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FORCT : A COMPUTER PROGRAM FOR CALCULATING FUTURE PRODUCTION FROM UNDISCOVERED OIL FILEDS

by

A.L. HINDE

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## SUMMARY

The FORTRAN program FORCT is used at BMR to calculate annual oil production from undiscovered oil resources, normally contained in a number of separate areas.

For each area, the input data consists of:-

1) the discovery rate of the fields;
2) the size of the smallest field;
3) the year of the first discovery, and the lead time between discovery of a field and production of oil.

For each area, a number of individual cases may be studied depending on the choices of:

4) the total volume of undiscovered oil in the area; and
5) either the volume of the largest field or the number of fields in the area.

A straight line relationship is assumed between the logarithms of rank and volume of the various oilfields. Their order of discovery is assumed to be random, with the probability of discovery being proportional to field size. This is simulated in the computer by the selection of random numbers (Monte Carlo method).

Once discovered, a field produces oil according to a pre-determined lead time and production profile.

Each iteration produces a profile for the combined production of oil from all the fields over a 30 year period. Repeated iterations produce the final output, which is an average profile for the combined production of oil from all the fields over a 30 year period, with an indication of the 95 percent confidence limits of the profile (ie $\pm$ two standard deviations).

## INTRODUCTION

The calculation of future rates of oil production from undiscovered fields requires information on the number, size, and productivity of the fields, future rates of discovery, and the lead time between discovery and production. The program described in this record requires the user to stipulate the size of the undiscovered oil resource. Given the number of fields and an estimate of the size of the largest and smallest field, the program can be used to break the undiscovered oil resource up into individual fields, assuming the field sizes are distributed according to an inverse power function. Future rates of discovery and estimates of the lead time between discovery and production may then be input and used in combination with an average field production profile to produce the estimate of future rates of oil production.

It should be emphasised that the output of the program described in this report reflects the various types of information fed in, and that these should be carefully estimated. The statistical variation printed with the output (ie the standard deviations of the yearly productions of oil) reflects only the statistical variation in the order in which discovery of the fields of various size are simulated.

## DESCRIPTION OF THE METHOD

The program allows for any number of cases in each of any number of areas to be analysed. For each such case, a number of sequential steps are involved in producing a production profile.

1. Read in : the number of areas to be processed; the number of runs, NRUNS, to be used in the Monte Carlo simulation; and a five digit seed for the random number generator.

2. Read in, for this area : a title; annual field discovery rate; size of smallest field; year of first discovery and the lead time between discovery of a field and production of oil.

3. Read in the number of cases, for this area.

4. Read in, for this case : total volume of undiscovered recoverable oil; and volume of largest field or number of fields.

5. Calculate the field sizes according to a log-log rank-volume relationship (subroutine FSIZE).

6. Carry out a Monte Carlo simulation to determine the annual oil production. This consists of a loop, which carries out the following iteration NRUNS times:
   6.1 Determine the order in which the fields are discovered (subroutine FDISC) by selection of random numbers;
   6.2 Using the discovery rate, year of first discovery, and lead time, calculate the combined annual production arising from all fields when discovered in this order (subroutine PRODN).

7. Determine an average production profile for all the iterations carried out in 6, and calculate the second moment.

8. Tabulate the average annual production and the standard deviation for a 30 year period, and plot the production profile with $\pm$ two standard deviations (subroutine PLOUT).

9. Go to 4, until all cases for this area have been processed.

10. Go to 2, until all areas have been processed.

Steps 5, 6, and 8 contain the main algorithms on which the program is based, and these are described in more detail in the following sections.

Calculation of field sizes (subroutine FSIZE)

In calculating the field sizes, it is assumed that they are distributed according to an inverse power, frequency distribution:

$$f(V) = K_2 V^{-1-K_1}, \quad V_1 \leq V \leq V_N \qquad (1)$$

where $K_2 = -K_1/(V_1^{-K_1} - V_N^{-K_N})$

$N$ = number of fields.

That is, decreasing field sizes occur with increasing frequency, between the upper and lower limits, $V_1$ and $V_N$.

It can be shown that for this distribution, log volume is linearly related to log rank (Riesz, 1978a):

$$V_i = V_1 i^a \text{ (or } \log V_i = a \log i + \log V_1) \qquad (2)$$

where $V_1$ is the size of the largest field;

$V_i$ is the size of the i'th largest field;

i is the rank, i = 1, 2, ..., N;

$a = 1/K_1 = \log (V_N/V_1)/\log(N)$.

