SYSTEM DYNAMICS SEMINAR SERIES, 1974
(MIT - System Dynamics)

SDG Seminar Series

MEMO 4/15/84
FROM Christian
TO SDG
RE Seminar Line-up

Here is the new line-up of seminars. As you can see there are a few open slots. If you have a topic you would like to present or have discussed, please let me know.

4/16	Patriots Day vacation. no seminar
4/23	Christian Kampmann: An illustrative model critique: the Tsembaga Population Control Model.
4/30	A guest lecturer will demonstrate a micro computer corporate simulation package.
5/1	open
5/7	Karl Klauset will share some if his experience in teaching system dynamics and chair a discussion of an appropriate curriculum in the field.
5/14	open
5/21	open

MEMO 5/10/84
FROM Christian
TO SDG
RE. Seminar Line-up

Here is the sparse line-up of seminars for the following couple of weeks:

5/14 Don Abrams will describe the work he is doing for his Masters Thesis: Implementing Spectral Analysis in DYNAMO.

5/21 John Morecroft will talk about his work in applying system dynamics in business: System Dynamics and Business Strategy.

The subsequent weeks are all open, if anyone has a pressing need to give a seminar. I will be coming around asking people individually.

F- System Dynamics Seminar

December 1, 1983

To: The System Dynamics Group

From: Bob Eberlein

Regarding: Seminar

Please note the following change in schedule

December 5: IAP Special

Christian will present a report on the IAP situation for 1984 and chair, with an iron fist, a highly structured discussion on the subject.

December 12: Nancy Hack

Nancy will discuss some of the aspects of dealing with the R.W. in sponsored academic research.

December 19: David Kreutzer

David will present a small model of technological change and self ordering.

November 2, 1983

To: System Dyanamics Group

From: Bob Eberlein

Regarding: Fall Seminar Schedule

Please note the change in the schedule. John Sterman will be presenting the November 7 seminar.

Seminars begin at 4:00 P.M. sharp and run until 5:30.

November 7: John Sterman "The Dynamics of The Great Wall"
John will discuss his trip to China and present slides that were taken during that time.

November 14 : Mark Paich "A Case for Modeling (or Cutting Through the Sawdust)"
Mark will discuss a case he has been working on modeling and how the modeling work relates to the more traditional case solution techniques.

November 21 : John Sterman "The Dynamics of the Rubber Market (or
____)

John will discuss the ups and downs of this bouncy commodity, including: the elasticity of demand, changes to stretch out the period of the cycle, the rubber frequency response bandwidth, flexible exchange rates and their effects on inflation of selected commodities and safe strategies for future uses. The talk will include a snappy question and answer session.

November 28 : Bob Eberlein "Dynamic Model Simplification"
Bob will present a seminar covering selected aspects of his dissertation work.

December 5 : David Kreutzer "Yet Another Simple Model"
David will be presenting just that.

December 12 : To be announced.

1 of 4.

{ AC 84790
FOR NATIONAL MODEL RELATED TOPICS }

JDWM JDM ~~[illegible]~~

MAILING LIST FOR TECHNICAL SEMINARS (INTERNAL).

1. – PROFESSOR FORRESTER E40-253
CJR 2. – CHARLIE RYAN ..
NJM 3. – NATHANIEL MASS ..
JML 4. – JIM LYNEIS ..
WAS 5. – BILL SHAFFER ..
DR 6. – DALE RUNGE ..
GWL 7. – GIL LOW ..
AKG 8 – AL GRAHAM ..
PMS 9 – PETER SENGE ..
DFA 10. – DAVE ANDERSEN ..
MGL 11. – MATS LINDQUIST ..
AM 12 – ALI MASHAYEKHI ..
BR 13. – BARRY RICHMOND
KS 14. – KHALID SAEED ..
HD 15. – HOMAYOON DABIRI ..
AFC 16. – ANNE CHAY ..
NF 17. – NATHAN FORRESTER .. *
MB 18. – MARIANO BLANC ..
KT 19. – KELSEY THOMPSON ..
NR 20. – NANCY ROBERTS ..
EBR 21. – PROF. ED. ROBERTS E52-535 *
~~22 – DR. VASSILY OKOROKOV~~
22. MIKE GARRET
23. CECILIA WONG
24. CRAIG STEPHENS
25. FRANK DAVIDSON
26. DIANE LEONARD-SENGE

2 of 4.

MAILING LIST FOR TECHNICAL SEMINARS

1. GEORGE RICHARDSON
R.D.2. BOX 145 A
LAKE BUEL ROAD
GREAT BARRINGTON
MASS. 01230

2. DR. ANTHONY C. PICARDI
DEVELOPMENT ANALYSIS ASSOCIATES INC.
675 MASSACHUSETTS AVE.
CAMBRIDGE MASS. 02139

/ 3. DR. ALAN SHORB
DEVELOPMENT ANALYSIS ASSOCIATES INC
675 MASSACHUSETTS AVE.
CAMBRIDGE MASS. 02139.

4. MR. HENRY WEIL
PUGH - ROBERTS ASSOCIATES
5 LEE STREET
CAMBRIDGE MASS 02139

5\. DAVID. W. PETERSON
PUGH - ROBERTS ASSOCIATES
5 LEE STREET
CAMBRIDGE MASS 02139

6\. MICHAEL R. GOODMAN
PUGH - ROBERTS ASSOCIATES
5 LEE STREET
CAMBRIDGE MASS 02139

7\. ALEXANDER C. PUGH
PUGH - ROBERTS ASSOCIATES
5 LEE STREET
CAMBRIDGE MASS 02139

8\. JOHN STRONGMAN
PUGH - ROBERTS ASSOCIATES
5 LEE STREET
CAMBRIDGE MASS 02139

9\. KENNETH R. BRITTING.
NORTHROP CORPORATION
100 MORSE ST
NORWOOD MASS. 02062

~~10. MS. CECILIA WONG #1~~
~~97 ST. STEPHEN STREET~~
~~BOSTON, MA 02115~~

11\. JOHN LAMB
BAIN + CO.
PILOT HOUSE
LEWIS WHARF
BOS 02110

12\. JEFF LUCOVE
31 EVANS ST
WATERTOWN
MASS 02172

13 DR. ALAN GAYNOR
BOSTON UNIVERSITY
SYSTEM DEVELOPMENT
and ADAPTATION DEPT.
704 COMMONWEALTH AV
BOSTON 02215

14\. RON ANASTASIA
143 CUSHING ST #3
CAMBRIDGE MA 02138
please include in mailing list.

Massachusetts Institute of Technology
Alfred P. Sloan School of Management
50 Memorial Drive
Cambridge, Massachusetts, 02139

November 8, 1977

System Dynamics Group
Building E40-253

MEMO: D-2820

TO: System Dynamics Group

FROM: Judy Amis

SUBJECT: Technical Seminar--November 17, 1977

The next seminar will take place on THURSDAY, NOVEMBER 17, from 4:00 p.m. to 5:30 p.m. in the Schell Room of the Sloan School. Dr. James Bell, Associate Professor of Philosophy at the University of South Florida in Tampa, will discuss "Philosophical Foundations of System Dynamics." Abstracts will be available at the seminar.

Dr. Bell will deliver the lecture at the Dynamics of Physical and Social Systems class prior to the seminar. The class will be held in 9-250 as usual. Dr. Bell will be available to meet and discuss informally any matter of interest to you, either individually or collectively. Please see me if you want to schedule any time with Dr. Bell. Except for the class lecture from 2:00 until 3:00 and the seminar from 4:00 until 5:30 (both on Thursday) he has Thursday morning and most of Friday free.

Massachusetts Institute of Technology
Alfred P. Sloan School of Management
50 Memorial Drive
Cambridge, Massachusetts, 02139

September 28, 1977

System Dynamics Group
Building E40-253

MEMO: D-2786

TO: System Dynamics Group

FROM: Judy Amis

SUBJECT: Technical Seminar--October 4, 1977

The first seminar this Fall will take place on TUESDAY, OCTOBER 4, from 9:30 a.m. to 11:00 a.m. in the Schell Room of the Sloan School. Professor Jean D. Lebel, French engineer and physicist, will discuss "System Dynamics Applications in France". His topic will include industrial application to shift workers in oil refineries.

An honors graduate of "Superlec" (Ecole Supérieure de l'Electricité) and now President of its Alumni Association, Jean Lebel has been a leading advocate and teacher of system dynamics in France. He is a professor at the Ecole Supérieur de l'Aéronautique et de l'Astronautique in Toulouse and also at a graduate school in Paris. Professor Lebel studied at MIT and Harvard, is an officer of the IEEE, and recently shared a television broadcast with the President of France. His wife, Madame Lebel, is Mayor of the village of St. Rémy-l'Honoré, where the couple live, outside Paris.

MIT-SD Tech Seminars
Lebel

Massachusetts Institute of Technology
Alfred P. Sloan School of Management
50 Memorial Drive
Cambridge, Massachusetts, 02139

September 28, 1977

System Dynamics Group
Building E40-253

MEMO: D-2786

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Monday, May 13, 1974

3:00-5:00 p.m.

Schell Room, E52-461

"Modeling the Dynamics of National Social and Economic Change"

will be discussed
by

Professor Jay W. Forrester
Germeshausen Professor

System Dynamics Seminar Series
Coffee served

NOTICE OF EVENT*

from

System Dynamics Group

Department or Sponsoring Organization

to

THE INSTITUTE CALENDAR
Judith Werner, Editor
~~Room 5-105, Ext. 2702~~
Rm. 5-111, Ext. 3-3279

May 6, 1974
Date

3:00-5:00 p.m.
Time

Topic:

Dynamic Models of the Business Cycle

Speaker(s):

Nathaniel J. Mass and Gilbert W. Low

Place:

E52-461

Admission:

Additional Information:

System Dynamics Seminar Series

Coffee served

Open to the public ____
Open only to the M.I.T. community x

Submitted by:

Emaline Cornett for R. Greene

E40-253 **Room and Extension:** x3-1574

April 12, 1974

*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

NOTICE OF EVENT*

from

System Dynamics Group
Department or Sponsoring Organization

to

THE INSTITUTE CALENDAR
Judith Werner, Editor
~~Room 5-105, Ext. 2702~~
Rm. 5-111, Ext. 3-3279

May 13, 1974	3:00-5:00 p.m.
Date	**Time**

Topic:

"Modeling the Dynamics of National Social and Economic Change"

Speaker(s):

Professor Jay W. Forrester

Place:

E52-461

Admission:

Additional Information:

System Dynamics Seminar Series

Coffee served

Open to the public_____
Open only to the M.I.T. community x

Submitted by:

Emaline Arnett

E40-253 **Room and Extension:** 3-1571

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*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

News Office
Sys. Dy. Semi

NOTICE OF EVENT*

from

System Dynamics Group
Department or Sponsoring Organization

to
THE INSTITUTE CALENDAR
Judith Werner, Editor
~~Room 5-105, Ext. 2702~~
Rm. 5-111, Ext. 3-3279

April 29, 1974	3:00-5:00 p.m.
Date	Time

Topic:

"A National Metropolitan Model Based on Urban Dynamics"

Speaker(s):

John H. Murphy
Postdoctoral Fellow

Place:

E52-461

Admission:

Additional Information:

System Dynamics Seminar Series
Coffee served

Open to the public____
Open only to the M.I.T. community x

Submitted by:
Emaline Cornett

E40-253 3-1571
Room and Extension:

*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

NOTICE OF EVENT*

from

System Dynamics Group

Department or Sponsoring Organization

to

THE INSTITUTE CALENDAR
Judith Werner, Editor
~~Room 5-105, Ext. 2702~~
Rm. 5-111, Ext. 3-3279

May 6, 1974	3:00-5:00 p.m.
Date	**Time**

Topic:

Dynamic Models of the Business Cycle

Speaker(s):

Nathaniel J. Mass and Gilbert W. Low

Place:

E52-461

Admission:

Additional Information:

System Dynamics Seminar Series

Coffee served

Open to the public ____
Open only to the M.I.T. community x

Submitted by:

Emaline Cornett for R. Greene

E40-253 **Room and Extension:** x3-1574

April 12, 1974

*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

Monday, April 8, 1974

3:00-5:00 p.m.

Schell Room, E52-461

"Applications of Urban Dynamics"
will be discussed
by
Louis E. Alfeld
Urban Dynamics Project Director
and
Walter W. Schroeder, III
Lowell Project Director

System Dynamics Seminar Series
Coffee served

Future Seminar Dates
- April 22 - Roger Naill, Dartmouth College
- May 6 - Gilbert Low and Nathaniel Mass
- May 13 - Professor Jay W. Forrester

MENS ET MANUS
1861

Massachusetts Institute of Technology
Alfred P. Sloan School of Management
50 Memorial Drive
Cambridge, Massachusetts, 02139

November 2, 1973

System Dynamics Group
Building E40-253

MEMORANDUM

TO: Professor Jay W. Forrester

FROM: Mr. Robert P. Greene Bob

RE: System Dynamics -- Seminar Series

The Group members have suggested a number of potential speakers and topics for the system dynamics open seminar series for next spring. They include:

1. Senge:

   "Statistical Estimation of Dynamic System Models of the 'System Dynamics' class.

2. Alfeld/Schroeder:

   "The First Public Application of Urban Dynamics -- the MIT-Lowell Project."

3. Meadows:

   "The Dartmouth Energy Project"

4. Forrester/Senge/Wright:

   "Model Validation"

5. Low:

   "Business Cycle Model"

6. Runge:

   "Ethics of Food Relief"

7. Peterson et. al.:

   "Dynamic Modeling of Energy Systems"

We should
think for next
fall of more
from outside
MIT, perhaps
not time to do so
for this spring
but it would
be good.

