AD-A042 286 GEORGE WASHINGTON UNIV WASHINGTON D C PROGRAM IN LOG--ETC F/G 12/2
SOLVING INVENTORY PROBLEMS USING THE FACTORABLE NONLINEAR PROGR--ETC(U)
JUN 77 G P MCCORMICK N00014-75-C-0729
UNCLASSIFIED SERIAL-T-357 NL

1 OF 1
ADA
042286

END

DATE
FILMED
8-77

7

(12)

THE
GEORGE
WASHINGTON
UNIVERSITY

STUDENTS FACULTY STUDY R
ESEARCH DEVELOPMENT FUT
URE CAREER CREATIVITY CO
MMUNITY LEADERSHIP TECH
NOLOGY FRONTIE ESIGN
ENGINEERING APP ENC
GEORGE WASHIN NIV

**INSTITUTE FOR MANAGEMENT
SCIENCE AND ENGINEERING**
SCHOOL OF ENGINEERING
AND APPLIED SCIENCE

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE; ITS DISTRIBUTION IS UNLIMITED

SOLVING INVENTORY PROBLEMS USING THE FACTORABLE NONLINEAR PROGRAMMING LANGUAGE

by

Garth P. McCormick

Serial T-357
1 June 1977

The George Washington University
School of Engineering and Applied Science
Institute for Management Science and Engineering

Program in Logistics

Contract N00014-75-C-0729
Project NR 347 020
Office of Naval Research

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

⑭

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. ~~REPORT NUMBER~~
Serial-T-357

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
⑥ SOLVING INVENTORY PROBLEMS USING THE FACTORABLE NONLINEAR PROGRAMMING LANGUAGE.

5. ~~TYPE OF REPORT & PERIOD COVERED~~
⑨ SCIENTIFIC rept.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
⑩ GARTH P. MCCORMICK

8. CONTRACT OR GRANT NUMBER(s)
⑮ N00014-75-C-0729

9. PERFORMING ORGANIZATION NAME AND ADDRESS
THE GEORGE WASHINGTON UNIVERSITY
PROGRAM IN LOGISTICS
WASHINGTON, D.C. 20037

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
OFFICE OF NAVAL RESEARCH
CODE 430D
ARLINGTON, VA 22217

12. ~~REPORT DATE~~
⑪ 1 JUNE 1977

13. NUMBER OF PAGES
15

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
⑫ 17p.

15. SECURITY CLASS. (of this report)
NONE

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
FACTORABLE PROGRAMMING
INVENTORY MODELS
NONLINEAR OPTIMIZATION MODEL

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This memorandum is intended to aid the logistics practitioner in setting up his algebraic statement of an optimization model in such a way that it can be automatically processed and solved by a canned nonlinear programming algorithm. The example used is the Schrady-Choe optimal inventory model. The model algorithm interface is accomplished by a new version of the factorable nonlinear programming language which allows for symbolic input.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

NONE
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

405 337

1B

THE GEORGE WASHINGTON UNIVERSITY
School of Engineering and Applied Science
Institute for Management Science and Engineering

Program in Logistics

Abstract
of
Serial T-357
1 June 1977

SOLVING INVENTORY PROBLEMS USING THE FACTORABLE NONLINEAR PROGRAMMING LANGUAGE

by

Garth P. McCormick

This memorandum is intended to aid the logistics practitioner in setting up his algebraic statement of an optimization model in such a way that it can be automatically processed and solved by a canned nonlinear programming algorithm. The example used is the Schrady-Choe optimal inventory model. The model algorithm interface is accomplished by a new version of the factorable nonlinear programming language which allows for symbolic input.

THE GEORGE WASHINGTON UNIVERSITY
School of Engineering and Applied Science
Institute for Management Science and Engineering

Program in Logistics

SOLVING INVENTORY PROBLEMS USING THE FACTORABLE NONLINEAR PROGRAMMING LANGUAGE

by

Garth P. McCormick

1. Introduction

With the ability to solve general nonlinear optimization (programming) problems has come the development of more sophisticated and realistic models. One example of this in the logistics area is the presentation in [1] of an optimal inventory model. This model was solved by the Sequential Unconstrained Minimization Technique (SUMT) using as the interface between the algebraic statement of the problem and the canned algorithm, four FORTRAN subroutines. This traditional mode of input to the nonlinear programming algorithm was required since function value and derivative information is necessary to solve the problem efficiently. A first attempt at providing a simpler model/algorithm interface was done by Pugh, et al., [2] and was a very sophisticated computer code allowing for general forms of symbolic input. Unfortunately, this code was slow. A more sparse approach to problem representation was developed in [3]. Internally, the code was fast, but the user was restricted to numerical input. This code is in the process of undergoing revision [4] and in this memorandum the inventory model given in [1] is presented in the new format which allows for mnemonic symbolic input for variable, constant, and function names. This will make the existing nonlinear programming codes more accessible to practitioners. This memorandum is an adjunct to the users manual [4] and should be used in conjunction with it and the original paper [1].

