Summary

DYNAMIC OR 'DYNAMIC' HYPOTHESIS ?

BY
RAIMO KELOHARJU
HELSINKI SCHOOL OF ECONOMICS

Dynamic hypothesis is a product of insights that the modeller has. It is dynamic in the following sense:

(1) There is a causal equivalence between structure and behavior
(2) System behavior is a function of time.

Optimization in SD requires a **computerized feedback** process in model construction. There are no technical constraints that preclude starting from a set of causal relationships. When the right dynamic hypothesis is a subset of this set, the computer might be able to deduce the hypothesis from causal raw material using the value of an objective function.

Now we have a 'dynamic' hypothesis which is dynamic in the sense that the hypothesis itself will change continuously during the optimization process. This 'dynamic' hypothesis might, therefore, also be called 'transient hypothesis'.

A directed graph, manifesting dynamic hypothesis, can be converted to a matrix or vice versa as they are mathematically equivalent descriptions of the same phenomenon. In the matrix version, horizontal lines indicate independent variables and vertical lines dependent ones. Fig.1 shows how a simple problem might be described in two ways:

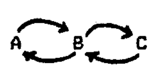

Fig.1a

	A	B	C
A		1	
B	1		1
C		1	

Fig.1b

Figure 1. Alternative ways of describing a problem

But there is a major difference in the approaches used. **Fig.1a relates to system analysis, Fig.1b to system synthesis.** Suppose now that Fig.1a describes a dynamic hypothesis. The picture indicates then that a modeller has been able to analyse the over-all dynamic effect of the causal relationships shown. Therefore, we have received an end product.

Fig.1b describes a set of causal relationships each indicated by a number one in the corresponding matrix cell. The focus of interest is now in each separate causal relationship. This synthesis alternative deserves closer attention because managers think in open-loop, not in closed-loop terms.

'Dynamic' hypothesis is based on the system synthesis approach, but further assumes , that a selection problem must be solved: How to choose the right subset of causal relatioships from the set available. Thus we do not have an end product, but raw material that should be combined in some way. I suggest that a computer might do this transformation work. But I would be reluctant to say that dynamic and 'dynamic' hypothesis are universal concepts that are mutually exclusive. On the contrary, it is quite likely that a repetitive use of both variations will give the best results.

Application example

Production can be based on a sales forecast or on firm orders that have supplemented the backlog. The choice between these two modes of action depends on continuity and on the volume of future demand. To simplify the presentation to follow, the future is assumed to be known.

Suppose that we have a system that is customer driven indicating that production is an order-taker. Figure 2 shows the simplified causal-loop diagram of the system. A horizontal line between demand and supply marks the boundary between the customer and the producer. Consequently backlog and inventory belong to different companies, even though they belong to the same system. In this framework, a model can be constructed from the standpoint of either demand or supply. However it requires that the corresponding model part be described in more detail.

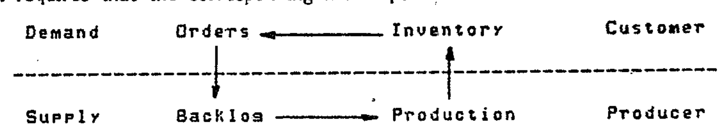

Figure 2. Framework for the application example

Modelling in SD proceeds at two stages: reproduction and improvement. At the reproduction stage, a model is constructed that is an acceptable description of the present system. At the improvement stage, the reproduction version is changed. In order to get an 'empirical' yardstick for comparisons in this study, model improvement was performed first, and use was made of the viewpoint of the customer. As a result, the optimal decision rule for the customer-ordering-behavior was found.

This model version generated graphs which we can now label 'real world' behavior. The production decision rule was very simple in that model but could it be found again from a set of potential decision rules ? We shall attempt to find it with a new model to be assembled by means of transient hypothesis.

Suppose that costs should be minimized. Because model behavior and costs (via the objective function) are substitutes as yardsticks, some error between real world behavior and model behavior can be minimized when optimization is based on error-related **relative** costs. Model improvement required an **absolute** measure in real cost terms rather than a relative measure. Figure 3 illustrates the similarity of the reproduction and improvement stages when cost functions are either relative or absolute. Demand data and cost function are needed to generate numerical values for a model and decisions.

