

Industrial Dynamics Without DYNAMO

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ABSTRACT

This paper presents an alternative implementation technique for systems models of the type described in J.W. Forrester's book Industrial Dynamics. Methods for converting Industrial Dynamics models written in the specialized language DYNAMO into equivalent State-variable models are presented, and a simple Fortran IV computer program for analyzing the translated models is discussed. A significant advantage of this new technique is that it allows the use of any small computer with a Fortran capability as a research tool for systems dynamics studies, making the field of Industrial Dynamics available to a wider range of institutions than is presently the case.

INTRODUCTION

Industrial Dynamics is defined (1) "as the study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy." Traditionally, Industrial Dynamics models are developed and exercised in a special-purpose computer language called DYNAMO. This paper will present an alternative approach to the use of DYNAMO for a representative system model to illustrate the use of classical state-variable modelling theory (2) to accomplish the same functions using a simple FORTRAN program.

EXAMPLE INDUSTRIAL DYNAMICS PROBLEM

Consider the simple production-distribution system described in (3). The basic system structure and variable name assignments are as shown in Figure 1. Retail Inventory level is supplied by a production system activity shown in this upper portion of the diagram, and retail sales and inventory are shown in the lower portion of the diagram. Retail orders to drive the production process are taken to be an exponentially smoothed function of Retail Sales.

The DYNAMO source code and printed output for the model are also shown in Figure 1. Figure 2 depicts the plotted output produced by the DYNAMO program on a line printer. The program was run on an IBM 360/75 computer.

STATE-VARIABLE SIMULATION APPROACH

The basic DYNAMO operational procedure is simple first order integration of system flow rates variables into level variables. It is possible in many cases to decompose a set of DYNAMO equations into an equivalent state variable system representation through a separation of the rate and level components. For example, the difference equation describing the behavior of Retail Inventory in the example:

$$RI.K = RI.J + (DT) (FP.JK - RS.JK).$$

may be written as a continuous state variable differential equation in the following manner:

$$\dot{RI} = FP - RS, \text{ where } RI \text{ is taken as } \frac{d(RI)}{dt}.$$

similarly, the other "level" variables, including the exponentially smoothed ARS, may be written:

$$\begin{aligned}\dot{F}OB &= RO - FP \\ \dot{A}RS &= (1/TARS) (RS - ARS) \\ \dot{P}A &= (1/TAP) (PI - PA)\end{aligned}$$

Since Factory Production rate is equal to Production Ability, and Retail Orders are set equal to Averaged Retail Sales, two simplified equations can be written:

$$\begin{aligned}\dot{R}I &= PA - RS \\ \dot{F}OB &= ARS - PA\end{aligned}$$

Finally, noting that $PI = FOB/WBD$ from the DYNAMO Model, the equation for Production Ability Rate may be rewritten:

$$\dot{P}A = (1/TAP) (FOB/WBD - PA)$$

The model is now in a form suitable for simulation using a state variable modeling routine (See for example, 4). To avoid the necessity for convolution techniques to handle the control input RS, Retail Sales rate, this input will be absorbed into the system matrix, albeit at the expense of a higher dimensional system.

Let RS be a step input at time zero. Then, a fifth state variable may be written describing the behavior of this input in the following manner:

$$\dot{R}S = 0,$$

with $RS(0) =$ desired input level at time 0.

The augmented system is now of dimension 5, and may be written:

$$\begin{bmatrix} \dot{R}I \\ \dot{F}OB \\ \dot{P}A \\ \dot{A}RS \\ \dot{R}S \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & -1 \\ 0 & 0 & -1 & 1 & 0 \\ 0 & \frac{1}{(TAP)(WBD)} & \frac{-1}{TAP} & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{TARS} & \frac{1}{TARS} \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} RI \\ FOB \\ PA \\ ARS \\ RS \end{bmatrix}$$

Figure 3 shows the simulation input for the state variable program and the corresponding printed output. Figure 4 depicts the graphical output from the state-variable simulation. Note the high degree of correspondence to the DYNAMO Solutions in the earlier figures. Space does not permit a full development of the underlying theory here, but it can be shown that the numerical solution via the state-space approach is in fact more accurate than that produced by the DYNAMO integration scheme.

CONCLUSIONS

The state variable approach provides a compact, mathematically precise method for system definition. The computer simulation of linear systems described in this manner for non-linear systems with parameters held constant over fixed sampling time intervals is straightforward, and may easily be accomplished without resorting to any of the special purpose simulation languages.