2. The Inventory Model

Below is given a brief development of the optimization problem. For more details the reader is referred to [1] and [5].

Fixed Inputs and Constants

N = number of items in inventory ($n = 2N$ is the number of variables or unknowns in the nonlinear programming problem)

c_i = item unit cost (in dollars)

v_i = item unit volume

λ_i = mean demand per unit time

(μ_i, σ_i) = mean and standard deviation of lead time demand distribution for ith item.

Let

$\phi(x) = (1/\sqrt{2\pi}\; e^{-x^2/2}$ the normal density function, and

$\Phi(z) = \int_z^\infty \phi(x)dx$ the right hand cumulative normal distribution function.

K_1 = investment limit in dollars

K_2 = reorder work load limit

K_3 = volume limit

Derived Quantities

$$\beta_i(z) = \frac{1}{2}[\sigma_i^2 + (z-\mu_i)^2]\ \Phi\left(\frac{z-\mu_i}{\sigma_i}\right) - \frac{\sigma_i}{2}(z-\mu_i)\ \phi\left(\frac{z-\mu_i}{\sigma_i}\right)$$

$$B_i(Q_i, r_i) = \frac{1}{Q_i}[\beta_i(r_i) - \beta_i(Q_i+r_i)]\ ,\ EOH_i = r_i + Q_i/2 - \mu_i + B_i(Q_i, r_i)$$

The optimization problem is

$$\underset{\{Q_i, r_i\}}{\text{minimize}} \ \Sigma_{i=1}^{N} B_i(Q_i, r_i) \quad \text{(expected time-weighted shortages)}$$

subject to

$$\Sigma_{i=1}^{N} c_i \left(r_i + \frac{Q_i}{2} - \mu_i + B_i(Q_i, r_i) \right) \leq K_1 \quad \text{(investment constraint)}$$

$$\Sigma_{i=1}^{N} \frac{\lambda_i}{Q_i} \leq K_2 \quad \text{(reorder workload constraint)}$$

$$\Sigma_{i=1}^{N} v_i \left(r_i + \frac{Q_i}{2} - \mu_i + B_i(Q_i, r_i) \right) \leq K_3 \ , \quad \text{(capacity constraint)}$$

$$Q_i \geq 0 \ , \ i = 1, \ldots, N \ .$$

3. The Model in Factorable Form

The factorable programming language which provides the interface between the algebraic statement of the optimization problem and canned optimization algorithms assumes that the problem can be written in the following canonical factorable form:

$$\min_{x \in E^n} X^N(x)$$

$$\text{Subject to:} \quad L_i \leq X^i(x) \leq U_i \ , \qquad \text{for} \quad i=1,\ldots,N-1$$

(possibly $L_i = -\infty$ and/or $U_i = +\infty$) where $X^i(x) \equiv x_i$ (for $i = 1,\ldots,n$) and the remainder are defined recursively as follows:

given $X^p(x)$, for $p = 1,\ldots,i-1$, then for $i = n+1,\ldots,N$,

$$X^i(x) = \sum_{p=1}^{i-1} T_p^i[X^p(x)] + \sum_{p=1}^{i-1} \sum_{q=1}^{p} V_{q,p}^i[X^p(x)] \cdot U_{p,q}^i[X^q(x)] \ ,$$

where the T's, U's, and V's are functions of a <u>single</u> variable.

In writing down his particular problem in canonical factorable form the user should obey two fundamental rules. The quantities $X^p(x)$ are called concomitant variable functions (cvfs) and on the right-hand side of the defining equation for any X^i there cannot appear any X^p where $p \geq i$. Furthermore, no more than two factors can appear in any product term.

