

THE DYNAMICS OF A DISTRIBUTION SYSTEM
SIMULATED ON A SPREADSHEET

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ABSTRACT:

The dynamics of a typical production-distribution system, namely from manufacturer to distributors to retailers has been simulated with the aid of Lotus 123 on a personal computer. The original simulation program DYNAMO was run on an IBM 1620 mainframe computer but we successfully converted it to run on a personal computer using LOTUS 123.

This paper deals with problems encountered in using the present MS-DOS limited PC machines to run application programmes written for earlier mainframe machines. It is also shown that results very comparable with those obtained on mainframe machines can be generated on a simple PC.

OPSOMMING:

Hierdie referaat beskryf die ervaring van magisterstudente met die omskakeling van die simulasië-program DYNAMO vir die ondersoek van die dinamika van industriële stelsels van hoofraamrekenaar na 'n persoonlike rekenaar.

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1. INTRODUCTION

Industrial dynamics is the study of the information feedback characteristics of industrial activity to show how organizational structure, policies on orders and inventories and delays in decisions and actions interact to influence the success of the enterprise.

Simulation is widely used to study these phenomena. A model is nevertheless a mathematical representation of a real system and the results are only as good as the underlying assumptions. The model will contribute to a better understanding and changes in the underlying factors may be manipulated by the model to see the effects.

We have taken an existing simulation program called DYNAMO which ran on an IBM 1620 mainframe computer and converted it successfully to run on a personal computer using LOTUS 123. The program, although time consuming, generates the same results and offers us a better understanding of the underlying dynamics of industrial systems. The personal computer also provides us with improved access to this kind of simulation.

2. MODELING

In constructing a useful dynamic model it is essential to have the purpose of the model clearly in mind. Only by knowing the questions to be answered can we safely judge the pertinence of factors to include in or omit from the system formulation.

The system organizational structure takes is a multi-echelon three level production-distribution system. The underlying factors of such a system and its response to various inputs and assumptions regarding the operating doctrines at various levels of the system, are considered.

2.1 INVENTORY POLICY

In a typical enterprise there are policies that govern the placing of orders and the maintaining of inventory for each level. We consider three principal components of orders:

- (a) Orders to replace goods sold,
- (b) Orders to adjust inventories upward or downward as the level of business activity changes and
- (c) Orders to fill the supply pipelines with in-process orders and shipments.

Orders may be treated in the following ways.

- (i) After the sales analysis and clerical delay orders to the next higher echelon include replacement of actual sales.
- (ii) A gradual upward or downward adjustment is made in inventories as the rate of sales increases or decreases.
- (iii) One component of orders in process is necessarily proportional to the average level of business activity and to the length of time required to fill an order.

2.2 EXPONENTIAL DELAY

In order to get an understanding of the transient response of exponential delay consider the particular example of a delay in shipping goods from factory to distributors. This may be visualized by thinking of shipping goods simultaneously by different methods of transportation to a number of different distributors located in various places. This being an "impulse" input we wish to study their rate of arrival at their destinations.

In order to satisfy more obvious characteristics of the actual shipping process 2nd and 3rd order delays are necessary. The output of a first order delay would be the input for a second order delay and so on. The outputs usually take on the form of an exponential unctio. The input for a first order delay is assumed to be a step function .

To refine these delay functions a further study of the actual systems of item-by-item delays and their distribution is necessary.

The DYNAMO simulation program applied the above mentioned inventory policies and exponential delays in this manner.

3. THE DYNAMO MODEL

DYNAMO (DYNAMIC Models) is a special purpose compiler for mathematical modeling of dynamic feedback systems. The DYNAMO language is easily understood with a simple time notation. The output from DYNAMO includes graphic results. It does not require the equations to be in computational order and will create some of the required initial conditions. The error checking facility checks for logical inconsistencies and provides extensive error comments.

DYNAMO consists of approximately 10000 instructions written in machine language. It can handle a model with up to 1400 equations and was designed to run on an IBM 1620 mainframe computer. The time required to run an average model on an IBM 1620 mainframe computer will be approximately 0,2 minutes.

The production-distribution system was simulated on DYNAMO by

Jay W. Forrester and his results reported in his book "Industrial Dynamics" published in 1961.

In the model simulated, the three sectors- retailer, distributor, and factory- are very similar to one another. Two types of variables have been defined- levels and rates. In addition, auxiliary variables were defined.

Levels represent those variables that represent quantifiable quantities if the system was brought to rest. This includes inventories, unfilled orders and orders in transit.