REFERENCES

1. Forrester, J.W., Industrial Dynamics, M.I.T. Press, Cambridge, 1961.
2. Derusso, P.E., Roy, R.J. and Close, C.M., State-Variables for Engineers, John Wiley & Sons, New York, 1965
3. Jarmain, W.E., Problems In Industrial Dynamics, M.I.T. Press, Cambridge, 1973 pp. 118-124.
4. Melsa, J.L., Computer Programs for Computational Assistance in the Study of Linear Control Theory, McGraw-Hill, New York, 1970.

PAGE 2 INVENTORY CONTROL MODEL 1 USING DYNAMO II

PAGE 2

INVENTORY CONTROL USING DYNAMO II 3/04/76

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* ***** ZC000 L J J A R R R
INVENTORY CONTROL MODEL I USING DYNAMD II      RETAIL SALES U/W
ARS=100     AVERAGE RETAIL INVENTORY U
HTS=100     RETAIL INVENTORY U/W
QSS=100     FACTORY PRODUCTION U/W
PSS=100     FACTORY ORDER ABILITY U/W
PA=100      PRODUCTION ORDER BACKLOG U
COR=200     RETAIL ORDERS U/W
WOF=100     TURNS TO AVG. RETAIL SALES W
TAPSE=1     DESIGNED MFG LOG W
TAPSE=2     TIME ADJUST PRODUCTION U/W
ARS.=ARCS.J.(DT)(I)/(TARS) (RS.UK-ARS.J)   AVG. RETAIL SALES
FOR.=FORCJ+(DT)(RC) (JK-FP.CJ)              ORDER BACKLOG
OT.K=RI.(DT)(FP) (K-RS.UK)                   RETAIL INVENTORY
PT.K=PAP.I.(DT) (I/TAP) (PI) (U-D.A.U)       PRODUCTION INDICATED
PC.K=LAPS.K./AD                                RETAIL ORDERS RELATES TO OLD RETAIL SALES
PC.KL=LPS.K.*                                  FACTORY RETAIL SALES INCREASE
PC.KL=LPS.K.*                                  RETAIL PRODUCTION RELATES TO PRODUCTION ACT.
WS.KL=LPS.K.*                                  FACTORY RETAIL SALES INCREASE
DTED=O.I/LB.GTH=50/VRTPEH=1/VPLTPERE=1
RTI=FCR.RC.DA.RS
RTIAA/FCD=3/RD=C/P4=D/RS=F
TESTPGM
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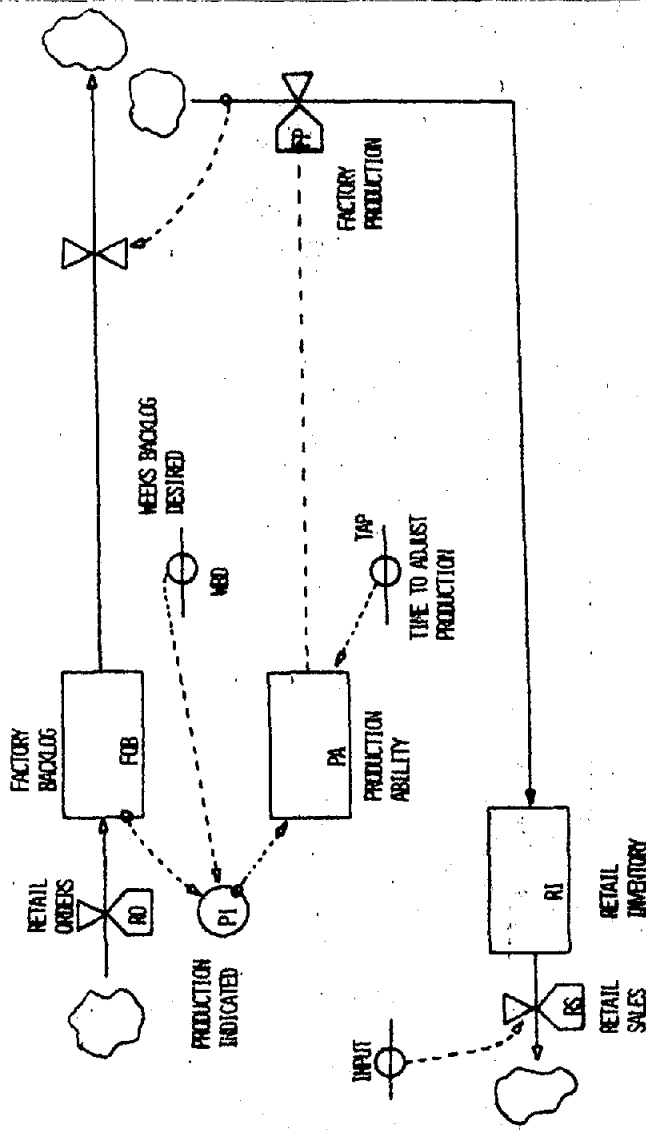