Figure 3. Demand and cost information generate a model

Use of a relative cost function requires that one of the graphs should be selected as the **reference mode** to be imitated. A **reference point** from another curve is also needed to guide the curve fitting procedure. Production starting rate PSR and the final value of inventory INV were chosen for that purpos In more complicated models, an **error index** is needed which combines the reference mode based information from several 'real world' graphs.

Model formulation begins from the causal relationships matrix of Figure 4. Each matrix row is a general description of some model equation. The first row shows, for example, that INV=f(INV,PCR,SAL). The 'ones' underlined indicate additions to the 'real world' version.

The production starting rate PSR will now be defined as a set from which the computer has to select the right subset. For purposes of exposition, a transformation to an open-loop, hierarchical structure will be made. The decision tree thus received looks similar to a Bill of Material in mass-production but there is one fundamental difference: Instead of minimizing assembly lead time with a fixed product structure, a variable model structure will be used keeping the solution interval DT fixed.

Any SD equation can be disaggregated to its components in order show the hierarchy of causal relationships. We see from Figure 4, for example, that PSR=f(BCOR,AVP,IPIC) and BCOR=f(BLG,TBLG). This recursive procedure produced the structure of PSR, given in Figure 5. Hierarchical levels (not the same as level variables in SD) were defined in terms of **causal distance** from the decision rule.

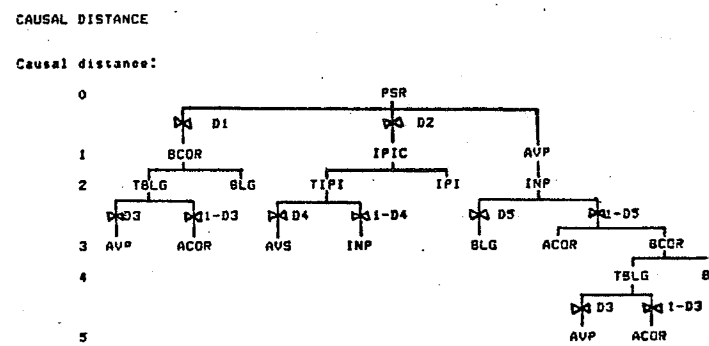

Figure 5. The PSR-equation in the decision tree form

Five decision parameters (D1,...,D5), indicated with valves, were added to the model to give structural variety for the optimization process. A high-echelon valve can cancel out the effects of a low echelon valve. For example, D3 might have any value when D1 has the value of zero.

Use of decision parameters transforms the optimization process into **multi-objective optimization** within a single-objective objective function. For example, target backlog TBLG is a linear combination of average production AVP and Average Customer Order Rate ACOR:

$$TBLG.K=D3*AVP.K+(1-D3)*ACOR.K \text{ , where } 0 \leq D3 \leq 1$$

Decision parameter D3 is a variable in the optimization process and thus receives some value which corresponds to the minimum regret from the over-all viewpoint.

There are three target values for the producer: Target Backlog TBLG, Indicated Production INP, and Target In-Process Inventory TIPI. Each of these terms should be collected from weighted components, deriving from demand and supply. The decision parameters D3, D4 and D5 are there for this purpose. The decision parameters D1 and D2 assess proportional controllers. Thus both economic and technical viewpoint were needed in the transient hypothesis formulation.

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I. Introduction

The SD approach is based on control theory. As with general system theories, it postulates that system structure causes system behavior. Computer simulation used to be the only means of solving complicated models at the time SD was invented. Therefore,

(1) only system structure and system behavior could be used as yardsticks in model validation

(2) without an intuitive or intelligent guess, that related structural explanation to model behavior, all modelling work would have been fruitless or at least extremely laborious.

In computer simulation, no automatic feedback from model behavior to structural changes is feasible. A human link is needed and, therefore, system dynamists have rightly argued about the significance of insights gained from the very modelling process. Without insights, no feedback mechanism would work properly in model construction. The authoritarian relationship between man and machine, prevailing in SD, is an outgrowth of this situation.

II. Hypothesis types

Dynamic hypothesis is an intuitive explanation concerning the causal relationships that produce observed system behavior. It is generally believed by system dynamists that a dynamic hypothesis is necessary before any modelling efforts can begin.

Dynamic hypothesis is a product of insights that the modeller has. It is dynamic in the following sense:

(1) There is a causal equivalence between structure and behavior
(2) System behavior is a function of time.