The major rates of flow that are important are the orders from customers, sales to customers, orders and sales between the retailer and distributor.

In addition to levels and rates, there are also important delays that contribute to the system behavior. The principal delays in the rates of flow are delays in filling customer orders, delays in ordering from the distributor, delays of orders in the post and delays in shipping goods to the retailer.

These levels, rates and delays were then combined in a model that represents the behavior of a production-distribution system. The sets of equations were then evaluated for a predetermined time interval, and results monitored and graphed. We found that this solution interval should be less than one-sixth the length of time needed for the delays defined in the system in order to get acceptable definition of the sequence of events taking place.

The model run by Forrester was calculated over a period of 100 weeks, this gave the model enough time to stabilize properly.

In the DYNAMO model all output graphs that are required must be specified beforehand. These graphs are then generated as the model runs. Any changes can easily be accommodated by changing the necessary variables.

4. CONVERTING THE MODEL TO PC

Due to PC's being freely available, we decided to convert the DYNAMO model to run on a PC using the popular spreadsheet programme Lotus 123. The PC used was an IBM compatible machine with dual floppy drive and with 640 Kb memory.

The model was entered in the calculating sequence with the retail sector, distributor sector and factory sector formulae following sequentially. This amounted to a total of 73 rows of formulae, including initial conditions. Provision was made for the delay factors and limiting factors such as potential maximum factory output. Initially the solution interval was kept at 0,05 weeks.

The small solution interval caused the first major problem. The

PC ran out of memory after simulating approximately 20 weeks of history. After varying the solution interval it was found that the maximum value that gave usable results was 0,28 weeks. Any value bigger than this caused severe instability, mainly due to the relatively large change in levels and rates over this time span. This did however, increase the simulation ability to 30 weeks, but this was not enough to stabilize the model. It was clear from the DYNAMO model that approximately 100 weeks of simulation were needed. We decided to split the simulation into two distinct runs, using the final values of the first run as input values for the second run. The Lotus 123 "file extract" facility was used to store the result from each run on a file, and then using the "file combine" facility to draw the values needed for graphical results. This procedure was totally driven by macros.

The system of combining files had definite time advantages in loading the program, but the memory capabilities of the drive limited its effectiveness. Only limited critical information, such as ordering rates could be stored, which hampered investigation of Industrial Dynamics. In addition, a large number of data points were generated and stored. With a solution interval of 0,2 weeks, 500 data points were stored for a 100 weeks for a single variable. A method had to be found to only store the necessary number of data points per variable while generating all variables. The minimum acceptable memory capability would be a 75 x 100 matrix which could easily be accommodated on a PC.

Using a series of copy, range values and delete functions, the weekly increments could be calculated singularly. For example, using a solution interval of 0,2 weeks, the calculations are copied for the five days (0,2 weeks = 1 day), and four of the days data is then erased to get the end-of-week data. Although this severe runtime is long, (50 minutes per run), it would enable the user to extend the data to at least 100 weeks on a standard 640 K PC. The logic of incremental steps is also sound in that limited week generation is possible.

Interesting enough we found that even extended runtimes for simulation is not a practical problem on a personal computer - the problem is simply set to run overnight or at any other time the machine is not needed.

5. BRIEF USER'S MANUAL

Although the program is powerful, it is very simple to use. The program is menu-driven and figure 1 below gives the menu structure created for this programme:

UNLIMITED	LIMITED	REGENERATE	SHOW	QUIT
STEP	RANDOM	GRADUAL	PULSE	

Figure 1: Menu Structure

5.1 DESCRIPTION OF FUNCTIONS:

- UNLIMITED** Unlimited factory capacity is chosen.
- LIMITED** Factory capacity will be limited to the entered amount.
- REGENERATE** Once a run has been made, the data has largely been valued (No formulae are present and a change in inputs would not change the end results). The regenerate function is responsible for returning the program to its original size and function, otherwise necessary data will be erased.
- SHOW** This enables users to enter the variables area of the program to make changes to delays, solution intervals and other constants.

QUIT Quits Lotus 123.

The next set of functions are specific for the demand curves. They were written to correspond to the structure of the original program.