The new format allowed for the factorable programming language allows for symbolic variable names instead of just numbers for the cvfs. The user may use any mnemonic devices to help in setting up the factorable canonical form. For the problem example above this could take the following form:

$$z_i = (r_i - \mu_i) \qquad , \quad i = 1,\dots,N \qquad (r_i - \mu_i)$$

$$y_i = z_i + Q_i \qquad , \quad i = 1,\dots,N \qquad (r_i + Q_i - \mu_i)$$

$$u_i = z_i/\sigma_i \qquad , \quad i = 1,\dots,N \qquad (r_i - \mu_i)/\sigma_i$$

$$v_i = y_i/\sigma_i \qquad , \quad i = 1,\dots,N \qquad (r_i + Q_i - \mu_i)/\sigma_i$$

$$w_i = \sigma_i^2 + z_i^2 \qquad , \quad i = 1,\dots,N \qquad (\sigma_i^2 + (r_i - \mu_i)^2)$$

$$t_i = \sigma_i^2 + y_i^2 \qquad , \quad i = 1,\dots,N \qquad (\sigma_i^2 + (r_i + Q_i - \mu_i)^2)$$

$$p_i = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{u_i} e^{-t^2/2} dt$$

$$q_i = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{v_i} e^{-t^2/2} dt$$

$$D_i(r_i, Q_i) = 1/2\ w_i[1 - p_i] - \frac{\sigma_i}{2} z_i \phi(u_i) \qquad [\beta(r_i) - \beta_i(r_i + Q_i)]$$

$$- \frac{1}{2} t_i [1 - q_i] + \frac{\sigma_i}{2} y_i \phi(v_i), \quad i = 1,\dots,N$$

$$B_i(Q_i,r_i) = D_i(r_i,Q_i)/Q_i\ , \qquad i = 1,\dots,N \qquad B_i(Q_i,r_i)$$

$$EOH_i = r_i + Q_i/2 - \mu_i + B_i(Q_i,r_i), \quad i = 1,\dots,N \qquad (EOH_i)$$

$$EXPINV = \Sigma_{i=1}^{N} c_i\ EOH_i \qquad \text{(EXPECTED INVESTMENT)}$$

$$EXPVOL = \Sigma_{i=1}^{N} v_i\ EOH_i \qquad \text{(EXPECTED VOLUME)}$$

$$REORD = \Sigma_{i=1}^{N} \lambda_i/Q_i \qquad \text{(WORK LOAD)}$$

$$SHORT = \Sigma_{i=1}^{N} B_i(Q_i,r_i) \qquad \text{(EXPECTED TIME-WEIGHTED SHORTAGES)}$$

Under the new system the user first declares the names of his variables and then the names of the data constants he uses. He also has the capability of placing bounds on ranges of variables using their symbolic names.

In Appendix A is given the listing of the card input for the inventory model developed in [1]. A slightly more elaborate model was presented in [5] based on material in [1]. The card listing for this model is given in Appendix B.

4. Conclusion

A brief description of the manner in which a particular logistics optimal inventory model can be described in the new factorable programming interface has been given. Hopefully the new flexible format which allows for symbolic names of variables, constants, and functions will make the use of optimization codes more widespread.

REFERENCES

[1] SCHRADY, D. A. and U. C. CHOE (1971). Models for multi-item continuous review inventory policies subject to constraints. Naval Res. Logist. Quart. **18** 451-463.

[2] PUGH, ROBERT E. (1972). A language for nonlinear programming problems. Mathematical Programming. **2** (2) 176-206.

[3] McCORMICK, G. P. (1974). A mini-manual for the use of the SUMT computer program and the factorable programming language. Technical Report SOL-74-15, Systems Optimization Laboratory, Department of Operations Research, Stanford University.

[4] de SILVA, A. Factorable programming manual with symbolic input. Draft Technical Paper, Institute for Management Science and Engineering, The George Washington University.

[5] McCORMICK, G. P. (1972). Computational aspects of nonlinear programming solutions to large scale inventory problems. Technical Memorandum Serial TM-63488. Program in Logistics, The George Washington University.