Optimization in SD requires a **computerized feedback** process in model construction. There are no technical constraints that preclude starting from a set of causal relationships. When the right dynamic hypothesis is a subset of this set, the computer might be able to deduce the hypothesis from causal raw material using the value of an objective function.

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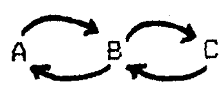

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III. Application example

1. General description

Production can be based on a sales forecast or on firm orders that have supplemented the backlog. The choice between these two modes of action depends on continuity and on the volume of future demand. To simplify the presentation to follow, the future is assumed to be known.

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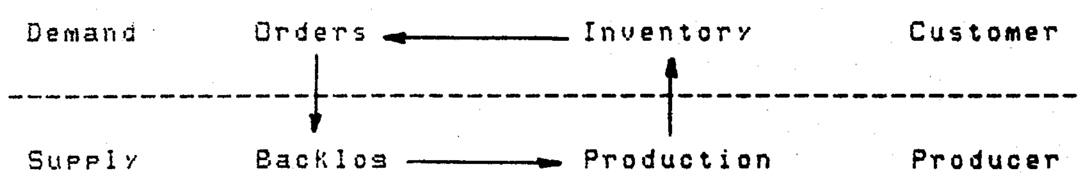

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Model formulation begins from the causal relationships matrix of Figure 4. Each matrix row is a general description of some model equation. The first row shows, for example, that INV=f(INV,PCR,SAL). The 'ones' underlined indicate additions to the 'real world' version.

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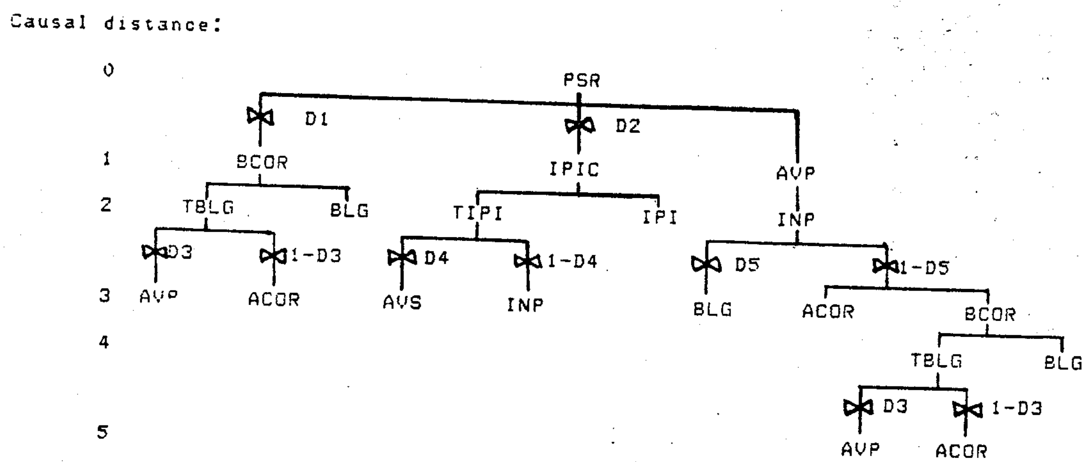
	INV	TINV	AVS	BLG	TBLG	BCOR	INP	AVP	PSR	PCR	IPI	TIPI	IPIC	SAL	COR	ACOR
INV	1									1				1		
TINV			1													
AVS			1											1		
BLG				1					1						1	
TBLG								1̲								1̲
BCOR				1̲	1̲											
INP				1̲		1̲										1̲
AVP							1	1								
PSR						1̲		1					1			
PCR									1							
IPI									1̲	1̲	1̲					
TIPI			1̲				1̲									
IPIC											1̲	1̲				
SAL																
COR	1	1	1	1												
ACOR															1̲	1̲

INV

INV = inventory
TINV = target inventory
AVS = average sales
BLG = backlog
TBLG = target backlog
INP = indicated production
AVP = average production rate
PSR = production starting rate
PCR = production completion rate
IPI = in-process inventory
TIPI = target in-process inventory
IPIC = in-process inventory correction
SAL = sales
COR = customer order rate
ACOR = customer order rate average

Figure 4. Causal relationships of the application example

CAUSAL DISTANCE



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Figures 4 and 5 did not define the form of causal relationships. This is a question that should at this point be discussed. In the 'real world' model, we assumed that indicated production was a linear function of order backlog. However the corresponding equation is based only on the supplier's viewpoint and needs reformulation. Decision parameter D5 provides the opportunity of adding another component to the decision rule, namely that of average incoming order rate ACOR and a proportional control term BCOR. In this way, we have been able to include a demand-related term, Average Production Rate AVP.