8. Roberts:

   "Health Dynamics"

9. Roberts:

   "Manpower Model for A.I.D."

10. Graham:

   "Puberty"

11. Foster:

   "Education"

12: Henry Weil -- Pugh - Roberts:

   "Environmental Impact Statements"

13. Forrester:

   "Economic Dynamics"

Some of the speakers and topics are probably not appropriate but we have more than enough for a credible program.

I would suggest that we deliberately attempt to balance presentations between our "in-house" group and outside speakers. Perhaps a schedule like the attached might be appropriate.

If you agree I will contact everyone for specific details.

RPG: bw

P. 3

34934

PROPOSED SYSTEM DYNAMICS SEMINAR SERIES

MONDAY AFTERNOONS 3:00 p.m. to 5:00 p.m.

SCHELL ROOM

DATE	SPEAKER	TOPIC
February 11 ✓	Forrester ✓	Validation ✓
ok — February 25	Senge	Statistical Estimation ^ Evaluating the Validity of ~~Evaluating~~ Econometric methods!
March 11	Peterson	~~Energy~~
Vacation March ~~25~~ 18	1/30 ~~Roberts~~ 34934	Health Dynamics
✓ April 1	Runge	The Ethics of Humanitarian Food Relief
April 8	~~Meadows~~ Naill	~~Resources or Energy~~ A Dynamic Study of the Use of Coal as a Transition Energy Source
April 22	Alfeld/Schroeder	Urban
✓ May 6	Mass/Low	Modeling Business Cycles
May 13	Forrester	National Economic Model

Dynamic Models of Cyclic Economic Activity

O.K.

JF

Nov 3

Estimation & Hypothesis Testing applied to S.D. Models

Dynamic Models of Cyclical Economic Activity

1/3/74

RG

JWT will present "Mon. aft. sem." on May 6 rather than May 13 as scheduled.

e

NOTICE OF EVENT*

from

System Dynamics Group

Department or Sponsoring Organization

to

THE INSTITUTE CALENDAR
Judith Werner, Editor
Room 5-105, Ext. 2702

Date: Monday, February 11, 1974

Time: 3:00-5:00 p.m.

Topic:

"Confidence in Models of Social Behavior--with Emphasis on System Dynamics Models"

Speaker(s):

Professor Jay W. Forrester

Place:

E52-461

Admission:

Additional Information:

System Dynamics Seminar Series

Open to the public_____
Open only to the M.I.T. community x

Submitted by:

Robert P. Greene

Room and Extension:

E40-253 3-1574

*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

2/20

Rg

Re: Mon SD Seminars

No speaker scheduled for 3/18 (Roberts declined).

Advise, pls.

1) Move other speakers fwd — to give JMF an opening later, if he wants please!
2) Lv. date open — have no seminar at all.
3) Get another speaker: Whom?

3/11/74

Gil

Can you and
Nat give me a
title for your
seminar scheduled for
May 13?

Dynamic Models of
Cyclic Economic Activity

2/28/74

Reg

Re: Mon aft seminars

I am leaving 4/1 open because of vacation.

Remaining schedule is as follows:

4/8 – Alfeld & Schroeder
4/22 Nail*
5/6 JWF
5/13 Moss & Low

*What is Nail's position at Dartmouth? I want to put this in announcement. R

Susan Walker
5-111

3-3279

News Office
Tech Talk
Inst. Calendar

March 20, 1974

Mr. Roger Naill
Research Associate
Thayer School of Engineering
Dartmouth College
Hanover, New Hampshire 03755

Dear Roger:

Several days ago I spoke with Mr. Greene about your plans for coming to MIT to present the seminar next month. He says it is quite agreeable with him for you to fly, as you requested. Whatever your decision, submit your expenses on the enclosed report to him. You will recall from your years at MIT that our Accounting Office requires all ticket stubs with these reports.

Everyone is looking forward to seeing you the twenty-second. In the interim, please let us know if there is anything more we can do.

Greetings to the Meadows. I hope their house has been restored following the tree damage.

Sincerely,

Emaline Cornett
Secretary to Professor Jay W. Forrester

eac
cc: ✓Mr. Robert P. Greene
Encls: MIT Travel Expense Voucher
Copy of seminar notice submitted to <u>Tech Talk</u>

NOTICE OF EVENT*

from

System Dynamics Group

Department or Sponsoring Organization

to

THE INSTITUTE CALENDAR
Judith Werner, Editor
~~Room 5-105, Ext. 2702~~
Rm. 5-111, Ext. 3-3279

April 22, 1974
Date

3:00-5:00 p.m.
Time

Topic:

A Dynamic Study of the Use of Coal as a Transition Energy Source

Speaker(s):

Roger Naill (Research Associate, Thayer School of Engineering, Dartmouth College)

Place:

E52-461

Admission:

Additional Information:

System Dynamics Seminar Series

~~Coffee served~~

Open to the public ____
Open only to the M.I.T. community X

Submitted by:

E40-253 Room and Extension: x3-1574

*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

Note: This supersedes the earlier notice for this seminar bearing the seminar title "Urban Dynamics"

NOTICE OF EVENT*

from

System Dynamics Group
Department or Sponsoring Organization

to

THE INSTITUTE CALENDAR
Judith Werner, Editor
~~Room 5-105, Ext. 2702~~
Rm. 5-111, Ext. 3-3279

April 8, 1974
Date

3:00-5:00 p.m.
Time

Topic:

Applications of Urban Dynamics

Speaker(s):

Louis E. Alfeld and Walter W. Schroeder, III

Place:

E52-461

Admission:

Additional Information:

System Dynamics Seminar Series

~~Coffee served~~

Open to the public ____
Open only to the M.I.T. community x

Submitted by:

Emaline Cornett For R. P. Greene
E40-253 Room and Extension: x3-1574

*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

NOTICE OF EVENT*

from

System Dynamics Group

Department or Sponsoring Organization

to

THE INSTITUTE CALENDAR
Judith Werner, Editor
~~Room 5-105, Ext. 2702~~
Rm. 5-111, Ext. 3-3279

April 8, 1974 — 3:00-5:00 p.m.

Date — **Time**

Topic:

Urban Dynamics

Speaker(s):

Louis E. Alfeld and Walter W. Schroeder, III

Place:

E52-461

Admission:

Additional Information:

System Dynamics Seminar Series

Coffee served

Open to the public ____

Open only to the M.I.T. community x

Submitted by:

E40-253 x3-1574

Room and Extension:

*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

NOTICE OF EVENT*

from

System Dynamics Group

Department or Sponsoring Organization

to

THE INSTITUTE CALENDAR
Judith Werner, Editor
~~Room 5-105, Ext. 2702~~
Rm. 5-111, Ext. 3-3279

March 18, 1974
Date

3:00-5:00 p.m.
Time

Topic:

"The Ethics of Humanitarian Food Relief"

Speaker(s):

Dale E. Runge

Place:

E52-461

Admission:

Additional Information:

System Dynamics Seminar Series

Coffee served

Open to the public____
Open only to the M.I.T. community xx

Submitted by:

Room and Extension:

E40-253, x 3-1574

*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

Delivered
2/12/74

2/25
coffee ordered
from Mrs. Ht.
+1 pot +ca

NOTICE OF EVENT*

System Dynamics Seminar Series — Monday, Feb. 25, 1974
Description — Day — Date

to

The Institute Calendar
Judith Werner, Editor
Room ~~5-105~~/ 5-111, Ext. 3-3279

from

System Dynamics Group
Department or Sponsoring Organization

Topic:

"Evaluating the Validity of Econometric Methods for Dynamic Systems"

Speaker (and Position):

Peter Senge, DSR Staff

Place:

E52-461

Time:

3:00-5:00 p.m.

Open to the public ______
Open only to the M.I.T. community x

Admission:

--

Additional Information:

Coffee

Submitted by:

Robert P. Greene — R P Greene

Room and telephone numbers:

E40-253 — 3-1574

*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

jw/42767

coffee
25125

cancelled
due to illness

NOTICE OF EVENT*

from

System Dynamics Group
Department or Sponsoring Organization

to
THE INSTITUTE CALENDAR
Judith Werner, Editor
Room 5-105, Ext. 2702

Monday, February 11, 1974
Date

3:00-5:00 p.m.
Time

Topic:

"Confidence in Models of Social Behavior--with Emphasis on System Dynamics Models"

Speaker(s):

Professor Jay W. Forrester

Place:

E52-461

Admission:

Additional Information:

System Dynamics Seminar Series

Open to the public ___
Open only to the M.I.T. community x

Submitted by:
Robert P. Greene

Room and Extension:
E40-253 3-1574

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*The deadline for submitting notices of events to the Editor is 12:00 noon on Mondays preceding the next week's issue.

D-1967

CONFIDENCE IN MODELS OF SOCIAL BEHAVIOR-- WITH EMPHASIS ON SYSTEM DYNAMICS MODELS

by

Jay W. Forrester
Germeshausen Professor
Massachusetts Institute of Technology

December 10, 1973

CONTENTS

I. BACKGROUND OF THE VALIDITY DEBATE 4

- A. MENTAL MODELS 5
  1. Everyone Uses Models
  2. Mental Models in Social Decisions
  3. Strengths of Mental Models
  4. Weaknesses of Mental Models
- B. DESCRIPTIVE MODELS 9
- C. SOLVABLE MATHEMATICAL MODELS 11
- D. STATISTICAL MODELS 12
- E. SYSTEM DYNAMICS MODELS 17
  1. The Nature of System Dynamics Models
  2. System Dynamics Models on the Social Scene

II. NATURE OF VALIDITY IN MODELS 24

- A. VIEWPOINTS 24
  1. The Operators
  2. The Observers
- B. VALIDITY AS SEEN BY AN OPERATOR 26
  1. Validity--Defined by an Operator
  2. A Model is a Theory
  3. Proof of Validity Impossible
  4. A Model is a Tool
  5. The Operator Seeks Shared Confidence
- C. VALIDITY AS SEEN BY AN OBSERVER 28
  1. Validity--Defined by an Observer
  2. A Model is a Computational Result
  3. Validity is a Definition
  4. A Model is a Collector's Item
  5. The Model-Building Observer Seeks Debate

III. VALIDITY AND PURPOSE 32

- A. PURPOSE AS SEEN BY AN OPERATOR 32
- B. PURPOSE AS SEEN BY A MODEL-BUILDING OBSERVER 33

IV. CIRCUMSTANCES FOR ESTABLISHING CONFIDENCE 35
  A. STATISTICAL MODELS 35
  B. SYSTEM DYNAMICS MODELS 39

V. EVALUATING SYSTEM DYNAMICS MODELS 47
  A. STRUCTURAL-VERIFICATION TEST 48
  B. ALTERNATE-STRUCTURE TEST 49
  C. PARAMETER-VERIFICATION TEST 50
  D. EXTREME-CONDITION TEST 51
  E. MISTAKEN-IDENTITY TEST 53
  F. SYMPTOM-GENERATION TEST 55
  G. POINT-PREDICTION TEST 55
  H. CHANGED-BEHAVIOR-PREDICTION TEST 58
  I. PARAMETER-SENSITIVITY TEST 59
  J. EXTREME-POLICY TEST 61
  K. SURPRISE-BEHAVIOR TEST 61
  L. FAMILY-MEMBER TEST 63
  M. SYSTEM-IMPROVEMENT TEST 64

VI. SUMMARY 66
References 69

D-1967

CONFIDENCE IN MODELS OF SOCIAL BEHAVIOR-- WITH EMPHASIS ON SYSTEM DYNAMICS MODELS

by

Jay W. Forrester
Germeshausen Professor
Massachusetts Institute of Technology
December 10, 1973

Formal computer models representing social systems have become sufficiently advanced to influence thought and policy. As models begin to affect practical affairs, their validity becomes an important issue.

When models were limited to research purposes, only the in-group of any one professional discipline cared about validity, and then, more as a measure of research skill than as a matter of public significance. But, when models become interdisciplinary, enter public debate, are taken seriously in molding thought, and influence social policy, the question of validity properly becomes a public issue.

A model is a representation of some aspect of reality. It can be a geometric model such as a floor plan for a building. It can be a static relationship such as the curve that shows the amount of water flow through a valve for each setting of the valve-control handle, or a model might represent an equilibrium solution to a set of equations that describe the ultimate condition toward which some dynamic system is evolving. Or a model might be a fully dynamic representation that contains the underlying mechanisms that produce changing conditions through time.

Models differ, not only in the aspect of reality that they represent, but also they differ according to the vehicle used to present the model. Models can lie in mental images. Models can take the form of physical replicas of the real system, such as an airplane model in a wind tunnel or an architectural model of a city plan. Mental models can be moved from the human mind to the written page where they become more explicit descriptive models, somewhat less subject to differing interpretations, and more widely accessible. Models can take the form of mathematical equations in several styles. The equations may be simple enough so that a closed solution can be obtained, and from the solution all possible conditions of the system can be derived. The mathematical equations may represent only a fragment of a system or may be intended to represent the essential entirety of a functioning social system. The equations may be no more than statistical probabilities of occurrence, or they may contain dynamic internal generating mechanisms for tracing system behavior through time.

Mental models have always come first in every field of human endeavor. When the deficiencies of the mental models were sufficiently evident, and when competing formal models became possible, formal models have augmented mental models.

Formal models have gone beyond mental models to the extent that the formal models have been able to do a better job than the mental models. In general, formal models have first found their place in those professional fields where important dynamic behavior is caused by simple structures and where the systems of interest are essentially linear. Conditions for easy use of formal models are found in science and engineering. Within the fields of technology, formal models are again more prevalent where the important systems are simple and linear. For example, in physics formal models entered sooner and to a greater extent than in chemistry and biology. Formal models have had much more extensive use in electrical engineering, because of its simplicity and linearity, than in chemical engineering and aerodynamics.