In order to calculate the field sizes, it is necessary therefore, to know the values of $V_1$, a, and the number of fields, N. Because the total volume, given by,

$$V_{TOT} = V_1 + V_2 + \ldots + V_N = V_1(1 + 2^a + \ldots + N^a) \qquad (3)$$

and the size of the smallest field, $V_N$, are known (specified in the input) it is only necessary to specify one of the parameters, $V_1$, a, or N. The other two can be derived by solving equations (3) and (4):

$$a = \log (V_N/V_1)/\log(N) \qquad (4)$$

The program accepts either $V_1$ or N, as these are easier for most people to visualise than the slope of the log-log relationship, a. If N is specified, $V_1$ and N are determined simultaneously from equations (3) and (4) (this is done numerically). If $V_1$ is specified, a and N are determined. In the latter case, however, an exact solution is not possible because N must be restricted to the integers. Consequently, the fields will not add up exactly to $V_{TOT}$. The difference, however, will be small, provided $V_N$ is small relative to $V_1$.

If N is specified, it must be less than $V_{TOT}/V_N$, otherwise the field sizes will all be less than $V_N$. Similarly, if $V_1$ is specified, it must be between $V_{TOT}$ and $V_N$.

Subroutine FSIZE determines the field sizes and produces a vector array containing the fields in decreasing size. It also prints out the field sizes. The maximum number of fields allowed is 100.

Determination of discovery order (subroutine FDISC)

Once the field sizes have been determined, random numbers are used to determine the discovery order. The first step in the Monte Carlo loop is to produce a list of fields in which the order of discovery is random, except that the probability of discovery, at any particular time, is equal to the field size divided by the total remaining volume:

$$\text{probability (field } i \text{ being discovered next)} = V_i \Big/ \left( \sum_{j}^{\text{remaining fields}} V_j \right)$$

This random ordering is carried out by subroutine FDISC, using the array of field sizes produced by FSIZE, as follows:

1. a random number between 0 and 1 is generated;
2. the field volumes are converted into fractions of the total volume;
3. starting at the first field, the fractions are summed until the sum exceeds the random number;
4. the last field included in the sum is considered to be discovered first, and is removed from further consideration;
5. this process is repeated using all the remaining fields in order to determine the order in which the subsequent fields are to be discovered.

Calculation of annual production of oil (subroutine PRODN)

Once discovered, each oilfield produces oil according to a predetermined lead time and a production profile. The production profile for each field is assumed to be identical and is expressed as a percentage of the total field volume produced in each calendar year.

| Year, i | percent of total field volume produced, $F_i$ |
|---|---|
| 1 | 4.3 |
| 2 | 8.6 |
| 3 | 8.6 |
| 4 | 8.6 |
| 5 | 8.6 |
| 6 | 8.6 |
| 7 | 8.6 |
| 8 | 8.6 |
| 9 | 7.8 |
| 10 | 6.5 |
| 11 | 4.9 |
| 12 | 3.9 |
| 13 | 3.4 |
| 14 | 2.6 |
| 15 | 2.0 |
| 16 | 1.0 |
| 17 | 1.0 |
| 18 | 1.0 |
| 19 | 0.8 |
| 20 | 0.6 |
| 21 | 0 |

In any particular year, the total volume of oil produced is the sum of the volume produced from each individual field in that year. Production in year i is given by,

$$Q_i = \sum_{j=1}^{N} V_j \, P_{(i\text{-first year of production} + 1)}$$

where N = number of fields

$V_j$ = size of the j-th field

$P_k$ = % of total field produced in the k'th production year (as tabled above)

$P_k$ = 0 if $k < 1$ or $k > 20$

Subroutine PRODN calculates and records $Q_i$ for a 30 year period, and it also calculates and records $Q_i^2$ (so that the standard deviation can be calculated) for each iteration of subroutine FDISC and PRODN. The values of $Q_i$ and $Q_i^2$ are accumulated for each iteration.

After NRUNS iterations, the accumulated values of $Q_i$ and $Q_i^2$ are used in the main program to calculate the profile of average annual production and its second moment.

Tabulation and plotting of results (subroutine PLOUT)

Subroutine PLOUT calculates the standard deviation of the annual production. The average and standard deviation of the annual production are then printed for the 30 year period. Values for average annual production are plotted with a '*' symbol and values for plus and minus two standard deviations are plotted with '.' symbols alongside the printed values.