APPENDIX A

SYMBOLIC FACTORABLE PROGRAMMING INPUT FOR SIMPLE SCHRADY-CHOE MODEL DESCRIBED IN [1]

```
UTILITY: VERSION 6, 3/8/73                             MONDAY    JAN 31,1977    17:17

// EXEC FORT6,DSN='U.LR3434.LODMOD',PROG=FACSYM
//GO.SYSLIB  DD
//   DD DSN=GWU.FORTLIB,DISP=SHR
//GO.FT05F001 DD *
 0.10000D-04 0.10000D 01 0.10000D-04 0.40000D 01 1.95000D 02   6   6   0
 600.          270.          300.          200.          260.         400.
  MULTI ITEM INVENTORY PROBLEM USING SYMBOLIC INPUT
    6   31    6    0    1
 V    Q1
 V    Q2
 V    Q3
 V    R1
 V    R2
 V    R3
 D    K1                8000.
 D    K2                  15.
 D    K3              200000.
 D    L1                1000.
 D    L2                1500.
 D    L3                2000.
 D   MU1                 100.
 D   MU2                 200.
 D   MU3                 300.
 D   SG1                 100.
 D   SG2                 100.
 D   SG3                 200.
 D    C1                   1.
 D    C2                  10.
 D    C3                  20.
 D   VV1                   2.
 D   VV2                   6.
 D   VV3                  10.
 D  SG21               10000.
 D  SG22               10000.
 D  SG23               40000.
 D   DPI           .398942280
 S    Z1  R1  LIN          1.     -100.
 S    Z2  R2  LIN          1.     -200.
 S    Z3  R3  LIN          1.     -300.
 S    U1  Z1  LIN         .01
 S    U2  Z2  LIN         .01
 S    U3  Z3  LIN        .005
 S    W1      CON        SG21
 S    W1  Z1  POL          2.
 S    W2      CON        SG22
 S    W2  Z2  POL          2.
 S    W3      CON        SG23
 S    W3  Z3  POL          2.
 S    P1  U1  NOR         1.0
 S    P2  U2  NOR         1.0
 S    P3  U3  NOR         1.0
 Q    D1  W1  LIN          .5
 Q    D1  P1  LIN         -1.        1,
 Q    D1  Z1  LIN        -50.
 Q    D1  U1  ESQ         -.5       DPI
 Q    D2  W2  LIN          .5
 Q    D2  P2  LIN         -1.        1.
```

```
Q    D2     Z2 LIN          -50.
Q    D2     U2 ESQ           -.5       DPI
Q    D3     W3 LIN            .5
Q    D3     P3 LIN           -1.        1.
Q    D3     Z3 LIN         -100.
Q    D3     U3 ESQ           -.5       DPI
Q    B1     D1 LIN           1.
Q    B1     Q1 POL           -1.
Q    B2     D2 LIN           1.
Q    B2     Q2 POL           -1.
Q    B3     D3 LIN           1.
Q    B3     Q3 POL           -1.
S  EOH1     Z1 LIN           1.
S  EOH1     Q1 LIN            .5
S  EOH2     Z2 LIN           1.
S  EOH2     Q2 LIN            .5
S  EOH3     Z3 LIN           1.
S  EOH3     Q3 LIN            .5
S  EINV   EOH1 LIN            C1
S  EINV   EOH2 LIN            C2
S  EINV   EOH3 LIN            C3
S  EVOL   EOH1 LIN           VV1
S  EVOL   EOH2 LIN           VV2
S  EVOL   EOH3 LIN           VV3
S  REOR     Q1 POL           -1.        L1
S  REOR     Q2 POL           -1.        L2
S  REOR     Q3 POL           -1.        L3
L    Q1     Q3               0.0
U  EINV   EINV                K1
U  REOR   REOR                K2
U  EVOL   EVOL                K3
S  SHOR     B1 LIN           1.
S  SHOR     B2 LIN           1.
S  SHOR     B3 LIN           1.
S
   1     1     1
   2     2     1
   3     3     1
   4    28     2
   5    29     2
   6    30     2
 600.         270.        300.        200.        260.        400.
    3         2     2       1      1      1      1      1      1      1
0.100000D-02 0.100000D-02
    1         1
//GO.FT07F001 DD SYSOUT=B
```

