimate of the initial population at risk of migration. If only one year data (the year prior to the census) are available the five year rate must be estimated as approximately

$$m^{ij}_{aa+1} = k\,\tfrac{1}{2}\,(M^{ij}_{a-1a}(t+4,t+5) + M_{aa+1}(t+4,\ t+5)) \,/\, (P_{a+1}(t+5) \,/\, s_{aa+1})$$

where k will 5 if survey data are unavailable for the empirical ratio between one and five year migration flows.

The principal cohort survival model equation then becomes, if there are two regions i and j in the model,

$$P^{ix}_{a+1}(t+5) = (s^{ix}_{aa+1} - m^{ijx}_{aa+1})\,P^{ix}_{a}(t) + m^{ji}_{aa+1}\,P^{jx}_{a}(t)$$

and

$$P^{jx}_{a+1}(t+5) = (s^{jx}_{aa+1} - m^{jix}_{aa+1})\,P^{jx}_{a}(t) + m^{ij}_{aa+1}\,P^{ix}_{a}(t)$$

The main advantage of such a model is that it connects together the populations of the two regions explicitly, whereas the net migration model does not.

The migration rates needed to be projected forward using model migration schedules and overall parameters such as the gross migra production rate. The reader is referred to the International Institute for Applied Systems Analysis's volumes on Migration and Settlement, edited by A. Rogersand F. Willekens for further details on multiregional population models, of which the bi-regional cohort survival model is a simple example.

5.4 An accounting model

The problem with the bi-regional cohort survival model is that it fails to deal with external migration. This deficiency could be dealt with by adding in a net external migration rate. Another difficulty is that migration in the Indian census has been measured using the last migration question, and migration data so generated are inconsistent with the multi-regional cohort survival model. Both problems can be dealt with using an accounting model but such a model using last migration data is yet to be put to the test (see Rees 1984 for further details and a guide to the literature on accounting models).

6. CONCLUSIONS

This paper has shown how the population of India and of subnational areas can be projected with limited information. In doing this two purposes will have been served. Firstly, it is hoped that Indian planners with responsibility for regional and urban matters will be able to use, build on and improve on the data and models presented here. Secondly, general students of population will benefit from an exposure to many of the steps in conventional population projection which in official publications or academic works are glossed over.

REFERENCES

Cassen, R.H. (1978) *India: population, economy and society.* Macmillan, London.

Cassen, R.H. and Dyson, T. (1976) New population projections for India. *Population and Development Review,* 2,1.

Coale, A.J. and Demeny, P. (1966) *Regional model life tables and stable populations.* Princeton University Press, Princeton, New Jersey.

Government of India (1981) *India: a reference manual.* Publications Division, Ministry of Information and Broadcasting, Delhi.

Population Reference Bureau (1982) *World fertility chart.* Population Reference Bureau, Washington, D.C.

Rees, P.H. (1979) *Migration and settlement: 1. United Kingdom.* Research Report RR-79-3, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Rees, P.H. (1984) Does it really matter which migration data you use in a population model? Working Paper 383, School of Geoggraphy, University of Leeds UK.

Rogers, A. and Willekens, F. (ed.) (1978-82) *Migration and settlement.* 3 volumes of collected Research Reports. International Institute for Applied Systems Analysis, Laxenburg, Austria.

United Nations (1981a) *World population prospects as assessed in 1980.* Department of International Economic and Social Affairs, Population Studies No. 78, United Nations, New York.

United Nations (1981b) *Statistical yearbook for Asia and the Pacific 1981.* Economic and Social Commission for Asia and the Pacific, United Nations, Bangkok.

United Nations (1983) *Demographic yearbook 1983.* Department of International Economic and Social Affairs, Statistical Office, New York.

Visaria, P. and Visaria, L. (1981) India's population: second and growing. *Population Bulletin,* 36,4 (October), Population Reference Bureau Inc., Washington, DC.

Woods, R. (1982) *Theoretical population geography.* Longman, London.

World Bank (1982) *World development report.* Oxford University Press, London.