The backlog target TBLG is now assumed to be a non-linear function of average material flow in the customer-producer network. The average material flow is being treated as a linear combination of Average Production AVP and Average Customer Order Rate ACOR. The linear form of INP is thus a simplification of the assumed non-linearity. Figure 6 shows the relationships described above.

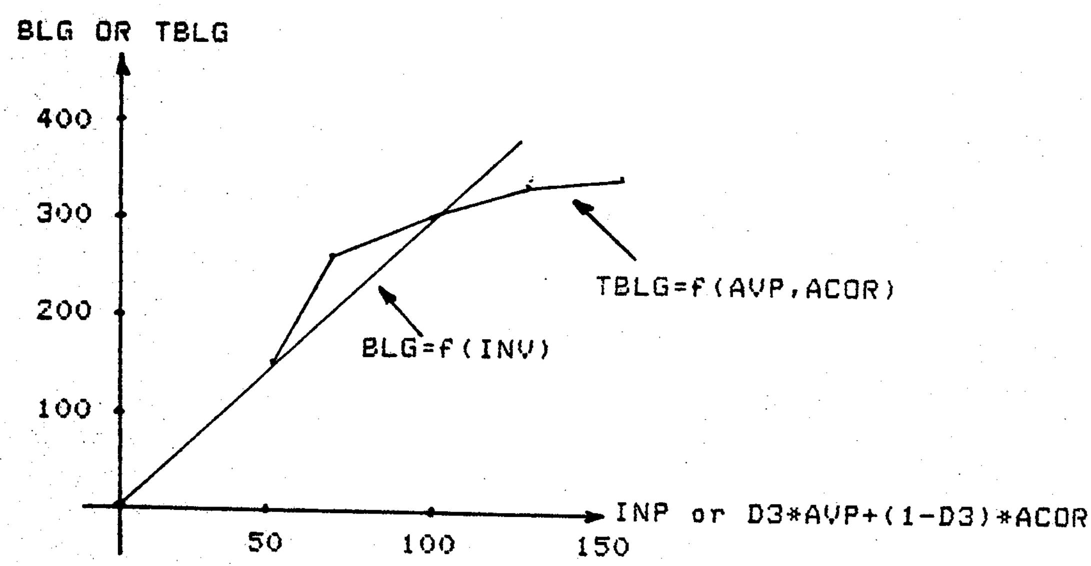

Figure 6. The relationship between BLG and TBLG

The transient hypothesis describes the process where the computer tries to find target values for certain optimization parameters. The objective function OBJ4 is an example of a case where a reference graph but no reference point was used. However the objective function OBJ5 also contained a reference point. Figure 7 shows that the reference point was needed to push the initial decision parameter values close to their target values.

Decision parameter	Initial value	Target value	Final value OBJ4	Final value OBJ5
D1	1	0	.610	.030
D2	1	0	.244	.030
D3	.5	no effect	.997	.927
D4	.5	no effect	.270	.010
D5	.5	1	1	.990

Figure 7. A model fitting experiment

The reference point effect can also be seen from Figure 8. It shows the target curves for PSR and INV, generated by OBJ3, as well as the curves produced with the objective functions OBJ4 and OBJ5. From the standpoint of model behavior, there was no difference between the target values and and OBJ5-produced values.This clearly shows that the differences between the corresponding decision parameter values are not significant. Therefore, D1, D2 and D5 can be rounded off to the nearest integers.