APPENDIX B

SYMBOLIC FACTORABLE PROGRAMMING INPUT FOR MODIFIED SCHRADY-CHOE MODEL DESCRIBED IN [5]

```
UTILITY: VERSION 6, 3/8/73                             MONDAY    JAN 31,1977    16:48

            // EXEC FORT6,DSN='U.LR3434.LODMOD',PROG=FACSYM
            //GO.SYSLIB  DD
            //  DD DSN=GWU.FORTLIB,DISP=SHR
            //GO.FT05F001 DD *
             0.10000D-04 0.10000D 01 0.10000D-04 0.40000D 01 1.95000D 02   6   6   0
              600.        270.        300.        200.        260.        400.
              MULTI ITEM INVENTORY PROBLEM USING SYMBOLIC INPUT
                6   43    6    0    1
            V    Q1
            V    Q2
            V    Q3
            V    R1
            V    R2
            V    R3
            D    K1                 8000.
            D    K2                   15.
            D    K3               200000.
            D    L1                 1000.
            D    L2                 1500.
            D    L3                 2000.
            D   MU1                  100.
            D   MU2                  200.
            D   MU3                  300.
            D   SG1                  100.
            D   SG2                  100.
            D   SG3                  200.
            D    C1                    1.
            D    C2                   10.
            D    C3                   20.
            D   VV1                    2.
            D   VV2                    6.
            D   VV3                   10.
            D  SG21                10000.
            D  SG22                10000.
            D  SG23                40000.
            D   DPI            .398942280
            S    Z1   R1 LIN           1.      -100.
            S    Z2   R2 LIN           1.      -200.
            S    Z3   R3 LIN           1.      -300.
            S    U1   Z1 LIN          .01
            S    U2   Z2 LIN          .01
            S    U3   Z3 LIN         .005
            S    Y1   Z1 IDN
            S    Y1   Q1 IDN
            S    Y2   Z2 IDN
            S    Y2   Q2 IDN
            S    Y3   Z3 IDN
            S    Y3   Q3 IDN
            S    V1   Y1 LIN          .01
            S    V2   Y2 LIN          .01
            S    V3   Y3 LIN         .005
            S    T1      CON         SG21
            S    T1   Y1 POL           2.
            S    T2      CON         SG22
            S    T2   Y2 POL           2.
            S    T3      CON         SG23
            S    T3   Y3 POL           2.
```

```
S   QQ1    V1  NOR          1.0
S   QQ2    V2  NOR          1.0
S   QQ3    V3  NOR          1.0
S    W1        CON         SG21
S    W1    71  POL           2.
S    W2        CON         SG22
S    W2    Z2  POL           2.
S    W3        CON         SG23
S    W3    73  POL           2.
S    P1    U1  NOR          1.0
S    P2    U2  NOR          1.0
S    P3    U3  NOR          1.0
Q    D1    W1  LIN           .5
Q    D1    P1  LIN          -1.          1.
Q    D1    Z1  LIN         -50.
Q    D1    U1  ESQ          -.5         DPI
Q    D1    T1  LIN          -.5
Q    D1   QQ1  LIN          -1.          1.
Q    D1    Y1  LIN         +50.
Q    D1    V1  ESQ          -.5         DPI
Q    D2    W2  LIN           .5
Q    D2    P2  LIN          -1.          1.
Q    D2    Z2  LIN         -50.
Q    D2    U2  ESQ          -.5         DPI
Q    D2    T2  LIN          -.5
Q    D2   QQ2  LIN          -1.          1.
Q    D2    Y2  LIN          50.
Q    D2    V2  ESQ          -.5         DPI
Q    D3    W3  LIN           .5
Q    D3    P3  LIN          -1.          1.
Q    D3    Z3  LIN        -100.
Q    D3    U3  ESQ          -.5         DPI
Q    D3    T3  LIN          -.5
Q    D3   QQ3  LIN          -1.          1.
Q    D3    Y3  LIN         100.
Q    D3    V3  ESQ          -.5         DPI
Q    B1    D1  LIN           1.
Q    B1    Q1  POL          -1.
Q    B2    D2  LIN           1.
Q    B2    Q2  POL          -1.
Q    B3    D3  LIN           1.
Q    B3    Q3  POL          -1.
S  EOH1    Z1  LIN           1.
S  EOH1    Q1  LIN           .5
S  EOH1    B1  IDN
S  EOH2    Z2  LIN           1.
S  EOH2    Q2  LIN           .5
S  EOH2    B2  IDN
S  EOH3    Z3  LIN           1.
S  EOH3    Q3  LIN           .5
S  EOH3    B3  IDN
S  EINV  EOH1  LIN           C1
S  EINV  EOH2  LIN           C2
S  EINV  FOH3  LIN           C3
S  EVOL  EOH1  LIN          VV1
S  EVOL  FOH2  LIN          VV2
S  EVOL  FOH3  LIN          VV3
```

T-357

```
UTILITY: VERSION 6, 3/8/73                             MONDAY    JAN 31,1977    16:48

             S REOR    Q1 POL        -1.          L1
             S REOR    Q2 POL        -1.          L2
             S REOR    Q3 POL        -1.          L3
             L   Q1    Q3            0.0
             U EINV FINV              K1
             U REOR REOR              K2
             U EVOL EVOL              K3
             S SHOR    B1 LIN        1.
             S SHOR    B2 LIN        1.
             S SHOR    B3 LIN        1.
             5
                1    1    1
                2    2    1
                3    3    1
                4   40    2
                5   41    2
                6   42    2
              600.        270.        300.        200.        260.        400.
                   3      2      2      1      1      1      1      1      1      1
             0.10000D-02 0.10000D-02
                   1      1
            //GO.FT07F001 DD SYSOUT=B
```