Social systems are more complex, far more nonlinear, and more influenced by internal random noise than are most physical systems. Formal models, having first been used in the simpler physical sciences, have been improved enough to make their way through engineering and agricultural genetics to the social sciences.

In spite of the vast time and effort expended on formal models in the social sciences, formal modeling of social phenomena has had negligible impact on practical policy design. Formal modeling will not have arrived until it has substantially augmented and displaced mental models for social decision-making. Thus far, the impact of formal models on society has been minor. Mental models still dominate. But some formal models have become strong enough to interact with mental models. When a formal model begins to exert influence, its validity will be questioned just as the validity of the preceding mental models was questioned.

Validity, as applied to models of society, is a misunderstood concept. "Validity" has a very different meaning as seen by different groups. To the manager, politician, engineer, or medical doctor, a model is valid if it is appropriate, and is more useful than alternative models that are available; validity implies relative usefulness of comparative models. But in much of the social science literature, validity is a formal logical concept rather than a pragmatic issue. Particularly in statistical models, validity is a logical numerical deduction that follows from <u>assumed</u> premises that determine the data, structure, and computational procedure to be used; validity implies an internal consistency, given the assumptions, but does not establish the appropriateness of either the assumptions or the use to which the results will be put. Much of the current debate about validity arises because the concept itself travels under incompatible definitions.

I. BACKGROUND OF THE VALIDITY DEBATE

Until recently, political decisions have depended on only the mental models used in the exercise of judgment and intuition. But recently two simultaneous changes have begun to alter the methods for arriving at public policy. First, life has become so complex that the old mental models using intuition and judgment have begun to fail even more often than previously. Second, formal models of various kinds have been introduced with claims that they improve on the earlier mental models.

Some of the formal models have been too persuasive to be lightly dismissed, but the new formal models have often differed substantially in their implications from the mental models with which they compete. The contrasts and disparities have raised questions of model validity.

Five classes of models are distinguished in the following discussion--mental models, descriptive models, solvable mathematical models, statistical models, and system dynamics models. Mental models are the mental images, remembered events, and organized experiences that a person uses in arriving at decisions. Descriptive models are explicit descriptions in written language that capture and organize information from the mental models. Solvable mathematical models are relatively simple sets of solvable equations. Statistical models are assumed relationships with parameters derived by statistical analysis from numerical data. System dynamics models are state-variable nonlinear structures drawn from mental and descriptive models.

In the past, the validity of mental and descriptive models has been the subject of continuous debate. However, the validity of formal mathematical and statistical models has been relegated to the back rooms of professional analysis. But now, as system dynamics models enter the political process, debate on their validity enters the public arena.

A. MENTAL MODELS

1. Everyone Uses Models

All decisions and actions are based on models. No one has a family, school system, city, or country in his head. Instead, he has a series of mental images that represent the surrounding social systems. These mental images are representations of the real system. They are simplifications and abstractions.

Mental models are rich in static detail; that is, they contain geographical and physical relationships. Mental models are also rich in anecdotical information representing events and special occurrences. Mental models also store numerous fragments of cause-and-effect sequences that relate pressures to actions. Mental models also include generalizations representing classes of structures and situations.

Mental models are the basis for almost all personal and political action. On the basis of mental models, men and societies arrive at decisions. The decisions are a consequence of manipulating the mental models. The manipulation consists of selecting from the wealth of available information those particular relationships that seem relevant. The chosen information is then fitted together in an effort to deduce its future implications. In other words, one selects information, fits it together into a mental model for the immediate purpose, and then attempts to foresee what the model implies for the future.

Mental models have great strength. They have been the principal means for deciding on social action. But such models have increasingly serious weaknesses. The complexities of evolving social systems, their nonlinearities, and the changing structure of such systems makes mental models unreliable.

Mental models for personal and social decision-making are gradually accumulated by a social culture. They exist in the forms by which one generation communicates with the next. Folklore and the example set by action convey expectations that become part of the mental-model structure. Religion forms part of the cultural heritage. A liberal arts education conveys a framework of mental models through the study of history, historical novels, art, and descriptive theories of social behavior. Laws, constitutions, and court precedents add to the mental images that control behavior.

Personal experience is recorded as memories for future guidance. Until personal experiences can be classified into general categories, they remain as isolated fragments of information. But as they are classified, experiences coalesce into generalized mental models. The frameworks transmitted from the culture provide interpretive structures through which personal experience is filtered and fitted more quickly into comprehensive models that can be applied to future decisions.

2. Mental Models in Social Decisions

Mental models dominate all personal, management, and political decisions. The mental models are drawn from the culture and from personal experience. The models contain structure representing the relationships between man and his surroundings. The models contain parameters representing the degree of various influences. The models are used to generate expectations for the future. If those expectations are unfavorable, the mental models are used to choose alternative decisions.

A society can function only if the mental models of enough people coincide over a wide enough region to yield a social consensus. When a law is passed in Congress, enough of the mental models have coincided to yield a majority vote. But the model that justified the vote was never explicitly described. Each congressman operated from a different detailed model.

But even when a consensus prevails, mental models are different from one another, each is a partial model of reality, and none is fully accessible even to the individual possessing it. Political argument arises over both real and imagined differences between mental models. Many of the debated points arise, not because the models are different, but because one man misunderstands another's mental model.

Political debate is debate over the validity of models. It includes debate about model structure (how are things related in real life?), model parameters (how strong are the influences?), and model dynamics (what do the assumptions imply?).

3. Strengths of Mental Models

Mental models have great strengths on which should be built any other models that are presented as improvements. The capacity to create mental models was shaped by the process of biological evolution. Until man learned to manipulate symbols, no other models were available.

Mental models are a way station on the road to other models. Practically all the information society possesses has been processed through mental models. Descriptive models are created from mental models. Theory for formal models comes from mental models and descriptive models. Much of the quantitative data has been interpreted through mental models. Mental models serve as filters to summarize the wealth of information impinging on the human senses.

Mental models constitute our richest storehouse of information. The content of mental models far outstrips the amount of information in libraries. Mental models are imbedded in a processing system that yields new associations of concepts to produce new structures and theories.

4. Weaknesses of Mental Models

Although mental models have been the best models available, they show severe weaknesses for dealing with today's major social issues. The weaknesses arise from the lack of clarity in mental models, from the ambiguity in transmitting mental models from one person to another, from the fluid and changing nature of mental models, from the difficulty in comparing mental models with the real world, from the incompleteness of such models, and from the unreliability in projecting the assumptions of mental models into their future consequences.

Mental models are not clearly stated. They consist of vague impressions. A person has a wealth of information from which to choose but can use only a few items at one time; therefore, the mental models change form, alter their structures, and depend on a differing stream of assumptions as the mental images shift and coalesce into new patterns. Mental models are unclear, partly because they are fluid and turbulent and partly because the underlying assumptions are never specifically articulated.

Because of the fluidity and lack of clarity, mental models are difficult to convey from one person to another. Spoken and written language is ambiguous at best and rapidly loses its precision with careless usage.

Mental models are difficult to verify and evaluate. Their lack of clarity defies attempts at rigorous comparison between one person's mental model and any comparative information, be that information of an objective character or merely another person's mental model.

In general, mental models are incomplete. Essential structures are missing. Linkages between the assumed parts are fragmentary because the model is never fully and explicitly described. The incompleteness usually goes undetected.

The greatest weakness in mental models arises from the inability of the human mind to project a set of assumptions forward into their dynamic future consequences. A social system can be technically described as a high-order, nonlinear set of feedback loops. Even very simple members of the same family of systems, which are encountered in engineering systems, are far beyond the capability of the human mind to solve by inspection. Given the same set of underlying assumptions, different people come to different conclusions about future implications. Much political controversy arises neither from incompatible assumptions nor from differing goals but, instead, from the inability to reliably determine the consequences of a set of agreed facts.

The weaknesses of mental models serve as incentive to find better models.

B. DESCRIPTIVE MODELS

Written descriptions can be clearer and more explicit models than are mental models. Writing forces clarification of thought and permits an orderly linking together of the fragments of mental models.

The best of the descriptive models stand as classics in their fields. Each social and psychological science has its examples. In economics the classical descriptive models stand in the writing of such people as Adam Smith, Thomas Malthus, Karl Marx, Joseph Schumpeter, and John Maynard Keynes. No comparable descriptive models of economic behavior seem to have appeared in the last several decades. Baumol offers an explanation in his book under the heading, "The Magnificent Dynamics,"

> "We consider these older dynamic systems simply because, although imperfect, they represent an approach to which there are few recent examples. That this is the case may perhaps be attributed to the timidity of later theorists, for the approach is of a magnificent cast, ambitiously attempting to analyze the growth and development of entire economies over relatively long periods of time--decades or even centuries.....after the marginal revolution of the seventies, however, positivism came into vogue, and as a result thought became less daring and imaginative in character.....with the noteworthy exception of Schumpeter's work very few significant contributions to dynamics were made."*

The strength of the great descriptive models arises from their close tie to the wealth of information available from mental models. The description is not constrained to exclude any aspect of observed reality. The descriptive model can cover a wide range of aggregation, develop concepts on the basis of individual action, and assert consequences of collective action. The descriptive models were not confined to any one intellectual discipline and spanned what is now narrowly defined as economics as well as demography, politics, psychology, and sociology. The descriptive models are rich in concepts.

But the descriptive models have conspicuous weaknesses to limit their applicability. No rigorous framework exists to ensure that all loose ends are tidied up. No procedure exists to identify gaps in the theory. Above all, no method is available within the descriptive-model process to determine with certainty the dynamic consequences of the assumptions asserted in the descriptive theory.

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*Reference G, page 13.

C. SOLVABLE MATHEMATICAL MODELS

Much theorizing in the social sciences is conducted in the framework of solvable mathematical equations. When compared with the complexities of real life, mathematics is a pitifully weak tool. Only simple sets of equations can be solved. The essence of life is nonlinearity, but mathematical solutions can be obtained, with unimportant exceptions, only for linear approximations. Because solvable equations do not have the power to deal with reality, their use is likely to take the form of an exercise in formal logic. The separation between mathematical economics and reality is made by Kaldor:

> "I should go further and say that the powerful attraction of the habits of thought engendered by 'equilibrium economics' has become a major obstacle to the development of economics as a <u>science</u>.....Taken at its purest and most abstract level, the pretensions of this equilibrium theory are modest enough. Although Debreu describes the subject-matter of his book as 'the <u>explanation</u> of the price of commodities resulting from the interaction of the agents of a private ownership economy,' it is clear that the term 'explanation' is not used in the ordinary everyday sense of the term. It is intended in a purely logical and not in a 'scientific' sense; in the strict sense, as Debreu says, the theory is 'logically entirely disconnected from its interpretation.' It is not put forward as an explanation of how the actual prices of commodities are determined in particular economies or the world economy as a whole. By the term 'explanation' Debreu means a set of theorems that are <u>logically</u> deducible from precisely formulated assumptions.....The whole progress of mathematical economics in the last thirty to fifty years lay in clarifying the minimum requirements in terms of 'basic assumptions' more precisely: without any attempt at verifying the realism of those assumptions, and without any investigation of whether the resulting theory of 'equilibrium prices' has any explanatory power or relevance in relation to actual prices."*

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*Nicholas Kaldor in his Goodricke Lecture, May 1972, page 1237, Reference K.

D. STATISTICAL MODELS

In the social sciences the word "model" is used in many different ways. In the extreme, any relationship is referred to as a model. An equation statistically relating housing, jobs, and size of city to population movement would be referred to as a model even though the relationship does not have dynamic structure and does not deal with how job and housing availability are altered by the migration itself.

The social science literature is loaded with studies of statistical relationships between one variable and one or more others. Various forms of statistical methods are used to derive the relationships. Tremendous time and effort go into such studies. Generally the results are filed and forgotten. The process is clearly described by Leontief for economic models:

> "In no other field of empirical inquiry has so massive and sophisticated a statistical machinery been used with such indifferent results. Nevertheless, theorists continue to turn out model after model and mathematical statisticians to devise complicated procedures one after another. Most of these are relegated to the stockpile without any practical application or after only a perfunctory demonstration exercise."*

Little can be done with the individual statistical relationships. At best, they are fragments of some larger dynamic system. At worst, they are meaningless because the systems from which the data were drawn will usually violate the assumptions about structure, auto- and cross-correlation, random disturbances, and linearity necessary for the analysis methods to be valid.

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*Wassily Leontief, presidential address, The American Economic Association, December 1970, page 3 of Reference L.

The justification for such data-gathering and analysis seems to lie either in the presumption that theories of structure can in time be assembled out of the separate studies, or that powerful theories of structure and behavior do not exist and that social behavior consists of tremendous numbers of individually minor activities. This latter view has been expressed as:

> "If we are right in characterizing not only present but future social theories as predominantly multivariate simulations, lacking strongly dominant variables, then several important things follow. Predictions from such theories are highly dependent upon numerous empirical measurements. From the point of view of a person who controls any one variable, only a little can be predicted without entering large numbers of parametric measures on the other variables into his calculations. It is in the nature of things that the social sciences are data rich and theory poor. It is not just that we are at a primitive stage in them."*

But in the same meeting I expressed quite the opposite view as coming out of our work on the dynamics of social systems:

> "The hope for designing better systems lies in the existence of key influence points in complex systems where a small number of actions will radiate a desirable effect throughout the system. Here the reader should note the exactly opposite opinions presented in the paper by Pool and in my paper on complex systems.....In my paper I say, 'But a fourth characteristic of complex systems is a high sensitivity to a few parameters and a sensitivity to some changes in structure.....There are a few points in any system to which behavior is sensitive. If these points are changed, they cause pressures to radiate throughout the system. Behavior everywhere seems to be different. But it is not because people have been persuaded or forced to act differently. It is because, responding in the old way to new information, they naturally take different actions. The parameters and structural changes to which a system is sensitive are usually not self-evident, they must be discovered through careful examination of system dynamics.' In other words, I contend that the social sciences are 'theory poor' only in the sense that the existing theories are wrong or inadequate. They are not

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*Pool, Ithiel de Sola, in Reference F, page 317.