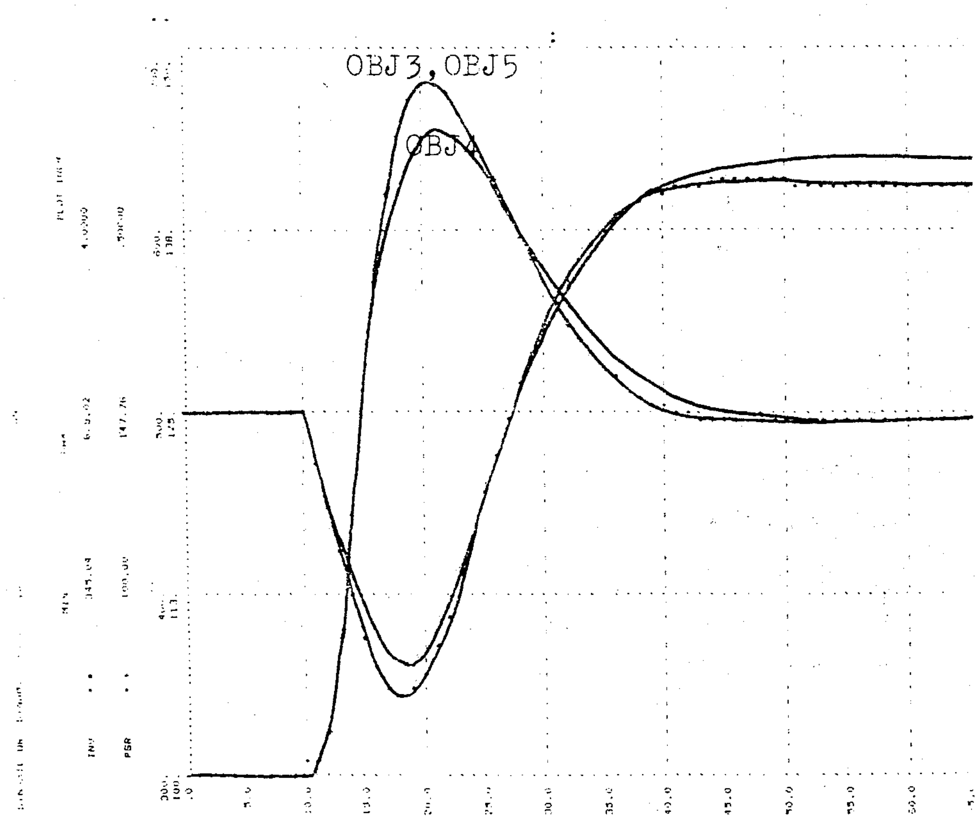

Figure 8. Curve fitting with and without a reference point

Figure 9 shows statistical information, collected from the OBJ5 run. We see from the figure that the exact values of the decision parameters we were looking for were found by iteration 22. This suggests that the range of objective function values between 259 and 192 produced practically the same model behavior. The corresponding parameter ranges indicate the magnitude of parameter tolerance that is allowable for rounding off purposes.