THE GEORGE WASHINGTON UNIVERSITY
Program in Logistics
Distribution List for Technical Papers

The George Washington University
    Office of Sponsored Research
    Library
    Vice President H. F. Bright
    Dean Harold Liebowitz
    Mr. J. Frank Doubleday

ONR
    Chief of Naval Research
        (Codes 200, 430D, 1021P)
        Resident Representative

OPNAV
    OP-40
    DCNO, Logistics
    Navy Dept Library
    OP-911
    OP-964

Naval Aviation Integrated Log Support

NAVCOSSACT

Naval Cmd Sys Sup Activity Tech Library

Naval Electronics Lab Library

Naval Facilities Eng Cmd Tech Library

Naval Ordnance Station
    Louisville, Ky.
    Indian Head, Md.

Naval Ordnance Sys Cmd Library

Naval Research Branch Office
    Boston
    Chicago
    New York
    Pasadena
    San Francisco

Naval Research Lab
    Tech Info Div
    Library, Code 2029 (ONRL)

Naval Ship Engng Center
    Philadelphia, Pa.
    Hyattsville, Md.

Naval Ship Res & Dev Center

Naval Sea Systems Command
    Tech Library
    Code 073

Naval Supply Systems Command
    Library
    Capt W. T. Nash

Naval War College Library
    Newport

BUPERS Tech Library

FMSO

Integrated Sea Lift Study

USN Ammo Depot Earle

USN Postgrad School Monterey
    Library
    Dr. Jack R. Borsting
    Prof C. R. Jones

US Marine Corps
    Commandant
    Deputy Chief of Staff, R&D

Marine Corps School Quantico
    Landing Force Dev Ctr
    Logistics Officer

Armed Forces Industrial College

Armed Forces Staff College

Army War College Library
    Carlisle Barracks

Army Cmd & Gen Staff College

US Army HQ
    LTC George L. Slyman
    Army Trans Mat Command

Army Logistics Mgmt Center
    Fort Lee

Commanding Officer, USALDSRA
    New Cumberland Army Depot

US Army Inventory Res Ofc
    Philadelphia

HQ, US Air Force
    AFADS-3

Griffiss Air Force Base
    Reliability Analysis Center

Maxwell Air Force Base Library

Wright-Patterson Air Force Base
    HQ, AF Log Command
    Research Sch Log

Defense Documentation Center

National Academy of Science
    Maritime Transportation Res Board Library

National Bureau of Standards
    Dr E. W. Cannon
    Dr Joan Rosenblatt

National Science Foundation

National Security Agency

WSEG

British Navy Staff

Logistics, OR Analysis Establishment
    National Defense Hdqtrs, Ottawa

American Power Jet Co
    George Chernowitz

ARCON Corp

General Dynamics, Pomona

General Research Corp
    Dr Hugh Cole
    Library

Planning Research Corp
    Los Angeles

Rand Corporation
    Library

Carnegie-Mellon University
    Dean H. A. Simon
    Prof G. Thompson

Case Western Reserve University
    Prof B. V. Dean
    Prof John R. Isbell
    Prof M. Mesarovic
    Prof S. Zacks

Cornell University
    Prof R. E. Bechhofer
    Prof R. W. Conway
    Prof J. Kiefer
    Prof Andrew Schultz, Jr.

Cowles Foundation for Research
    Library
    Prof Herbert Scarf
    Prof Martin Shubik

Florida State University
    Prof R. A. Bradley

Harvard University
    Prof K. J. Arrow
    Prof W. G. Cochran
    Prof Arthur Schleifer, Jr.

New York University
    Prof O. Morgenstern

Princeton University
    Prof A. W. Tucker
    Prof J. W. Tukey
    Prof Geoffrey S. Watson

Purdue University
Prof S. S. Gupta
Prof H. Rubin
Prof Andrew Whinston

Stanford
Prof T. W. Anderson
Prof G. B. Dantzig
Prof F. S. Hillier
Prof D. L. Iglehart
Prof Samuel Karlin
Prof G. J. Lieberman
Prof Herbert Solomon
Prof A. F. Veinott, Jr.