> theory poor in the sense that strong and powerful theories of behavior cannot and will not exist. The assumption of a large number of weak variables leads to massive data gathering with this data used in statistical models. But such models ignore the feedback structure of the system and cannot possibly lead to an adequate understanding of dynamic behavior. Starting from the other direction we can organize the kinds of structures and relationships which observation of the system components reveals. This leads to an entirely different conclusion about the importance of theory and data. My studies indicate that theory, that is, the proper system structure, is of the utmost importance. When structure and theory are handled properly, the design of an improved system becomes surprisingly insensitive to the numerical values of parameters."*

Data is often organized into so-called "models" by various styles of regression analysis. The procedure yields a statistical relationship between observed values of variables for which numerical values have been obtained. But the results do not impinge strongly on the political world and its mental models. The measured data are available for only a tiny fraction of the relationships that run through the mental models. The measured data are often controversial. Different studies yield different results so that the statistical correlations are scarcely more convincing than the plausible values adopted in the mental models. As a result of the shortcomings in the statistical correlations, the formal analysis does little for the main deficiencies in the mental models--it does not determine which relationships are important, and it does not give the future time behavior implied by the data.

The importance of trying better to understand economic behavior has led to extensive research in developing econometric models. A large literature on methodology exists. Numerous such models have been created.

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*Forrester, Jay W., in Reference F, pages 507-8.

An econometric model starts with some assumed causal relationships between a set of variables for which time-series data is available. The structure of the equations contains symbolic parameters coupling the variables that are presumed to have interdependence. The statistical methods use the time-series histories of the variables as the basis for deriving numerical values of the coupling parameters.

Econometric models have intruded only slightly on the political and managerial domain of mental models. Econometric models are not derived in any direct and verifiable manner from the sources on which the mental models are based. The parameter values in the models are a consequence of mathematical manipulation and are not individually relatable to real-life human motivations. Most such models are driven by exogenous variables in such a manner that the models do not generate long-term economic behavior out of their own internal structure. In short, they do not belong to the "magnificent dynamics" sought by the early theorists.

Some in the economics profession express strong doubts about the ability of econometric analysis to clarify validity issues in economic models:

> "My starting point is the smallness of the contribution that the most conspicuous developments of economics in the last quarter of a century have made to the solution of the most pressing problems of the times. The most conspicuous developments I take to have been.....econometric analyses of systems of economic forces.....But the running of regressions between time series is generally a very different matter. Where, as so often, the fluctuations of different series respond in common to the pulse of the economy, it is fatally easy to get a good fit, and get it for quite a number of different equations. Nor in any case do I see how any statistical procedure can enable us to distinguish causal from merely contingent relations, so as to 'explain' or 'account for' the variable taken as dependent.....I conclude that though fortunately some possibilities do exist of testing assumptions about behaviour against statistical aggregates, running regressions between time series is only likely to deceive."*

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*E. H. Phelps Brown, presidential address to the Royal Economic Society, July 1971, pages 1 and 6 of Reference M.

Econometric models are generally light on theory and heavy on data manipulation. Far more emphasis is given to the numerical value of coefficients than to the structure within which the coefficients are placed. One can argue that the reverse would be more proper. Practitioners of econometric modeling methods seem reluctant to depend on mental models and reject all information that does not exist in an "objective" form. But the choice of data to be used, the equation structure into which the data is to be fitted, and the statistical methods to be employed are all subjective decisions. When the process is completed a subjective decision governs whether or not the results are to be trusted for an operating decision. And quite often, even the author of a paper suggests that the results should not be trusted:

> "Alongside the mounting pile of elaborate theoretical models we see a fast-growing stock of equally intricate statistical tools. These are intended to stretch to the limit the meager supply of facts.....in all too many instances sophisticated statistical analysis is performed on a set of data whose exact meaning and validity are unknown to the author or rather so well known to him that at the very end he warns the reader not to take the material conclusions of the entire 'exercise' seriously."*

The econometric methodology strongly discourages the formulation of general nonlinear relationships even though many of the most important behavior modes in real social systems arise because of nonlinear relationships. Econometric models are limited to relationships that have held under system conditions prevailing at the time of data collection; but some of our greatest social problems arise because our social systems are operating under conditions that have not previously been encountered (often referred to as structural changes). Most importantly, econometric models cannot deal with variables for which data has not been collected. They assume that the world

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*Leontief, pages 2 and 3, Reference L.

is described only by those variables that have been quantitatively measured. This assumption alone would exclude them from entering the realm of the mental models that dominate political and economic behavior. The mental models deal heavily, and I believe appropriately so, with intangible issues such as confidence, integrity, fear, and expectations. Unless such variables are incorporated in formal models, formal models will not be able to address the realm of the mental model.

E. SYSTEM DYNAMICS MODELS

System dynamics models have crept onto the social scene since 1961. Their impact has been entirely out of proportion to the small number of published books and articles and the few people engaged in the field.

1. The Nature of System Dynamics Models

A system dynamics model is a computer simulation model that, in the pure case, contains only endogenous variables. Mathematically, a system dynamics model is a set of first-order, nonlinear integrations. A system dynamics model is not driven from time-varying outside influences, it is a laboratory replica of the system it represents. It should create within itself those behavior modes of the actual system that the model was constructed to investigate. The model should generate the symptoms of difficulties that are observed in the real world.

A system dynamics model is derived from mental models and formal descriptive models. In other words, a system dynamics model comes from direct observation of the actual world. Both the structure and the parameter values of a system dynamics model come from observation and descriptive knowledge. Time-series data is not used in the creation of the model or its parameter values. Any existing time-series numerical data that is available is used as a basis for judging the behavior of the model as manifested by corresponding time-series output generated by the model.

The theory underlying decision-making in the real world is a much more important input to a system dynamics model than it is to an econometric model. The structure of a system dynamics model must be defended in its own right, based on social and psychological observation. Structure cannot be treated lightly on the assumption that subsequent derivation of parameter values will authenticate the structural assumptions.

Any theory-building process that will yield structure can be extended to yield parameter values. There can be no clean separation between structure and parameters. Structure can be changed to convert one set of parameters into another, or parameters can be used for activating and suppressing structure. Structure and parameters both come out of theory and theory comes from observation of the system. The relevant observations reside in mental models and the descriptive models. Brown pleads for more transfer from direct observation into theory:

> "For our knowledge of the behaviour of economic agents we must rely mainly on the patient accumulation of direct observations.....my argument implies the removal of the traditional boundary between the subject-matters of economics and other social sciences.....For the economist whose search for causes brings him up against convention, mood, passion or culture to say 'At this point I stop: you must send for another trade' is quite usual but quite stultifying. When the actual way in which decisions are reached in the board room or across the bargaining table has been discussed, it has been said that economics as such has nothing to contribute.....Where an economic problem arises, let us observe whatever seems significant, and follow clues to causes wherever they may lead..... economists can gain insight into historical experiences by studying them.....Clinical intuition has been defined as reasoning from experience not consciously recalled; and history is vicarious experience.....It has long been agreed that the economist is not trained who is not numerate; but neither is he trained if he is not historiate.....My argument further calls for some change of esteem. In every science the ascending scale of intellectual status tends to be one of rarification: the more abstract, the more rigorous, the more general, so much the more distinguished.....In economics at least

> those who devote themselves to the direct observation of attitudes and behaviour have.....been.....called hewers of wood and drawers of water. The findings of those who have been at pains to ask businessmen what they actually do, have been smiled at as impressionistic, as somehow unprofessional. In the present stage of our science, at least, I believe that this relative valuation should be inverted: we ought to value powers of observation more highly than powers of abstraction, and the insight of the historian more than the rigour of the mathematician."*

The first system dynamics models were developed for the design of a corporate policy.** Questions of validity did not arise in a substantial way because managers took part in the model formulation, were able to relate all model details to the assumptions already being made in mental models, and could relate the models directly to the business at hand. Generally the corporate models were proprietary so that little public literature was generated and validity questions from people not participating in the model formulation seldom were asked.

System dynamics models are an extension of the "case study" method of system analysis as used in schools of law, medicine, and business. The "case study" approach belongs to the same process as the "magnificent dynamics" of the economic classics. The descriptive models in economics presented an overview of the system including social, psychological, environmental, and managerial factors interacting with one another. The "case study" approach strives to create an overview in which the essential structure of the system is stripped of irrelevant material and held up for critical inspection. But the descriptive models of the social sciences and the "case study" approach to systems both run into difficulty after the model has been described. So many

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*E. H. Phelps Brown, pages 7-9, Reference M.

**Industrial Dynamics, Reference A.

pieces and relationships must be described that no one is able to convincingly estimate the consequences of the myriad assumptions.

A system dynamics model goes several important steps beyond the descriptive models and case studies. First, the theory of feedback systems (sometimes referred to as cybernetics) is used to filter the information available from mental models. Much of the information has no significance to a particular dynamic phenomena. Given the objectives of the dynamic study, only certain kinds of time delays, nonlinearities, and structure can be significant. Second, principles of system structure are used to organize the selected information. Third, the information that would otherwise stay in verbal descriptive form is converted to an explicit computer model: this means that all assumptions become quantitative. Assumptions, therefore, become more explicit. Taking a general descriptive assumption and casting it in quantitative form does not make it more accurate, but does make it completely precise. In other words, an assumption may be no closer than it was as a representation of reality, but it becomes unambiguous and others can see exactly what has been asserted. Fourth, the computer model can then be used to play the role of the actual system and produce behavior implicit in the structure and assumptions of the model. This is the most certain step in the entire process. There need be no doubt whatsoever that the output behavior of the model does arise from its structure and assumptions. The most difficult step in the process of using descriptive models--going from assumptions to consequences--becomes the easiest and most certain step in the use of system dynamics models.

By shifting debate away from the implications of a hypothesized model, emphasis is focused on the theory underlying the structure and parameters. Consequently, the tie between mental models, descriptive models, and system dynamics models is intensified. The system dynamics model becomes a formal representation of the content of the mental models and the descriptive models. It can deal with any tangible or intangible concept that can be expressed in words. It provides a common framework in which technology, economics, psychology, sociology, and environment can be interrelated on an equal footing.

2. System Dynamics Models on the Social Scene

Beginning in 1969 two formal models have cut across intellectual disciplines and have engaged the social sciences, political debate, and the public. Both are system dynamics models. One represents urban behavior* and the other deals with forces of growth at the world level.**

Both models stirred a degree of debate and reached a diversity of audience that is probably unprecedented for formal mathematical models of society. For example, the Urban Dynamics book has been reviewed in more than fifty professional journals, and has been the subject of Congressional hearings and quoted in the Congressional Record. The World Dynamics book was given major coverage in the London Observer, Christian Science Monitor, Fortune, Wall Street Journal, the conservation press, the zero population press, the underground student press, and Playboy. World Dynamics was debated in some thirty pages of testimony in the United Nations, became a front-page headline issue in a French election, and, along with The Limits to Growth, has triggered seminars, symposia, panel discussions, debates, radio programs, and a continuous stream of press coverage. Why?

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*Urban Dynamics, Reference B.

**The model first appeared in World Dynamics, Reference C, published in June, 1971. It was extended and disaggregated to become the model behind The Limits to Growth, Reference D, which was first circulated to several research groups in the spring of 1972 and later was made available to several dozen research activities in 1973. The details of the model with further revisions will appear in The Dynamics of Growth in a Finite World, Reference E.

System dynamics models have been accepted in the world of mental models because the system dynamics models have shown a high degree of face validity that other formal models have not achieved. They have presented accessible underlying assumptions in reasonable agreement with real-world observation. They have shown behavior consistent with perceived social change. But they have informed, surprised, and communicated by explaining behavior differently than had been done in the most prevalent mental models. Because system dynamics models are entering the world of the operator, they must be subjected to and withstand the same kinds of examination and criticism used to test mental and descriptive models. The debate about model validity is then moved outside of the narrow criteria used by the social science community.

The intensity of public and professional interest seems traceable to the way these models intrude on the realm of mental models. The system dynamics models are built from the same assumptions as mental models. They deal with the same issues, they address the same human concerns, they shed light on the major questions of the day, and they shift the balance of power in political debates.

The above two models have crossed disciplinary lines. They have both been reviewed in economics journals, the public press, editorial columns, engineering publications, scientific publications, and the environmental press. They have fostered research projects, theses, and successor books.*

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*Models of Doom, Reference H; On Growth, Reference I; and The World System, Reference J. From the jacket of the latter, "World system modeling is a new art. It makes use of scientific data, system dynamics principles, and computer simulated projections. In its present stage of development (represented by the work of Forrester, Meadows, and collaborators), it raises a multitude of fundamental issues."

System dynamics models have shown how formal quantitative computer simulation models can contribute to better understanding and clarification of issues in the world of mental models and descriptive models. Such has apparently come as a surprise to many who have been engaged in the construction of other types of formal mathematical models. Until recently, formal models have been so far from influencing the world of political debate that many have lost sight of such influence as being the primary reason for constructing models.

II. NATURE OF VALIDITY IN MODELS

Models are used by quite different groups for different purposes growing from divergent underlying philosophies. The debate about model validity is often more a debate about philosophies than about a model.

A. VIEWPOINTS

The difference in viewpoint about models is perhaps greatest between "operators" and "observers."