ITER	VALUE OF OBJ5	PARAMETER VALUES D1	D2	D3	D4	D5
1	.157E+07	.700E+00	.100E+01	.500E+00	.500E+00	.500E+00
2	.864E+06	.700E+00	.700E+00	.500E+00	.500E+00	.500E+00
3	.654E+06	.700E+00	.700E+00	.800E+00	.500E+00	.500E+00
4	.110E+07	.700E+00	.700E+00	.800E+00	.800E+00	.500E+00
5	.375E+06	.700E+00	.700E+00	.800E+00	.200E+00	.500E+00
6	.130E+05	.700E+00	.700E+00	.800E+00	.200E+00	.800E+00
7	.199E+04	.340E+00	.340E+00	.100E+01	.000E+00	.100E+01
8	.287E+04	.400E-01	.340E+00	.100E+01	.000E+00	.100E+01
9	.120E+04	.640E+00	.340E+00	.100E+01	.000E+00	.100E+01
10	.229E+04	.640E+00	.400E-01	.100E+01	.000E+00	.100E+01
11	.514E+04	.640E+00	.640E+00	.100E+01	.000E+00	.100E+01
12	.127E+04	.640E+00	.340E+00	.700E+00	.000E+00	.100E+01
13	.148E+04	.640E+00	.340E+00	.100E+01	.300E+00	.100E+01
14	.121E+04	.640E+00	.340E+00	.100E+01	.000E+00	.700E+00
15	.317E+04	.568E+00	.000E+00	.100E+01	.000E+00	.100E+01
16	.989E+04	.868E+00	.000E+00	.100E+01	.000E+00	.100E+01
17	.818E+03	.268E+00	.000E+00	.100E+01	.000E+00	.100E+01
18	.422E+03	.268E+00	.300E-01	.100E+01	.000E+00	.100E+01
19	.422E+03	.268E+00	.300E-01	.970E+00	.000E+00	.100E+01
20	.422E+03	.268E+00	.300E-01	.970E+00	.300E-01	.100E+01
21	.507E+03	.268E+00	.300E-01	.970E+00	.000E+00	.970E+00
22	.260E+03	.000E+00	.000E+00	.934E+00	.000E+00	.100E+01
23	.959E+03	.300E+00	.000E+00	.934E+00	.000E+00	.100E+01
24	.206E+03	.000E+00	.300E-01	.934E+00	.000E+00	.100E+01
25	.206E+03	.000E+00	.300E-01	.904E+00	.000E+00	.100E+01
26	.206E+03	.000E+00	.300E-01	.964E+00	.000E+00	.100E+01
27	.206E+03	.000E+00	.300E-01	.964E+00	.300E-02	.100E+01
28	.204E+03	.000E+00	.300E-01	.964E+00	.300E-02	.997E+00
29	.200E+03	.000E+00	.300E-01	.957E+00	.660E-02	.993E+00
30	.194E+03	.300E-01	.300E-01	.957E+00	.660E-02	.993E+00
31	.328E+03	.300E-01	.900E-01	.957E+00	.660E-02	.993E+00
32	.194E+03	.300E-01	.300E-01	.987E+00	.660E-02	.993E+00
33	.194E+03	.300E-01	.300E-01	.927E+00	.660E-02	.993E+00
34	.193E+03	.300E-01	.300E-01	.927E+00	.960E-02	.993E+00
35	.192E+03	.300E-01	.300E-01	.927E+00	.960E-02	.990E+00
36	.191E+03	.660E-01	.300E-01	.882E+00	.175E-01	.982E+00

FINAL SOLUTION

D1 = .030
D2 = .030
D3 = .927
D4 = .010
D5 = .990

NO OF OBJ5 EVALUATIONS 37
INITIAL VALUE OF OBJ5 .54883E+07
FINAL VALUE OF OBJ5 .19160E+03

Figure 9. Statistical information from OBJ5 optimization

IV. Concluding remarks

Finally we shall examine very briefly the position of the transient hypothesis relation to other concepts, as shown in Figure 10.

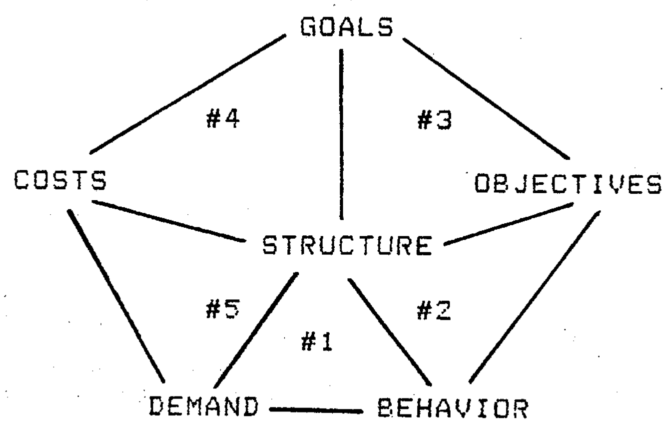

Figure 10. Relationship of some main concepts

Each triangle has a specific meaning:

No.1 : classical SD approach
No.2 : criteria available for judging the correctness of the model
No.3 : top management viewpoint
No.4 : functional management viewpoint
No.5 : automation approach

The transient hypothesis relates to that aspect of an automation approach where model structure is derived automatically from cost and demand information. The output from the transient hypothesis stage is likely to require simplification. Computer software has been developed for that purpose at the Helsinki School of Economics.