University of California, Berkeley
Prof R. E. Barlow
Prof D. Gale
Prof Rosedith Sitgreaves
Prof L. M. Tichvinsky

University of California, Los Angeles
Prof J. R. Jackson
Prof Jacob Marschak
Prof R. R. O'Neill
Numerical Analysis Res Librarian

University of North Carolina
Prof W. L. Smith
Prof M. R. Leadbetter

University of Pennsylvania
Prof Russell Ackoff
Prof Thomas L. Saaty

University of Texas
Prof A. Charnes

Yale University
Prof F. J. Anscombe
Prof I. R. Savage
Prof M. J. Sobel
Dept of Admin Sciences

Prof Z. W. Birnbaum
University of Washington

Prof B. H. Bissinger
The Pennsylvania State University

Prof Seth Bonder
University of Michigan

Prof G. E. P. Box
University of Wisconsin

Dr. Jerome Bracken
Institute for Defense Analyses

Prof H. Chernoff
MIT

Prof Arthur Cohen
Rutgers – The State University

Mr Wallace M. Cohen
US General Accounting Office

Prof C. Derman
Columbia University

Prof Paul S. Dwyer
Mackinaw City, Michigan

Prof Saul I. Gass
University of Maryland

Dr Donald P. Gaver
Carmel, California

Dr Murray A. Geisler
Logistics Mgmt Institute

Prof J. F. Hannan
Michigan State University

Prof H. O. Hartley
Texas A & M Foundation

Mr Gerald F. Hein
NASA, Lewis Research Center

Prof W. M. Hirsch
Courant Institute

Dr Alan J. Hoffman
IBM, Yorktown Heights

Dr Rudolf Husser
University of Bern, Switzerland

Prof J. H. K. Kao
Polytech Institute of New York

Prof W. Kruskal
University of Chicago

Prof C. E. Lemke
Rensselaer Polytech Institute

Prof Loynes
University of Sheffield, England

Prof Steven Nahmias
University of Pittsburgh

Prof D. B. Owen
Southern Methodist University

Prof E. Parzen
State University New York, Buffalo

Prof H. O. Posten
University of Connecticut

Prof R. Remage, Jr.
University of Delaware

Dr Fred Rigby
Texas Tech College

Mr David Rosenblatt
Washington, D. C.