1. The Operators

Operators are people who make decisions to control action. An operator must act. Even doing nothing is a decision by default. Doing nothing is an implicit decision not to act. The operator does not have the option of postponing a decision. Everyday he decides to take action or not on every option that lies within his reach.

A businessman is an operator as he makes decisions for guiding his company. A politician is an operator as he votes for laws and works toward consensus. A lawyer is an operator as he seeks resolution of legal conflicts. A medical doctor is an operator as he faces a patient with insufficient information and an incomplete model of biology but must recommend a course of treatment. An engineer is an operator as he designs a bridge or an airplane. A social scientist is an operator as he decides whom to marry, where to live, what social science research to do, and how to testify before a Congressional committee. In all of these situations, the operator uses incomplete information with partial and poorly identified models to arrive at a current course of action.

An operator must decide on the basis of the information available to him at the moment and with the best model he has for interpreting that information. He cannot wait until information is clearer. He cannot wait until he has a better model. Waiting is itself a decision to take no action. Taking no action is far from the same thing as avoiding a decision. Taking no action is a decision. The operator lives in the present because he is not able to act in the past or the future. He must make the best use he can of information that comes to him from the past to arrive at a present action that he believes will produce the most desirable consequences in the future. He uses the models available to him for converting past information into future expectations.

An operator knows that his information is deficient. If he stops to think about the mental models guiding his actions, he knows they are fragmentary and shifting. He shifts models in an ever-ending search for better models. The entire process of education is for the purpose of creating better models. Gaining experience is another way of saying that one is acquiring an expanded set of models. Using judgment and intuition is a way of acknowledging the necessity for mental models.

Gradually, various operators have found that their mental models can be augmented by formal models. No operator can give up his mental models. If for no other purpose, mental models will be used to select between formal models. The utility of formal models in the operating world will be judged by how well they mesh with the informal models that must also be used.

2. The Observers

Model-building observers take a very different view of models from that of model-building operators. They explain and criticize but do not act. They compare to the operator as the staff advisor compares to a manager.

Observers attempt to show the reasons for past behavior. Such an explanation need not be a guide to the future, it may be only a statistical correlation between past variables. The correlation may or may not hold in the future depending on how well understood are the conditions necessary for the correlation. In fact, action based on the correlation may change the basis of the correlation. The correlation may or may not be a guide to action because it can be obtained without containing control points through which influence can be exercised. Explanation is apt to be "research for its own sake" carried out in the hope that the resulting rearranged forms of data will yield new insights into social behavior.

Explanatory models are often conceived without an expectation that they are to be influential in decisions by operators. In fact, most journal articles presenting explanatory models stress incompleteness, doubts about assumptions, and inappropriateness of the particular formal model for current action.

B. VALIDITY AS SEEN BY AN OPERATOR

An "operator" takes a very different view of model validity from that taken by the "observer." The definitions of validity are different. The tests are different. The expectations are different, and models are put to different uses.

1. _Validity--Defined by an Operator_

The dictionary* gives two very different definitions of validity. One definition fits the viewpoint of the operator; the other definition fits the viewpoint of the model-building observer. As seen by the operator, validity means "well rounded or justifiable: applicable to the matter at hand: pertinent, sound. Able to affect or accomplish what is designed or intended: effective, efficacious." This is a practical and pragmatic definition. A model is valid if it does what is intended. It is valid if effective. It is valid if applicable to the matter at hand.

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*_Webster's Third New International Dictionary_.

2. A Model is a Theory

To an operator, a model is a theory of relationships. It is most effective if it reveals the critical relationships in a social system and omits irrelevant material that would clutter the picture. To an operator, a model is most useful if it is a dynamic model that contains within itself a theory of how the system changes through time and allows examination of how the behavior of the system would be altered by change in governing policies. To the extent that a model is a general theory, an operator wants to transfer the model from one member to another in a class of social systems. To the operator, a model is a representation of reality. It is useful to the extent that it coincides, for his purpose, with the real world.

3. Proof of Validity Impossible

When a model is taken as a substitute for reality there can be no objective proof of its validity. Validity means not absolute truth, but only a degree of confidence. The operator's model of a social system is like the engineer's theory of heat transfer or his theories about the strength of materials. These physical theories (including physical science theories such as Einstein's law) rest on no foundation that permits an absolute proof. They rest only on a foundation of confidence that has been generated by repeated demonstrations that the theories serve a useful purpose and have not been shown to be invalid for the purposes to which they are expected to apply. Validity in models is a subjective matter that is always judged by estimating how much evidence is necessary in a particular case to establish sufficient confidence to justify taking action on the model.

4. A Model is a Tool

A model means little to an operator unless he can use it. A model is a tool, it is a necessary way of arriving at decisions. He may not think of his mental images, his experiences, and his education as being models, yet he uses them as such. He sorts and organizes experience and selects the most relevant experience for guidance in the current situation. He must always choose a model. The more alert operator is continuously trying to improve his models by selecting the ones most relevant and discarding those that have served poorly.

5. The Operator Seeks Shared Confidence

To an operator, having others share confidence in his model is of the utmost importance. Generally his decisions affect others. Seldom is the operator a secure and absolute dictator. He must persuade, he must explain, he must lead. Such is true for any person in any station in life. At the very least he needs a degree of confidence in his own models and almost everyone deals with others in a framework where shared models are necessary.

A political leader must be able to establish credibility in his models so that he can maintain a consensus in support of his actions. Unless the models are ones already shared by the public, the political leader must choose models that can be understandably explained.

C. VALIDITY AS SEEN BY AN OBSERVER

The model-building observer who gathers numerical data and analyzes its statistics in a search for relationships holds a very different view of models and model validity from that of the operator. A model is the output of his work, not an input to his decisions. An important objective is to display skill in handling the methods of analysis. Validity is a measure of that skill to be judged by rules established by his peers.

1. Validity--Defined by an Observer

The dictionary[*] gives a second definition of validity that comes closer to the model-building observer's viewpoint than the definition appropriate to the operator. The definition speaks of validity "of an inference: correctly derived from its premises; specifically: true in terms of the logical principles of the logistic system to which the inference belongs." Validity here means correct derivation from premises. A proposition is true in terms of the logical system to which the inference belongs. The logical system is a closed system that begins with assumptions then derives consequences. The appropriateness of the assumptions is not a part of the validity issue, only the correctness of derivations from those assumptions. The process has been described:

> "In the presentation of a new model, attention nowadays is usually centered on a step-by-step derivation of its formal properties.....By the time it comes to interpretation of the substantive conclusions, the assumptions on which the model has been based are easily forgotten. But it is precisely the empirical validity of these assumptions on which the usefulness of the entire exercise depends."[**]

2. A Model is a Computational Result

Very often in the social sciences a model is simply the computational result of carrying through a conventional logical sequence. The process usually accepts uncritically the input data and structural hypothesis and then focuses on the computational processes that produce a numerical result. The numerical result is called a model. The exercise may be directed at "proving" a theory rather than arriving at operating decisions:

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[*] Webster's Third New International Dictionary.

[**] Leontief, page 2, Reference L.

> "at least four discernible 'revolutions' occurred in the late 1920's and the 1930's.....Another was the empirical or econometric revolution, with its insistence initially on the measurement of economic relationships and, subsequently and more ambitiously, on the testing of economic hypotheses--though the 'testing of hypotheses' is frequently merely a euphemism for obtaining plausible numbers to provide ceremonial adequacy for a theory chosen and defended on _a priori_ grounds.....Since intelligent and gifted young men and women will persevere until they succeed in finding statistical validation of an allegedly important theoretical relationship, and will then interpret their results as evidence in favor of the theory that originally suggested the relationship, their efforts will inevitably be extremely favorable to the theory in question."[*]

3. Validity is a Definition

In the mathematical social sciences validity is usually a defined concept. A model is valid if certain statistical tests are met. These are internal tests, they are part of "the logistic system to which the inference belongs." According to such formal terms, a model can be valid, and yet it may be irrelevant to an operator's decisions. According to the logical test of validity, a model could be valid and yet entirely contrary to reality.

4. A Model is a Collector's Item

In the social science literature, models tend to be ways of organizing and rearranging data. The resulting models are presented to others who are also creating models. The technique is examined, the formal measures of validity are admired, but seldom is it expected that one member of the peer group will use a model created by another. In fact, it is often not clear how such models can be used. The models become collectors' items in the literature.

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[*] Harry G. Johnson in his Richard T. Ely Lecture to the American Economics Association, pages 1-2, 9-10, Reference N.

5. The Model-Building Observer Seeks Debate

Many social science models are presented not to coalesce opinion, not as a basis of mutual action, not as a means of organizing the public, not to hold together a constituency, but as a basis for competitive debate. The observer has a purpose very different from that of the operator. The observer aims not to create a public constituency but instead to display individual effort, diligence, and virtuosity:

> "The same well-known sets of figures are used again and again in all possible combinations to pit different theoretical models against each other in formal statistical combat."*

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*Leontief, page 5, Reference L.

III. VALIDITY AND PURPOSE

Validity of a model can be judged only in the context of its purpose. Models are not good or bad in an absolute sense. They are appropriate or inappropriate in the context of some use. Different people can have different purposes for which they wish to use models. Two people with different objectives can arrive at entirely different opinions about the validity of a specific model.

Much of the validity debate surrounding system dynamics models arises from different viewpoints on model purpose.

A. PURPOSE AS SEEN BY AN OPERATOR

An operator expects a model to guide the decisions he must make. A model is an operating tool. It is valid if it is useful, particularly if it is the best available.

The operator must use his model as a means of communication, as a vehicle for persuasion, and as a method of generating consensus. Validity is measured in all the possible dimensions by which the model can be compared with the real world it represents.

When an operator engages in model construction, he does so to understand better the world around him as a guide to his own decisions. An advisor or staff assistant, if he is to be effective, must retain the operator's frame of mind and not slip into the viewpoint of the observer.

The operator, be he politician or manager or citizen, wants to understand his surrounding social system better, wants to balance sensibly the short-term against the long-term considerations, and wants to move closer to his future objectives. For him, the purpose of a model is a practical matter. A model should be utilitarian. To be utilitarian it must be understandable, and it must give concrete guidance. If a formal model is to exercise influence in the company of mental models, it must relate to the mental models and must be more persuasive.

Purpose as applied to models is a very specific concept. The purpose of a model is to guide a particular kind of decision. A model might be relevant to one kind of decision and not to another kind within the same system. For example, the Urban Dynamics model is addressed to the balance between industry, housing, and population. It is relevant to decisions that encourage or discourage construction and migration. But to the traffic commissioner, the model is of no value in deciding where to install the next set of traffic lights. The model is not a general model of all activities within a city. The model can be valid for some purposes and irrelevant or invalid for others. Validity cannot be discussed except in the context of a particular purpose.

B. PURPOSE AS SEEN BY A MODEL-BUILDING OBSERVER

Statistical models are usually for purposes quite different from operating models. Statistical models either summarize the relationships in historical data or are used for short-term forecasting. The data-summarizing model can be devoid of any specific decision-making implication. It is a statement of correlations between two or more variables as exhibited in a body of historical, numerical values. The forecasting model attempts to predict the future of a specific time series and leaves the implications of that prediction entirely to the person who may use it.

An econometric model is also a data-summarizing model. It establishes statistical relationships between a set of historical time series. The "purpose" is often to test hypotheses, but for what purpose? The situation is criticized by Worswick:

> "Surely such a comment cannot be made about econometrics: by its very name it is concerned with measurement, so how could it become detached from the facts?.....They are not, it seems to me, engaged in forging tools to arrange and measure actual facts so much as making a marvellous array of pretend-tools which would perform wonders if ever a set of facts should turn up in the right form.....For some economists indeed, 'the testing of hypotheses,' has become virtually synonymous with the specification of a set of mathematical equations and the estimation of their coefficients, the strength or weakness of the hypothesis being indicated by various tests of statistical significance..... The fact is that econometric models are not, as a rule, sharp instruments for discriminating between hypotheses. One has only to think of the recent controversies concerning the money supply, or to ask how many consumption functions are still in play. Such methods are better at telling us what is not the case, than at telling us what is."*

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*G. D. N. Worswick, Presidential Address to Section F of the British Association, pages 79-80, Reference O.

IV. CIRCUMSTANCES FOR ESTABLISHING CONFIDENCE

The debate over validity of models is misleading. A general impression has been created that objective quantitative methods exist for determining the validity of models. From the viewpoint of the operator, such is not true. The builder of statistical models claims objective measures of validity but these tests apply in a very narrowly defined manner and to only a very small segment of the full range of validity issues. The objective methods of statistical modeling are applied after many subjective judgments have been made about inputs and methods, and stop short of the subjective evaluation of how relevant the objective measures are to the circumstances facing the operator.

From the viewpoint of the operator there are no decisive validity tests for a model. Instead, there is a network of contacts between a model and reality. As the multiple contacts are explored without showing serious discrepancy between a model and the real world it represents, confidence in the model increases.

The relationships between reality, a model, subjective inputs, objective measures, and confidence are discussed in the next two sections dealing with statistical models and system dynamics models. The structure that connects the real world with the model and the two of them to the generation of confidence is very different for the two kinds of models.