FIGURE 1. SYSTEM STRUCTURE, DYNAMO CODE AND TABULAR DYNAMO OUTPUTS

PAGE 3 INVENTORY CONTROL MODEL I UNIT DYNAMO II 01/16/76 TESTPGM

RI=8,FOB=8,RO=C,PA=D,RS=E

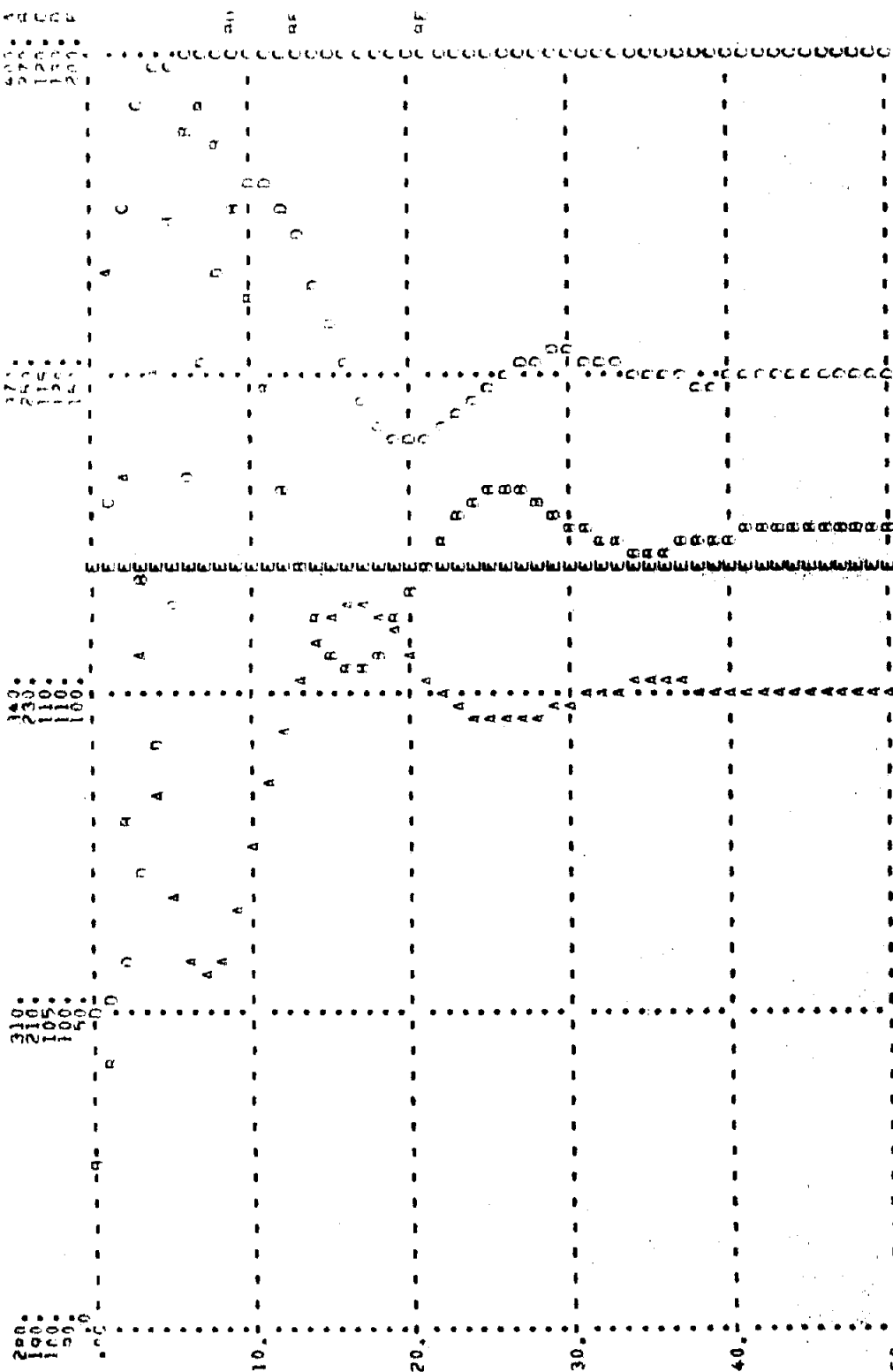


FIGURE 2. DYNAMO PROGRAM PRINTER PLOTTER OUTPUTS
(RI = A, FOB = B, RO = C, PA = D, RS = E)