Prof M. Rosenblatt
University of California, San Diego

Prof Alan J. Rowe
University of Southern California

Prof A. H. Rubenstein
Northwestern University

Dr M. E. Salveson
West Los Angeles

Prof Edward A. Silver
University of Waterloo, Canada

Prof R. M. Thrall
Rice University

Dr S. Vajda
University of Sussex, England

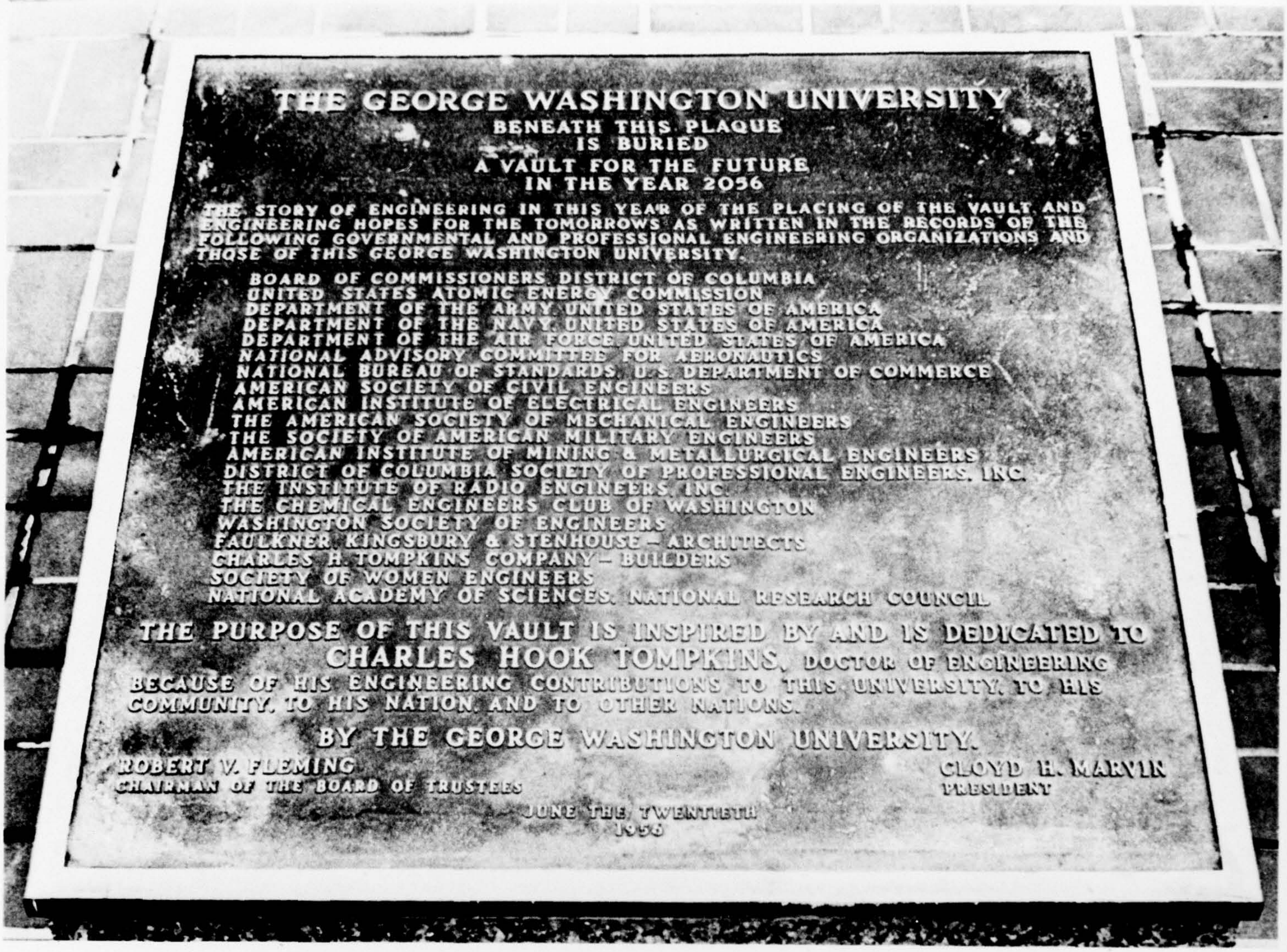
Prof T. M. Whitin
Wesleyan University

Prof Jacob Wolfowitz
University of Illinois

Mr Marshall K. Wood
National Planning Association

Prof Max A. Woodbury
Duke University

May 1976



THE GEORGE WASHINGTON UNIVERSITY

BENEATH THIS PLAQUE
IS BURIED
A VAULT FOR THE FUTURE
IN THE YEAR 2056

THE STORY OF ENGINEERING IN THIS YEAR OF THE PLACING OF THE VAULT AND ENGINEERING HOPES FOR THE TOMORROWS AS WRITTEN IN THE RECORDS OF THE FOLLOWING GOVERNMENTAL AND PROFESSIONAL ENGINEERING ORGANIZATIONS AND THOSE OF THIS GEORGE WASHINGTON UNIVERSITY.

BOARD OF COMMISSIONERS, DISTRICT OF COLUMBIA
UNITED STATES ATOMIC ENERGY COMMISSION
DEPARTMENT OF THE ARMY, UNITED STATES OF AMERICA
DEPARTMENT OF THE NAVY, UNITED STATES OF AMERICA
DEPARTMENT OF THE AIR FORCE, UNITED STATES OF AMERICA
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
NATIONAL BUREAU OF STANDARDS, U.S. DEPARTMENT OF COMMERCE
AMERICAN SOCIETY OF CIVIL ENGINEERS
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
THE SOCIETY OF AMERICAN MILITARY ENGINEERS
AMERICAN INSTITUTE OF MINING & METALLURGICAL ENGINEERS
DISTRICT OF COLUMBIA SOCIETY OF PROFESSIONAL ENGINEERS, INC.
THE INSTITUTE OF RADIO ENGINEERS, INC.
THE CHEMICAL ENGINEERS CLUB OF WASHINGTON
WASHINGTON SOCIETY OF ENGINEERS
FAULKNER, KINGSBURY & STENHOUSE – ARCHITECTS
CHARLES H. TOMPKINS COMPANY – BUILDERS
SOCIETY OF WOMEN ENGINEERS
NATIONAL ACADEMY OF SCIENCES, NATIONAL RESEARCH COUNCIL

THE PURPOSE OF THIS VAULT IS INSPIRED BY AND IS DEDICATED TO
CHARLES HOOK TOMPKINS, DOCTOR OF ENGINEERING
BECAUSE OF HIS ENGINEERING CONTRIBUTIONS TO THIS UNIVERSITY, TO HIS COMMUNITY, TO HIS NATION, AND TO OTHER NATIONS.

BY THE GEORGE WASHINGTON UNIVERSITY.

ROBERT V. FLEMING
CHAIRMAN OF THE BOARD OF TRUSTEES

CLOYD H. MARVIN
PRESIDENT

JUNE THE TWENTIETH
1956

To cope with the expanding technology, our society must be assured of a continuing supply of rigorously trained and educated engineers. The School of Engineering and Applied Science is completely committed to this objective.