## INPUT DATA

In order to run the program, a file called 'DATAF', with the data described below, needs to be prepared. As a convention, real data items are allowed 10 columns (F10.0 format) and integers five columns (I5 format).

| Line | Cols | Variable | Description | Format for entire line |
|---|---|---|---|---|
| 1 | 1-5 | NAREA | Number of areas to be processed | (3I5) |
| | 6-10 | NRUNS | Number of runs in the Monte Carlo loop (if omitted, 100 is used) | |
| | 11-15 | ISEED | Seed for the random number generator (if omitted, 12345 is used) | |
| 2 | 1-80 | TITLE | Descriptive title for area | (20A4) |
| 3 | 1-10 | DISR | Discovery rate | (2F10.0,2I5) |
| | 11-20 | VCUT | Size of smallest field | |
| | 21-25 | NSTART | Year of first field discovery | |
| | 26-30 | LEADTM | Lead time to production of oil after a field is discovered | |
| 4 | | NCASE | Number of cases to be considered for area | (I5) |
| 5 | 1-10 | VTOT | Total undiscovered recoverable oil volume | (2F10.0,I5) |
| | 11-20 | VP(1) | The size of the largest field | |
| | 21-25 | NP | The number of fields (maximum 100 allowed) | |

Notes:

1. In line 5, it is only necessary to specify either VP(1) or NP, if both are specified, then NP is used and VP(1) is ignored.

2. If VP(1) is used, and is small enough to produce more than 100 fields, an error message is printed and the program stops.

3. Lines 2 to 5 are repeated for each area to be processed (as specified with NAREA).

4. Line 5 is repeated for each case to be considered (as specified with NCASE).

The file 'DATAF', may be created with the following commands (after logging on)

```
ED,-
                enter data
*EOD
SF,DATAF  ) used if DATAF does not previously exist
          )
or DU,DATAF  ) used if DATAF already exists.
```

## RUNNING THE PROGRAM

The program resides in BMR's Hewlett-Packard computer, and is called FORCT. To run the program, after the data file 'DATAF' has been prepared, use the commands:

```
RP,FORCT:915:3     (to restore program FORCT)
RU,FORCT           (to run program FORCT: output to the terminal)
```

The output will be sent back to the terminal. To send the output to the printer, use the following commands:

```
RP,FORCT:915:3
RU,FORCT,6         (to run program FORCT; output to LU6)
LP,-XXXX           (to print the output file, -XXXX)
```

Here, -XXXX is the name of the list file produced by the program and the actual value of -XXXX to be used is given on the terminal at the completion of the program.

(Note: it is only necessary to use the command RP,FORCT:915:3, once for an entire terminal session, regardless of how many times FORCT is run).

Example terminal session

This example of a complete terminal session, including log-on and log-off, is given, so that persons with little or no experience of the computer system may run the program. Data or information that would be displayed on the terminal is underlined; data or information that is to be typed in by the user is not underlined. The symbol "^" indicates that a blank space is to be typed. The return key is to be pressed at the end of each line typed in.

Press any key
PLEASE LOG-ON: ALAN.RESAS

PREVIOUS TOTAL SESSION TIME etc ....

SECURITY CODE? 915

| | |
|---|---|
| ! ED,- | (Run the editor in input mode) |
| : ^^^^2^^^10 | (Beginning of data:<br>2 areas; 10 runs in Monte Carlo simulation) |
| : AREA 1 | (Title for first area) |
| : ^^^^^^8.75^^^^^^^^2.^1983^^^4 | (discovery rate 8.75; smallest field 2.,<br>first discovery year 1983; lead time 4 years) |
| : ^^^^2 | (2 cases) |
| : ^^^^^^950.^^^^^^250. | (first case: total 950; largest field 250.) |
| : ^^^^^^950.^^^^^^^^^^^^20 | (second case: total 950; 20 fields) |
| : AREA 2 | (title for second area) |
| : ^^^^^^^0.5^^^^^^^^2.^1983 | (discovery rate 0.5) |
| : ^^^^1 | (1 case) |
| : ^^^^^1000.^^^^^^200. | (total 1000; largest field 200.) |
| : *EOD | (exit from input mode) |

```
: DU,DATAF                          (if an error occurs here, use SF,DATAF)

DATAF CLOSED 9 LINES
! RP,FORCT:915:3                    (restore program FORCT)
! RU,FORCT,5                        (run program FORCT)

/FORCT: STOP 00000

FORCT LUN 06 SPOOL FILE -0333       (The spool file, -0333, varies
                                    from run to run)
! LP,-0333                          (send output to the printer)
! EX                                (log-off)
```

ACKNOWLEDGMENTS

Program FORCT was based on a program written for the CYBER 76 and outlined in Riesz (1978b). Changes were made to the manner in which the field sizes are calculated, the order in which the fields are discovered, and the production profile used. The author wishes to acknowledge the guidance of Dr D.J. Forman given while implementing these changes and for assistance in editing the manuscript. Thanks are also given to Mrs D. Leonard for typing the manuscript.

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