A. STATISTICAL MODELS

Figure 1 shows the circumstances surrounding the creation and evaluation of a statistical model. The enclosure in the upper left part of the figure represents the real world. Theory about structure and also data are drawn from the real world as an input to statistical analysis. Other inputs are essential for the analysis--a choice of statistical methods, assumptions

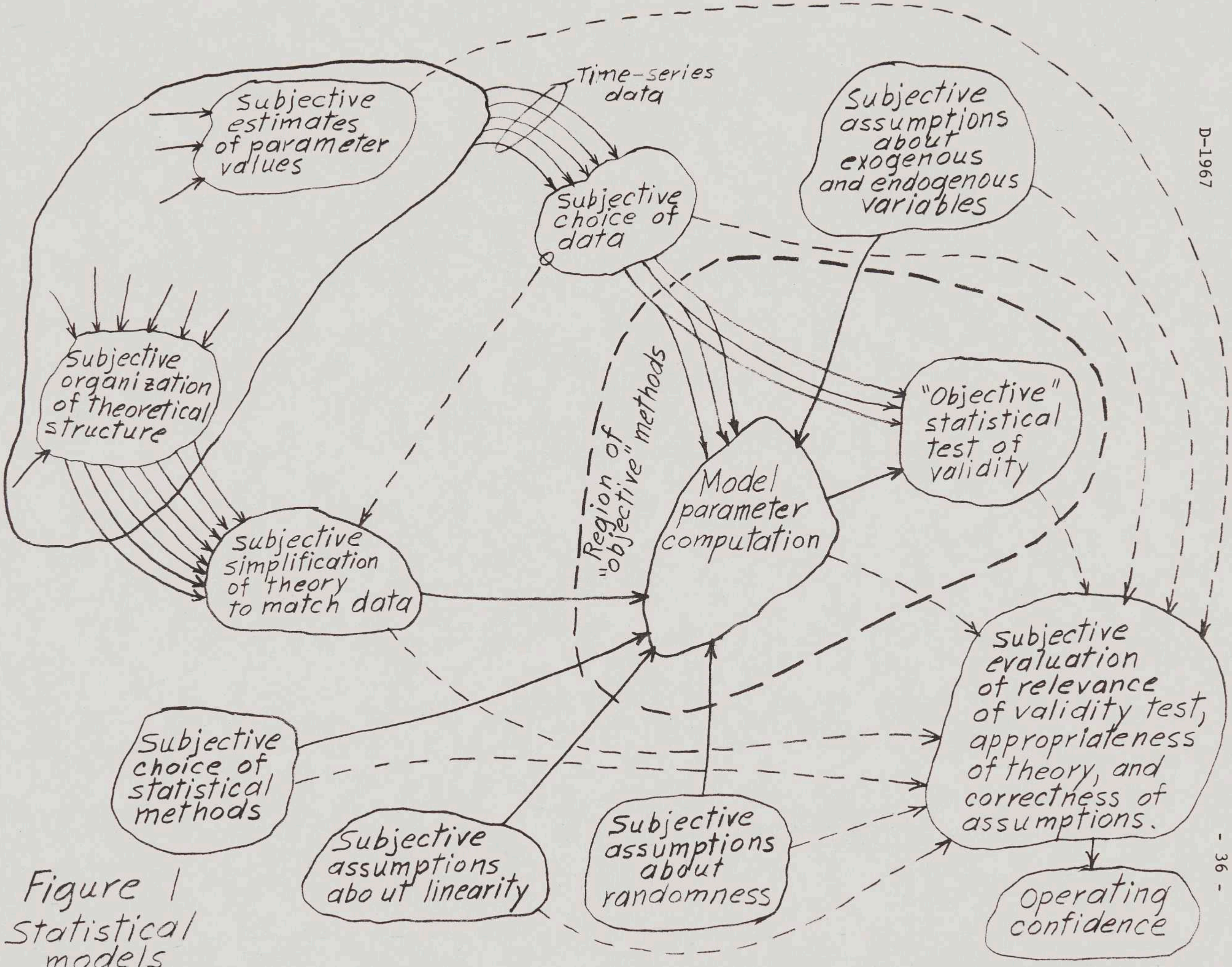

Figure 1
Statistical models

about linearity, assumptions about exogenous and endogenous variables, and assumptions about randomness in the data. Given the inputs, the statistical analysis produces parameters to fit the model structure drawn from theory. The structure and parameters, in effect, are then compared with the data to see how closely they fit; this produces an "objective" statistical test of validity.

In Figure 1 the many arrows from the real world into the "subjective simplification of theory to fit data" and the single arrow from that point to the statistical analysis implies the heavy hand of data availability in determining permissible theory. The theory can be no richer than the available data. The shortage of data restricts the usable theory to a very small subset of the theory that can be observed in the real world. The domination of data over theory is suggested by Worswick:

> "it is easy to write down a couple of dozen candidate explanatory variables in each case. How then are most equations encountered in econometric work restricted to half a dozen variables or less? Partly because candidate variables are put aside when no suitable measures happen to be available and partly because researchers naturally exercise judgment in selection of what they believe to be the most important or relevant variables."*

The objective statistical test applies only to the logical process within the dashed enclosure. The statistical-model researcher is content to stop at this point. His "objective" test tells him the probability that his model and parameters fit the data better than a null hypothesis of no interdependence between the variables. But the objective test does not relate to any operating purpose. It does not establish that the theory is relevant to

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*G. D. N. Worswick, page 81, Reference O.

some decision-making objective. It does not determine that the data chosen from the real world is appropriate. It can give misleading impressions about the assumptions regarding linearity, choice of variables, and the nature of randomness.

An operator cannot rely on the "objective" statistical tests. To establish operating confidence, he must still evaluate everything that went into the process against his purpose. But he is severely limited in bringing the real world to bear on his dilemma. He may be able to go back to the real world for subjective estimates of appropriate parameter values and compare these with the parameter values in the model. However, the model structure will probably be cast in a form such that its parameters are not the same ones to which his mental models give access. Except for some possibility of independent parameter checking, he must evaluate the same subjective choices made originally in the model construction but these assumptions do not connect with his mental models so he is without a basis for judgment. He cannot bring alternate information from the real world to bear on his decision about confidence.

The structure of the statistical model is dominated by the availability of data. Only those variables can be incorporated for which there is quantitatively measured information from the real world. Because so few of the real-world variables have been measured, the model is restricted to the most tangible variables. Yet, the operator knows that integrity, confidence, expectations for the future, values, preferences, and psychological pressures are of great importance in creating the behavior of social systems.

Figure 1 shows that the statistical procedures are immersed in a sea of subjective factors. The theory around which the model is constructed is subjective. A subjective choice has been made in selecting the measured data that will be used. Subjective choices of statistical methods must be made. A subjective assumption must be made regarding the degree to which linearity requirements of the analysis method are met. For some models, subjective choices are made in separating the data into exogenous and endogenous variables. Subjective assumptions are made about the nature of randomness in the real world.

After the subjective inputs, the "objective" measure is a formal process fitting the earlier definition of validity, "of an inference: correctly derived from its premises; specifically: true in terms of the logical principles of the logistic system to which the inference belongs." Given all of the subjective assumptions that have been put in, the validity measure tells how well the model that has been derived from the data fits that data, but it is done without reference to purpose, and it can give no evaluation of the appropriateness of the subjective assumptions underlying the process, nor does the "objective" measure give any indication of how important the statistical steps within the dashed enclosure are compared to those evaluations that are made outside.

The operator cannot trust the "objective" measures because they are so restricted in scope, and he has little other means of access for comparing the model to reality.

B. SYSTEM DYNAMICS MODELS

Figure 2 shows the corresponding relationships between real world, the model, and confidence for a system dynamics model. Compared to Figure 1, the "objective" validity computation is omitted, the number of subjective

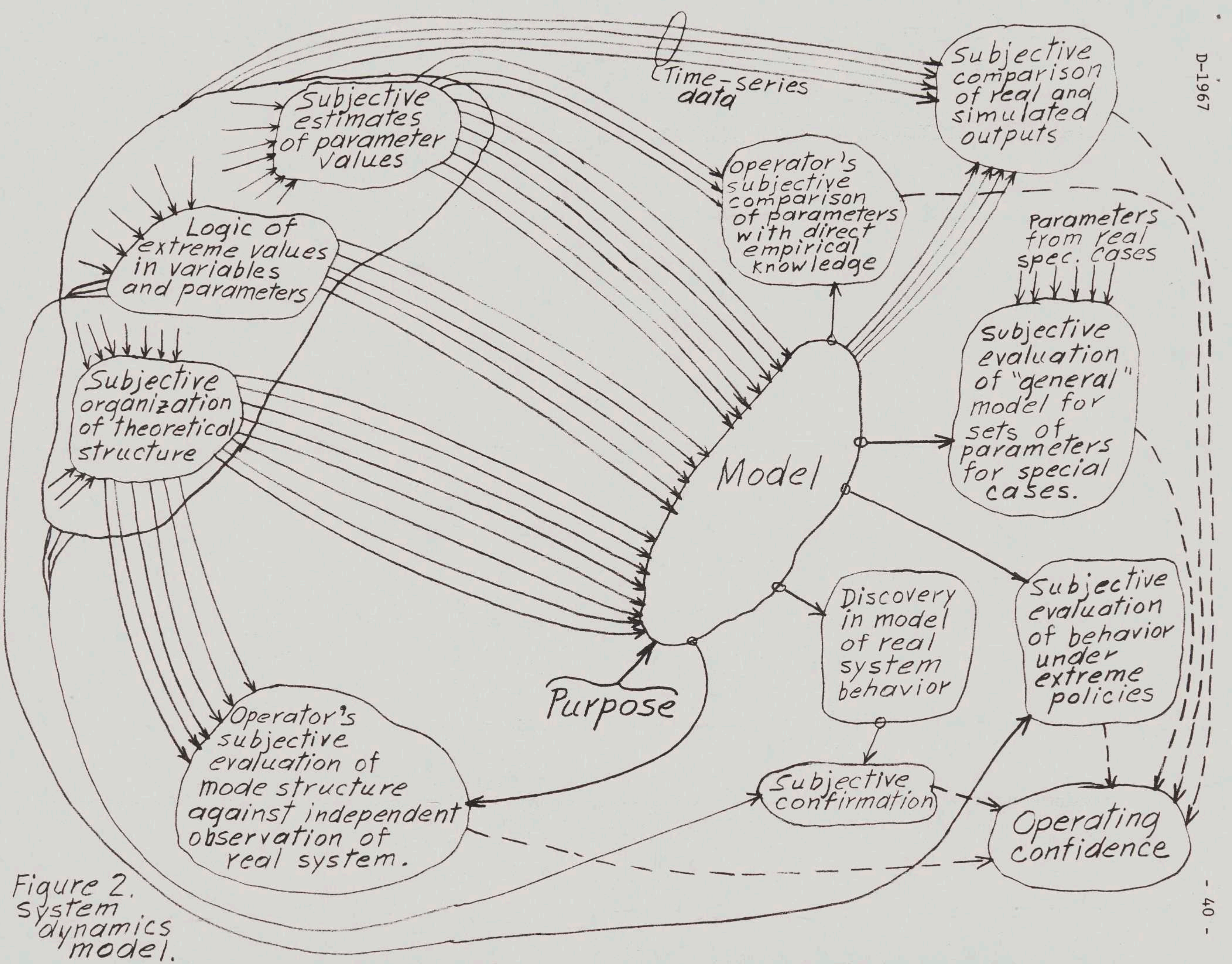

Figure 2. System dynamics model.

inputs to confidence are comparable, the amount and variety of outputs from the real world are vastly greater, and the kinds of evaluations are far more diverse.

In Figure 2 there need be no restriction on structural form or linearity. Therefore, the theoretical structure can be far richer.

Because the model structure and its parameters are not in any way tied to or restricted by the availability of quantitative measures and time-series data, the model is not restrained to a form determined by numerically measured inputs.

The parameter values come from the real world by the same channels as does structural theory. In other words, theory and structure both come from the available mental and descriptive models. No sharp distinction is possible between structure and parameters. In many ways they are one and the same thing. Generally speaking, parameters stand for variables whose variation is thought to be unimportant. One structure can be turned into another by setting parameter values to zero. It is no more reasonable to believe that one can estimate structure from real life than to estimate parameters. The structure asserts that one variable affects another. A parameter value asserts by how much. Setting parameter values is only a refinement on the first decision related to structure.

With the system dynamics model, any time series or cross-sectional data from real life is used in a totally different way from the usage in statistical models. The system dynamics model is made up entirely of endogenous variables. It is a laboratory replica of the real system. It can run by itself and should do the same things as the real system within the scope of its purpose. Therefore, it can generate output time-series data. Some of the variables in the model will correspond to variables for which real-world measurements have been made. The nature of the real-world time series can be compared with the nature of the model-generated time series. The appropriate basis for comparison is discussed in Section V.

In Figure 2 the model structure and parameters have far richer ties to the real world than in Figure 1. Only part of the available depth of interconnection is shown. Three categories of ties are illustrated.

First, a far heavier dependence is placed on real-world observation to produce the theory (or structure). The structure can be nonlinear, include feedback loops that produce high auto-correlation and cross-correlation in variables, and can deal with any variable that is considered important in the mental models of the real-world. The model structure is not limited to variables for which quantitative measures already exist; the intangible, psychological, and sociological variables can also be included.

Second, parameter values can all be assigned out of the knowledge available in mental and descriptive models. This is possible because the model makes direct contact with decision-making points in the real system. Each parameter has explicit meaning independent of all other parameters at the point in the real system to which it applies. Each parameter can individually be compared with the information existing in the vast mental-model store of information.

Third, the mental models contain a vast store of information that cannot possibly be reflected in time-series data. This information relates to the decision-making consequences of extreme values in variables and parameters. In other words, people often feel correctly confident that they know what would happen to the decision streams of the system if one or more of the state variables should take on extreme values outside of historical precedent. A full and proper formulation of a policy statement in a system dynamics model will produce the correct action under any combination, even a completely unlikely extreme combination, of state variables in the system. This knowledge of extremes from the mental models is a powerful input to realistic model formulation. The extreme values produce boundaries and asymptotes that help ensure satisfactory values of parameters in the normal operating ranges.