Many outsiders claim that SD is regarded with the awe of a religion. Probably the main reason for this impression is the strict adherence by system dynamists to certain fixed postulates which are not always generally accepted. Unfortunately, experience shows that "selling" a religion is very hard work. Perhaps this fact is the most fundamental point that favours the optimization approach in SD. 'Dynamic' hypothesis is just one example of its use and of the extra freedom to be gained when old beliefs are being treated as special cases of more general situations

APPENDIX

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* DYNAMIC OR 'DYNAMIC' HYPOTHESIS ?
NOTE
NOTE ORDINARY EQUATIONS
NOTE
L INV.K=INV.J+DT*(PCR.JK-SAL.JK)
A TINV.K=TIW*AVS.K
L AVS.K=AVS.J+DT/TAS*(SAL.JK-AVS.J)
L BLG.K=BLG.J+DT*(COR.JK-PSR.JK)
A TBLG.K=D3*TABHL(BTAB,AVP.K,50,150,25)+
X (1-D3)*TABHL(BTAB,ACOR.K,50,150,25)
T BTAB=200/265/300/325/340
A BCOR.K=(TBLG.K-BLG.K)/BCT
A INP.K=D5*BLG.K/TBW+(1-D5)*(ACOR.K+(TBLG.K-BLG.K)/BCT)
L AVP.K=AVP.J+DT/PAT*(INP.J-AVP.J)
R PSR.KL=AVP.K+STEP(1,10)*(D1*BCOR.K+D2*IPIC.K)
R PCR.KL=DELAY3(PSR.JK,PLT)
A IPIC.K=(TIPI.K-IPI.K)/ICT
L IPI.K=IPI.J+DT*(PSR.JK-PCR.JK)
N IPI=PLT*AVS
A TIPI.K=TIP*(D4*AVS.K+(1-D4)*INP.K)
R COR.KL=AVS.K+A1*(B1*TIC+(1-B1)*TINV.K-INV.K)
X /TAI+A2*(TBW*AVS.K-BLG.K)/TAB
L ACOR.K=ACOR.J+DT/TAOR*(COR.JK-ACOR.J)
N ACOR=AVS
R SAL.KL=100+STEP(25,10)
NOTE
NOTE INITIAL CONDITIONS
NOTE
N INV=TINV
N AVS=100
N BLG=300
N AVP=100
NOTE
NOTE DECISION PARAMETERS
NOTE
C A1=.41
C A2=1
C B1=.038
C D1=1
C D2=1
C D3=.5
C D4=.5
C D5=.5
NOTE
NOTE ORDINARY PARAMETERS
NOTE
C TAS=2
C TBW=3
C PAT=2
C PLT=3
C TAI=3
C TAB=4
C TAOR=3
C TIW=5
C TIC=500
C BCT=5
C TIP=4
C ICT=3
```

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NOTE
NOTE OBJECTIVE FUNCTIONS
NOTE
A OBX1.K=(TIW*AVS.K-INV.K)*(TIW*AVS.K-INV.K)
L OBJ1.K=OBJ1.J+DT*OBX1.J
N OBJ1=0
L INVX.K=INVX.J+DT*(INV.J-INVX.J)
N INVX=500
A OBX2.K=100*(INV.K-INVX.K)*(INV.K-INVX.K)
L OBJ2.K=OBJ2.J+DT*OBX2.J
N OBJ2=0
A OBJ3.K=OBJ1.K+OBJ2.K
A GUIDE.K=TABHL(PSRT,TIME.K,0,100,5)
T PSRT=3*100/125.94/148.02/143.06/134.18/
X 128.24/125.53/124.70/124.65/124.79/124.91/8*125
A DEV.K=GUIDE.K-PSR.KL
A ERR2.K=DEV.K*DEV.K
L OBJ4.K=OBJ4.J+DT*ERR2.J
N OBJ4=0
A IDEV.K=625-INV.K
A OBJ5.K=OBJ4.K+IDEV.K*IDEV.K
NOTE
NOTE OUTPUT EQUATIONS
NOTE
PRINT PSR
PLOT INV=*(300,700)/PSR=+(100,150)
C DT=0.5
C LENGTH=100
C PRTPER=5
C PLTPER=1
RUN
NOTE
NOTE MODEL DOCUMENTATION
NOTE
D AVP=(U/W) AVERAGE PRODUCTION
D AVS=(U/W) AVERAGE SALES
D BLG=(U) BACKLOG
D COR=(U/W) CUSTOMER ORDER RATE
D INP=(U/W) INDICATED PRODUCTION
D INV=(U) INVENTORY
D PAT=(W) PRODUCTION AVERAGING TIME
D PCR=(U/W) PRODUCTION COMPLETION RATE
D PLT=(W) PRODUCTION LEAD TIME
D PSR=(U/W) PRODUCTION STARTING RATE
D SAL=(U/W) SALES
D TAB=(W) TIME TO AVERAGE BACKLOG
D TAI=(W) TIME TO AVERAGE INVENTORY
D TAS=(W) TIME TO AVERAGE SALES
D TBW=(W) BACKLOG TARGET IN WEEKS
D TIC=(U) TARGET INVENTORY (IF CONSTANT)
D TINV=(U) TARGET INVENTORY (IF VARIABLE)
NOTE NEW SYMBOLS
D BCOR=(U/W) BACKLOG CORRECTION
D BCT=(W) BACKLOG CORRECTION TIME
D ICT=(W) IN-PROCESS INVENTORY CORRECTION TIME
D IPI=(W) IN-PROCESS INVENTORY
D IPIC=(U/W) IN-PROCESS INVENTORY CORRECTION
D TAOR=(W) TIME TO AVERAGE CUSTOMER ORDER RATE
D TBLG=(W) TARGET BACKLOG
D  TIP=(W) IN-PROCESS INVENTORY TARGET IN WEEKS
D TIPI=(U) TARGET IN-PROCESS INVENTORY
+
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CLASS II DOCUMENTATION STANDARDS FOR SIMULATION MODELS

1. ACCESS TO MODEL:

Name of Model: Dynamic or 'dynamic' hypothesis?

Name and current address of the senior technical person responsible for the model's construction: Dr.Raimo Keloharju, Helsinki School of Economics, Runeb.k. 14-16 00100 Helsinki 10