The system dynamics model has little appeal for the person who wants to analyze and summarize data. Furthermore, it has no appeal for the person who wants to hide behind "objective" measures of model validity. But to the operator, who can place only slight dependence on the "objective" measures, the system dynamics model is appealing. It makes contact with many more aspects of reality than does the statistical model.

The stronger emphasis on theory in the system dynamics model means that any person wishing to evaluate validity of the model should go back independently to the real world for confirmation of the theory of structure represented in the model. In other words, does the model represent the structure of the system as it is known to the second party? Does the evaluator find conformity between his perception of the structure of the real world and the perceptions represented in the model? In other words, the evaluator should retrace the process of creating model structure and verify its agreement with his own body of knowledge. This is expedited to the extent that the model comes accompanied by a strong descriptive model that ties mental models to the formal system dynamics model.

In a system dynamics model the original selection of model structure should be dominated by the purpose of the operator for whom the model is intended. The model is an operator's model. It is used for the development of policy to guide decisions. The model is useful only if it relates to decisions important to the operator. An operator can be any member of society; the model may guide momentous decisions by influential people, or it may assist the thinking and clarify the issues for a member of the voting public. Purpose enters at every stage in the formulation and the evaluation of a system dynamics model. The model is made for a purpose. Every kind of evaluation should be in terms of suitability for a purpose. There is no such thing as a system dynamics model being simply right or wrong. It can be valid for one purpose and invalid for another. Any discussion of validity must be in terms of the proposed use. Any doubts about model structure or parameter values should be in terms of how the model deficiencies might diminish usefulness.

An evaluator can address model parameters in the same way that he did model structure. Parameters, having come from the real world, have meaning back in that real world. The operator can examine model parameters against his own knowledge and that of other people to evaluate whether or not they are implausible or contrary to apparent facts.

The model generates a synthetic system behavior. It is an operating laboratory stand-in for the real system. One can compare the behavior of the system dynamics model with behavior observed in real life. The model can be compared with measured quantitative real-life variables. But the model does something that real life does not do. The model puts out quantitative time series for all of its variables whether or not those variables have numerical measures in real life. The quantitative outputs from the model for intangible variables can be compared with the mental-model knowledge in real life about those same variables. Plausibility of model behavior can thereby be determined.

Very often a system dynamics model will reveal behavior that had gone unrecognized in real life. In other words, it provides an interrelating and organization of real-life data that had not been recognized. It shows unsuspected relationships between known structure and known behavior.

Having attempted during formulation to produce structure and parameters that are valid over extreme ranges, the model can then be evaluated under extreme policy assumptions. Very often a high certainty exists for the reaction of a social system to extremes.

Many system dynamics models are models for a general class of systems. To the extent that a system dynamics model represents a general theory of the class of systems to which it applies, the model should behave like the individual members of the class. This test involves going back to the real world and drawing a new set of parameter values for the particular member of the class. For example, the Urban Dynamics model, given proper parameter values, should show the characteristic behavior of widely different kinds of cities. Such a test would mean picking parameter values suitable to the geography, outside environment, social conditions, and economic setting. All of the preceding tests could then be repeated for the special case. To the extent that many special cases are passed, greater confidence is established in the general structure and in the ability to choose parameter values.

As with the statistical model, the confidence that an operator will have in a system dynamics model is arrived at by subjective considerations. He must evaluate as many inputs as he feels are necessary to rank the model as better or worse than the mental model he would otherwise have used. He is not looking for absolute perfection. He is looking for improvement. The more improvement the better, but a comparison with his other alternative models is the significant test. Not only does he evaluate the model as such, but he must also evaluate the probable gains from changing to the new model against the costs, risks, and inconveniences involved. Only if the advantages are substantial is he likely to conclude that the effort in giving up his old mental models is justified.

In Figure 2 the operator has available to him many more kinds of tests than in Figure 1. He also has more different kinds of contact between the model and the real world.

With a good system dynamics model relevant to the purpose of a particular operator, the operator seldom exhausts all of the available validity tests before accepting the model. A few of the tests so overwhelmingly demonstrate the superiority of the model over the alternative mental models that a cost-benefit estimate quickly suggests that delays in adopting the model will cost more than the probable gains from more evaluation. For the operator, validity is a question of cost/risk trade-off.

V. EVALUATING SYSTEM DYNAMICS MODELS

As for any model representing some aspect of the real world, no procedure exists for proving the validity of a system dynamics model. Confidence rests on the absence of disproof. Each test of a model that is passed increases confidence in the model. When enough tests have been satisfied, a model is adopted, but one must realize that further tests could still be negative.

The larger the number of independent tests of a model against the real world, the greater will be the resulting confidence in the model. An operator places little dependence on a computed measure of confidence for a statistical model because such a measure is only one dimension of evaluation, furthermore, it is usually not even independent of the basis on which the model parameters were computed. On the other hand, as was illustrated in Figure 2, a system dynamics model can be compared in a variety of ways with the real world it is intended to represent.

The full extent of possible testing will probably never be used. If a system dynamics model passes several of the available tests, it will usually be judged more reliable than the competing mental models. At such a time, the model would be adopted even while further evaluation and improvement were being pursued.

The following tests are only part of those available. They are subjective in the sense that each must be evaluated and an opinion formed; none is based on a procedure whereby each person will arrive at the same answer. But such is the nature of evaluating models. The process is inherently the same as the task of evaluating the validity of mental models, except that the system dynamics model offers powerful additional points of contact with the real world.

A. STRUCTURAL VERIFICATION TEST

Structure in all models comes from theory. Theory comes from observation of the system, which means that theory comes from mental models. The expertise needed to verify the existence of model structure is less than the expertise necessary to create the model structure. Verifying structure means comparing the structure of a model with the structure of the real system to establish that the structure in the model does exist in real life.

Verifying that the model structure is to be found in the real system is easier and takes less skill than some other tests that involve structure. Many structures exist in the real system; it is easier to verify that the model structure is to be found in the real system than to verify that the most relevant structure has been chosen from the real system. The point is illustrated by reactions to the _Urban Dynamics_ model. No substantial criticism contends that the structure in the model does not exist in a real city. In other words, the model passes the test of the examiner being able to go from the model to the corresponding structure in the real system. Where a doubt exists it is in another dimension; is the most important structure included, or is sufficient structure included? For the _Urban Dynamics_ model, such questions are framed in terms of explicit representation of suburbs or the spatial subdivision of land area.

To pass the structural verification test, the model structure must coincide in a recognizable way with descriptive knowledge of the real system. The ability of the examiner to evaluate the degree of aggregation represented in the model will influence his conclusion. If his primary knowledge is at a very detailed level he may lack the overview necessary to evaluate a highly aggregated model. The model can pass the test of the operator who sees the broad-brush picture and not that of the lower-level operator, and vice versa. The model must be suited to its purpose and to the perspective of the operator it is to serve.

In the appropriate setting, the model must pass the structural verification test. The test requires that the structure in the model be recognizable in real life.

B. ALTERNATE-STRUCTURE TEST

The alternate-structure test asks if there is a different structure that would be more useful. This test may require a professional system dynamics modeler. He must find a structure that better meets all the other tests than does the proposed model. It is a more difficult test to apply than most others.

Until there are competitive system dynamics models addressed to the same purposes and issues, the alternate-structure test will not become a public test of model choice. Actually, any good system dynamics modeler goes through a series of alternate-structure tests in arriving at the structure that seems to meet his objectives. But in my experience, one structure is usually so far superior to the known alternates that the choice was clear and the alternatives did not justify presentation. The possibility always remains open that better structures (that is, better theories) can be discovered.

C. PARAMETER-VERIFICATION TEST

Just as the structure of a model can be verified against observation of real life, so can the values of parameters be compared to the knowledge available from mental and descriptive models. Structure identifies the inputs that influence a decision; parameters state the degree of the influence.

Structure-verification and parameter verification are not independent or different activities. If one concludes that an influence is so slight that the related parameter can always be considered to be zero, then the associated structure can be eliminated. If a parameter (a constant) is considered likely to change in value as a consequence of a particular combination of variables, then the parameter is converted to a variable with associated structure. In a model addressed to short-term issues, certain concepts can be considered constants (parameters) that for a longer-term view must be treated as variables. The dividing line between structure and parameters is fluid and changes with the purpose and time-horizon of the model.

But, within the intent of a particular model, the plausibility of parameters should be verifiable from direct observational knowledge of the real system. This will seem natural to the operator (see Section II.A.1). Both the ability of a model builder to draw parameters from real life and the ability of the verifier to check parameters against real life will, at least at first, be doubted by the statistical-model-building observer (see Section II.A.2). But the statistical model builder often exercises the same kind of direct parameter verification against real-life plausibility. When the observer statistically derives parameters from time-series data and those parameters clash with plausible theory and direct observation, the parameter value is rejected even though the statistical tests were met.

The attempt to derive parameter values from time series can lead to fallacious results. The point is illustrated in the article by Nordhaus and the reply by Forrester, et al. (see References P and Q). In this exchange, Nordhaus has attempted to show that certain demographic parameters in the World Dynamics model are incompatible with real-life time-series data relating population growth and GNP per capita. But in the reply (Reference Q) it is shown that the World Dynamics model actually generates the same time series as the real-life ones on which the Nordhaus argument is based. In other words, the model behaves in the real-life manner that was taken as an argument against the parameters of the model. The fallacy in the Nordhaus criticism of the model arises from an oversimplification that attributes all of the real-life behavior to one model parameter, whereas, many other variables and parameters were simultaneously interacting, as they actually do, to produce a result that coincides with the real-life result.

The parameter-verification test, like all other tests, is but one brick in the structure of confidence. It should be met, or the model modified until it is met, but by itself it is insufficient. On the other hand, it is a strong and necessary test.

D. EXTREME-CONDITION TEST

Much of the persuasive and convincing knowledge about real systems relates to the consequences of extreme conditions. For example, if in-process inventories reach zero then production must be zero, if there are no houses in a city then migration to the city will be strongly discouraged, if pollution rises high enough then death rate must rise, or if extensive starvation is occurring then economic effort will shift from more deferrable activities to food production.

An expertly constructed system dynamics model should be plausible and consistent with our expectations of reality at <u>every</u> policy statement in the model for <u>any</u> <u>extreme</u> and <u>unlikely</u> combination of levels (state variables) in the system. A model should be questioned if the extreme-condition test is not met. It is not an acceptable counter-argument to assert that the extreme conditions do not occur in real life and should not occur in the model. Even if the counter-argument is true, the model has still failed to use available knowledge of extreme asymptote and intercept information and, to that extent, fails to bound and restrict the normal operating range of its nonlinear parameters.

To make the extreme-condition test, one must ponder each rate equation (policy) in the model, trace it back through any auxiliary equations to the levels (state variables) on which the rate depends, and consider the implications of imaginary maximum and minimum (minus infinity, zero, plus infinity) values of each state variable and combinations to determine the plausibility of the resulting value of the rate equation.

The extreme-condition test is a strong test. The ability of system dynamics models to pass the mistaken-identity test (Subsection E below) is often attributable to their having been constructed to pass the extreme-condition test. The extreme-condition test is demanding of the evaluator's time but does not impose heavy demand for system dynamics competence. It can be done by anyone who can read algebra and knows the psychology and sociology of the system being modeled.

E. MISTAKEN-IDENTITY TEST

A system dynamics model should behave like the system it represents. It should generate the same time series that can be obtained from the real system. The model-generated time series should have the general visual characteristics of the time series from the real system.

The mistaken-identity test means that a person familiar in detail with the real system might mistake the model-generated data for having come from the real system. Bear in mind that no time-series data was used in the construction of the model. Furthermore, no exogenous time-series information is used to drive the model. From only the structure and parameters taken from descriptive information about relationships and decision processes in real life, the model should generate behavior with the dynamic character observed in the real system.

As an example of the mistaken-identity test, I have seen a production vice president, standing over computer-simulation plots from a model of his company, say to the board chairman, "See, I told you when we had the inventory peak four years ago that orders and employment would change this way." He was finding in a segment of the computer output a comprehensive replay of his past experience. But the model had in it no shred of that experience. Instead, it had the structure and policies that had generated the experience so the sequences of events were realistic.

To pass the mistaken-identity test, a model usually needs to contain random disturbances in one or more of its rate equations(decision functions).*

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*See Figures 15-20, 18-5, 18-6, 18-7, 18-19, 18-20, and 18-21, and Appendices F, K, and N of <u>Industrial Dynamics</u>, Reference A.

The random disturbances are especially important for systems whose most significant characteristic is damped oscillation. The random disturbances trigger the noncoherent fluctuations that are conspicuous in such systems. For models focusing on "life-cycle" dynamics, the random disturbances are less important because principal interest is in one-time phenomena. An example is the sudden reversal in Figure 3-1b of _Urban Dynamics_* of the underemployed/housing and underemployed/jobs ratios that occurs at the time the growth curve reaches its peak. The quick transition from low unemployment and tight housing to high unemployment and excess (abandoned) housing has characterized the American urban mode-change from growth to stagnation.

The better the system dynamics model, the more likely it is to generate behavior that cannot be distinguished from the real system the model represents. There are no other classes of models in the social sciences that are expected to meet the mistaken-identity test. The test must be made without exogenous variables that might drive the system in a predetermined behavior. The test involves not a single output variable from the model but an ensemble of variables so that relative timing of different variables can be examined.

Like other tests of model validity, the mistaken-identity test by itself is not decisive. But coupled with other tests it is powerful. The test verifies that the model does the right things. Other tests verify that the observed behavior is for the right reasons.

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*Reference B.

F. SYMPTOM-GENERATION TEST

The symptom-generation test is closely related to the mistaken-identity test. As part of the real-life behavior exhibited by the model, it should recreate the symptoms of difficulty that motivated the modeling. Presumably the model was made to show how a particular kind of undesirable situation arises, so it can be alleviated. Unless one can show how the internal policies and structure _cause_ the symptoms, he is in a poor position to alter those causes.

In a corporate model to deal with loss of market share, the model should start from the known policies and structure and show how the loss of market share is caused. If the corporate problem is instability of employment, the model should persuade one that, for the right reasons, it is generating the observed kind of employment fluctuation (see Chapter 17 and 18 of _Industrial Dynamics_*). If the objective is to understand and correct policies that cause unemployment and a faltering economy in an older American city, the appropriate model should show the internal mechanism of transition from growth to stagnation (see Figure 3-1 of Reference B).

A system dynamics model starts from perceived symptoms that are considered undesirable. The model should show how the symptoms are created. Policies in the model are then changed to seek ways to prevent the undesirable behavior.

G. POINT-PREDICTION TEST

The point-prediction test is discussed here, not because it is a good or suitable test, but because it ranks so high in the esteem of model

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*Reference A.

builders in the social sciences. The literature reveals that most writers accept as obvious the presumption that a good model should forecast a future state of the real system it represents. Typical is the brief comment by Worswick:

> "The idea of economics as positive science makes predictability the test of its performance, the prediction of relationships in situations not previously observed, as well as the prediction of future events, which in some ways is the acid test."*

But the point-prediction test cannot be met by any model in a useful way. Furthermore, a model can be of great usefulness without meeting the point-prediction test.

Point-prediction as a test of model validity was discussed at length and discounted in Industrial Dynamics** in 1961. Chapter 13 on "Judging Model Validity" contains in the section, "Predicting Future System State," a discussion of reasons for point-prediction not being a useful test in the class of systems to which our social systems belong. The class can be described as broad-band feedback structures containing substantial random disturbances. In such systems, effective prediction is not possible beyond the relatively short time horizon (a few weeks to a few months) over which the continuity and momentum of the system predetermines the future regardless of random noise and outside intervention. The very short-term prediction that might be possible is not

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*Page 80, Reference O.

**Reference A.

useful because intervention requires longer to affect the system than the horizon of the forecast. This entire matter is illustrated in Industrial Dynamics, Appendix K, on "Prediction of Time Series" where an experiment is conducted with a perfect model of a "real" system. In that appendix, a system dynamics model is defined as the real system. A model of the defined "real" system is then created by replicating exactly the equations of the "real" system even with the same initial conditions. The "real" system and the model contain the same kind and location of random-disturbance generators except that the generators do not start at the same values and therefore produce different streams of random numbers. The "real" system and its model begin to diverge so quickly that the model would not be a useful predictor of the "real" system. Yet it is shown that the model is a predictor of the "real" system in the context of the changed-behavior-prediction test discussed in the next subsection.

The intrinsic nature of social systems precludes effective use of the point-prediction test. It is not an appropriate kind of test for any style of model in spite of the great devotion to the test exhibited in the literature (especially the literature of econometric models).

If a model cannot forecast the future, by the same argument it cannot be expected to replicate the details of the past. A sharp distinction must be made between a model's behaving in a manner similar to the real system and showing instant-by-instant identity. The model can pass the mistaken-identity test without passing a point-prediction test (or the equivalent point-by-point replication of history). One expects a system dynamics model to predict, not a specific future system state, but how the desirability of behavior of the system will change in response to a change in governing policies.

H. CHANGED-BEHAVIOR-PREDICTION TEST

The important and possible prediction test for a system dynamics model is prediction of how the nature of behavior changes when a controlling policy is changed. A system dynamics model is not a decision-making model but a policy-making model. The model is not directed to predicting the immediate future so that a single immediate decision can be made. Instead, a system dynamics model is for the purpose of relating enduring policies to the nature of the resulting behavior of the system. In other words, the objective is not, "what should this decision be," but instead, "how should this kind of decision be made and influenced continuously and at all times as future opportunities for making decisions of this class arise." A decision relates to one isolated action. A policy is more permanent and describes how decisions of a particular kind are to be made. A system dynamics model is addressed to policy formation.

The changed-behavior-prediction test asks if the model properly predicts how the nature of the system will change if a governing policy is changed. The test can be made in several ways. On a particular system, one can make the test by changing a policy, presumably to attempt improvement, and see if the improvement occurs; the test then becomes the system-improvement test in Subsection M below. If the model, as it usually should, represents a family of systems, some of those systems will probably be operating under different policies and the policies of the model can be altered to see if its behavior takes on the different behaviors that distinguish the members of the family; the test then becomes the family-member test of Subsection L below. Or, the test can be made on a trial basis by changing policies in the model to verify the plausibility of the resulting behavioral changes.

I. PARAMETER-SENSITIVITY TEST

Parameter-sensitivity testing is part of the validity testing of a model. The test serves several purposes. It helps to show how well the model represents the real system. It also indicates the degree to which policy recommendations might be influenced by the uncertainty in parameter values in the model.

Under most circumstances, the policies derived from a system dynamics model are very insensitive to changes in parameter values. In fact, the behavior of the model is also surprisingly insensitive to most parameters. It appears that most real systems are likewise insensitive. Behavior of a corporation continues with its characteristic successes and failures over several changes of presidents and under changing external conditions. Inflation continues in spite of country, form of government, or succession of policies. All the older Northeastern cities in the United States show the same symptoms of aging and unemployment regardless of their being seacoast cities, manufacturing centers, or state capitols. Within the real-life existing range of parameter values, the values often seem to matter very little. Does the model show sensitivity, does that coincide with the dividing lines between subclasses of the family of systems represented by the model where the subclasses are distinguishable from one another in behavior?

Parameter-sensitivity testing produces additional opportunities for contact between the model and the real world. In various ways, the effect on the model from changing a parameter can be compared to observed or anticipated corresponding effects in the real system.

In addition to verification of the model, parameter-sensitivity testing can help to show the risk involved in adopting the model for policy making. If the same policies would be recommended, regardless of parameter values within any plausible range, the risk in using the model will be less than if two plausible sets of parameters lead to opposite policy recommendations. Exploration of this kind of parameter-sensitivity testing as related to policy is illustrated in Appendix B of Urban Dynamics.* There is illustrated the one known parameter change that could invalidate the recommended policies that were given in Section 5.7. The parameter change requires the assumption that people be almost totally indifferent to the availability of housing--indifferent to the extent that removing half of the housing in a city would have negligible effect on the people moving to and from the city. If the required assumption for invalidating the policy recommendation is judged implausible, then the parameter-sensitivity test suggests that the model is robust with respect to parameter values and that the policy recommendations are not likely to be affected by uncertainties in parameters.

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*Reference B

J. EXTREME-POLICY TEST

The extreme-policy test is the counterpart of the extreme-condition test. The extreme-condition test is a fragmentary test; it asks a question about a particular policy statement in the model. The extreme-condition test addresses the plausibility of a policy statement under arbitrary assumptions about the state variables (levels) in the system; it is a static test. The extreme-policy test is the inverse of the extreme-condition test.

In the extreme-policy test, a policy in the model is altered in some extreme and unlikely way. The model is then run to determine the dynamic consequences of the extreme policy. Does the model behave as we might expect for the real system under the same policy circumstances. For example, one could ask for the _Urban Dynamics_* model what would happen to the city if a particular building-construction rate were completely cut off; does the remainder of the system respond in other construction and migration streams as we might expect.

The extreme-policy test is important because we may be quite sure what would happen under the circumstances even though no real-life example has been observed. The test shows the resilience of the model to major policy changes. The better the model passes the test, the greater is justified confidence over the range of normal policy design.

K. SURPRISE-BEHAVIOR TEST

The better and more comprehensive a system dynamics model, the more likely it is to exhibit behavior that is present in the real system but which has gone unrecognized. The model is orderly and its behavior is reproducible.

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*Reference B.

Behavior in the model can be studied until it is understood. All variables in the model and their interactions can be traced.

When the model is fully understood, one often finds in it modes of behavior that had not been identified in the real system. The behavior is a surprise; does it also exist in the real system? To the extent that the model is a good model, the newly identified behavior will be observable in the real system. For example, a corporate model dealing with employment instability showed loss of market share as had actually been happening, but it also showed that the drop in market share was occurring at the time of business downturns because the product was <u>less available</u> during declining business than during times of high demand; the model showed a steeper reduction in production than in demand and inability to deliver at exactly the times when more sales could have been made; a review of the data showed the same timing had been occurring in the actual system. Several of the modes shown by the <u>Urban Dynamics</u>* model--low-cost housing producing unemployment in the city and job-training programs being of little use when there is a job shortage--were suspected by some but not widely recognized until the dynamic theory behind the behavior had been exposed.

Learning comes from surprise, from the unexpected. In the surprise-behavior test, a system dynamics model teaches lessons that were not asked or expected when the model was constructed. The surprise-behavior test creates a set of linkages between the model and the real system that were unanticipated while the model was being created.

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*Reference B.

L. FAMILY-MEMBER TEST

The most useful system dynamics models usually represent a family of social systems. In other words, the model is a general model of the class of system to which belongs the particular member of interest. The model is a general theory; its structure is the structure of the entire class. For example, a corporate model of loss of market share should deal with the general market share problem and should behave either with loss of market or with gain of market share as its parameters are changed to represent the contrasting companies. Likewise, the _Urban Dynamics_[*] model should be interpreted as a general model of urban growth and equilibrium; with appropriate choice of parameters it should behave like cities as different as New York, Dallas, West Berlin, a gold rush camp, the buildings on the top of Mount Washington, and Calcutta; to behave in such diverse ways, the parameters and tables of the model would have to be changed to represent the appropriate geographical, cultural, weather, sociological, and economic conditions.

The family-member test permits a repeat of the other tests of the model in the context of different special cases that fall within the general theory covered by the model. The general theory is embodied in the structure of the model. The special cases are embodied in the parameters. To make the test, one goes to the particular special member of the general family and picks parameter values that describe the special member. Then one examines the newly paramaterized model in terms of the various model tests to see if the model has withstood transplantation to the special case.

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[*] Reference B.

The family-member test is a test of the generality of the model. It also serves as a validity test by broadening the contact between the model and real life. As confidence is established in the breadth of applicability of the model, confidence is also enhanced in the model's being able to represent the particular application of interest and to show why that application differs from other members of the general family.

M. SYSTEM-IMPROVEMENT TEST

The ultimate test of a system dynamics model is in its identifying policies that lead to improved performance of the system. Were policies found by working with the model that improved model behavior and, when implemented, also improved the real system?

Although it is the final real-life test, the system-improvement test presents many difficulties. First, it will not be tried until the model from which the new policies come enjoys enough confidence for the implementation experiment to be made. Second, even when the real-life experiment is made and even if results are as predicted, the test is always clouded by some people asserting that the beneficial results came from causes other than the new policies; no matter what the outcome, interpretation of the actual policy implementation is subject to uncertainty as to whether or not other conditions were adequately constant to permit attributing the results to the policies. Third, the very long time constants of reaction in most social systems (running to months and years for a corporation to decades for a national economy) mean that results of the system-improvement test accumulate slowly.

In time, the system-improvement test becomes the decisive test but only as repeated real-life applications of a model lead overwhelmingly to the conclusion that the model pointed the way to improved policies. In the immediate choice of models facing the operator, he will usually be forced to judge validity from the other tests.

VI. SUMMARY

This paper has discussed the validity of formal models of social systems by focusing on the following points:

1. The primary purpose of a model is to assist an operator in making better decisions.
2. The best way to improve decisions is to develop superior policies for guiding decisions.
3. All decisions are now based on models--mental models.
4. There is no choice but to use models.
5. The important choice is in the model to use. An operator cannot postpone the choice. Any action or inaction implies a choice.
6. A useful formal model must couple to and work with the mental models that are already being used.
7. A formal model should represent some important aspect of the real world; it should not be driven by exogenous variables, which will obscure its dynamic implications; it should generate behavior like that of the real system because its internal processes replicate the processes of real life.
8. A system dynamics model meets the preceding specification. The so-called "explanatory" statistical models do not.
9. No decisive proof of model validity is possible. Statistical confidence tests are internal logical tests that

have only slight relevance to the operator's practical evaluation of a model.

10. System dynamics models make numerous strong contacts with the real world and with the mental models that govern the real world. An operator can deal with a system dynamics model because it is congruent with the models, information, data, and structure of the operating world.
11. Validity, in its multiple dimensions of importance to the operator, is far easier to establish for a system dynamics model than for other kinds of social science models.
12. All available information from the real world can be used in questioning validity of a system dynamics model--time-series data when it exists (see Sections IV.B and V.E) mental-model knowledge of structure and parameters, anticipated behavior of the system under extreme stress, behavior modes observed in the real world only after being first identified in the model, and the diversity of information from the individual members of the general class that the model represents.
13. Evaluating a formal model always involves comparing it with another model, either a previously adopted formal model or the current mental model. One model must be chosen as a guide to decisions. When a formal model

is offered that passes the initial and easy validity tests better than its predecessor, the decision on adopting the model always involves a compromise between the cost (and delay) of further evaluation of the new model and the risk of continuing to use the old and possibly inferior model.

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D-1721
Urban Dynamics Series

MEMORANDUM

TO: System Dynamics Group

FROM: Louis E. Alfeld

DATE: November 1, 1972

RE: Urban Dynamics Seminar Series

Each Friday afternoon, 1 - 2:30, beginning November 3, there will be an open seminar for the purpose of discussing technical aspects of modeling in the context of the urban dynamics project.

The series will open November 3 in E52-554 with a discussion on the subject of "What is a goal?" as used in system dynamics models. How do complex systems regulate themselves (e.g. temperature in the human body) and how do people implement goals for regulating systems (e.g. population maximums for cities)? What kinds of goals exist, how are they distinguished and how are they used? How are goals represented in system dynamics models?

LEA:wb