Who funded the model development? -

In what language is the program written? Dysmap

On what computer system is the model currently implemented? HP-3000/II

What is the maximum memory required to store and execute the program? 36 Kb (8bit)

What is the length of time required for one typical run of the model? 100 sec.(cpu) in simulation, 300 sec.(cpu) in optimization

Is there a detailed user's manual for the model? No, but for the Dysmap-Optimizer there is.

2. PURPOSE OF THE MODEL:

For what individual or institution was the model designed? For the 1981 SD Research Conference

What were the basic variables included in the model?
Inventory, sales, order backlog, production starting rate, customer order rate

Over what time period is the model supposed to provide useful information on real world behavior? over two years

Was the model intended to serve as the basis of:

- an academic exercise designed to test the implications of a set of assumptions or to see if a specific theory would explain historical behavior: x
- communication with others about the nature and implications of an important set of interactions: x
- projecting the general behavioral tendencies of the real system: ______
- predicting the value of some system element(s) at some future point in time: ______

3. MODEL SPECIFICATION AND THEORETICAL JUSTIFICATION:

Provide two diagrams illustrating the extreme behavior modes exhibited by the major model elements: See Fig.8 in the paper

If they are not included in the body of the paper indicate where the reader may find:

- a model boundary diagram that indicates the important endogenous, exogenous and excluded variables ______
- a causal influence diagram, a flow diagram, the computer program and definitions of the program elements ______

Is the model composed of:

- simultaneous equations ______
- difference or differential equations x
- procedural instructions ______

Is the model deterministic x or stochastic ______

continuous ______ or discrete x

4. DATA ACQUISITION

What were the primary sources for the data and theories incorporated in the model?

Data: only illustrative

Theory: ______

What percent of the coefficients of the model were obtained from:

- measurements of physical systems ______
- inference from social survey data ______
- econometric analyses ______
- expert judgment ______
- the analyst's intuition 100 %

What was the general quality of the data? ______

5. PARAMETER ESTIMATION

If they are not given in the publication, where may the reader obtain detailed information on the data transformations, statistical techniques, data acquisition procedures, and results of the tests of fit and significance used in building and analyzing the model? -

6. MODEL PERFORMANCE AND TESTING

Over what period was the model's behavior compared with historical data? 100 weeks

What other tests were employed to gauge the confidence deserved by the model? decision parameter values, objective function value

Where may the reader obtain a detailed discussion of the prediction errors and the dynamic properties of the model? ______

The dynamic properties of the model depend on the decision parameter values. See the paper.

7. APPLICATIONS

What other reports are based upon the model? ______

Name any analysts outside the parent group that have implemented the model on another computer system. ______

List any reports or publications that may have resulted from an evaluation of the model by an outside source. ______

Has any decision maker responded to the recommendations derived from the model? ______

Will there be any further modifications or documentation of the model? yes

Where may information on these be obtained? from the author