- STEP** The demand will show a step increase/decrease. The value of the step must be entered with consideration of the initial retail requisition.
- RANDOM** The demand will be according to a random distribution that must be typed in. Use of the Lotus 123 random function (@RAND) must be used to obtain different distributions.
- GRADUAL** This is a straight line increase. Because data is inputted on a daily basis (Solution interval $DT = 0.2$ weeks), the weekly increase must be multiplied by the solution interval and entered as a formula in Lotus 123 format.
- PULSE** The demand will pulse once before returning to the initial requisition level. Again the program has an input option.
- ALT-M** Generates program menu.
- ALT-G** Generates graphs again after completion of run. The save these graphs for printing, the user must enter the Lotus 123 framework and save under a unique name for each run.

5.2 MODIFICATION OF THIS PROGRAM

We foresee that the user would want to modify the program according to his own requirements. Anyone with knowledge of Lotus 123 macro execution would easily be able to do these modifications. This would also ensure that restrictions caused by large menus will be removed.

Two possible modifications, for example, are to input real data and to limit the number of weeks to be generated. The former will require the conversion of data to the corresponding solution interval and probably the use of file inputs. The latter is accomplished by changing the counter setting. In both cases it emphasizes the simplicity of modifications.

6. TEST RESULTS

Using the same values used in DYNAMO which are representative of a consumer-durable product line in inventory policy and exponential delay, we show multi-echelon response of the converted program for certain test conditions. Figures 2 and 3 show multi-echelon response for a 10% step increase in retail sales figures for order rates and inventory levels respectively.

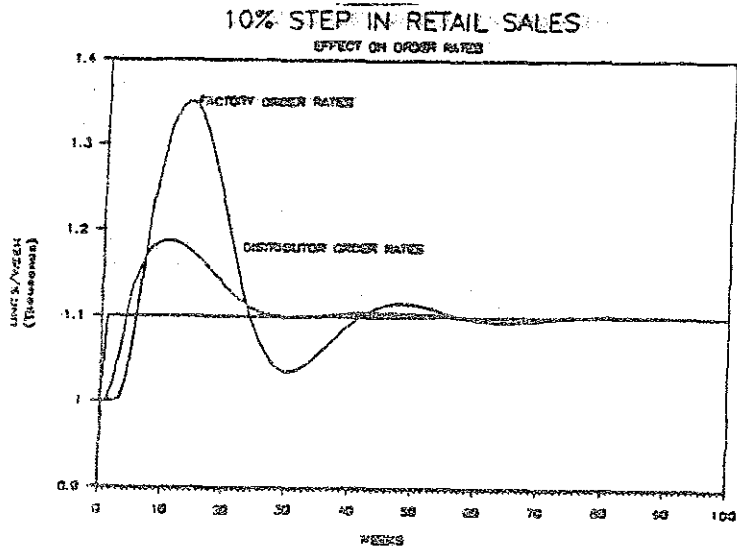


Figure 2

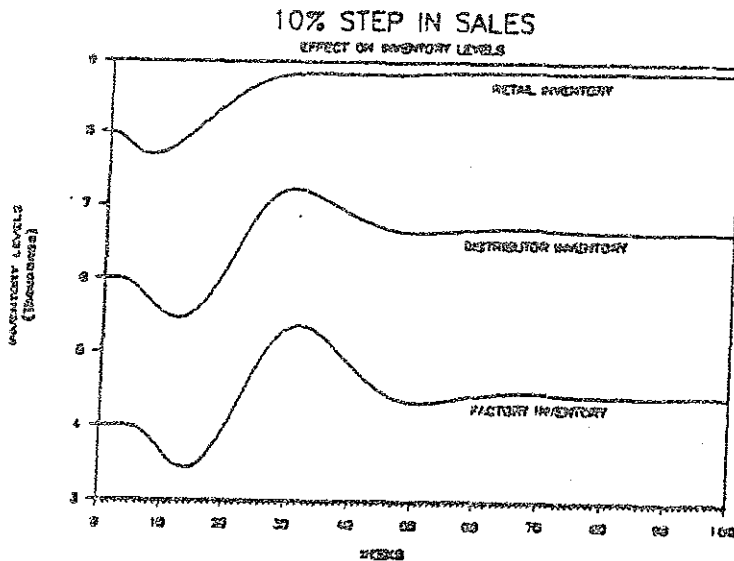


Figure 3

Deviations are amplified for each higher echelon in the production-distribution system. All order rates and inventory levels tend to stabilize at the new level respectively, but the time needed to stabilize increases along the echelon chain.

Similarly the multi-echelon response with limited factory capacity (1200 units/week) for a 10% step increase in retail sales figures is shown in figures 4 and 5 for order rates and inventory levels respectively.

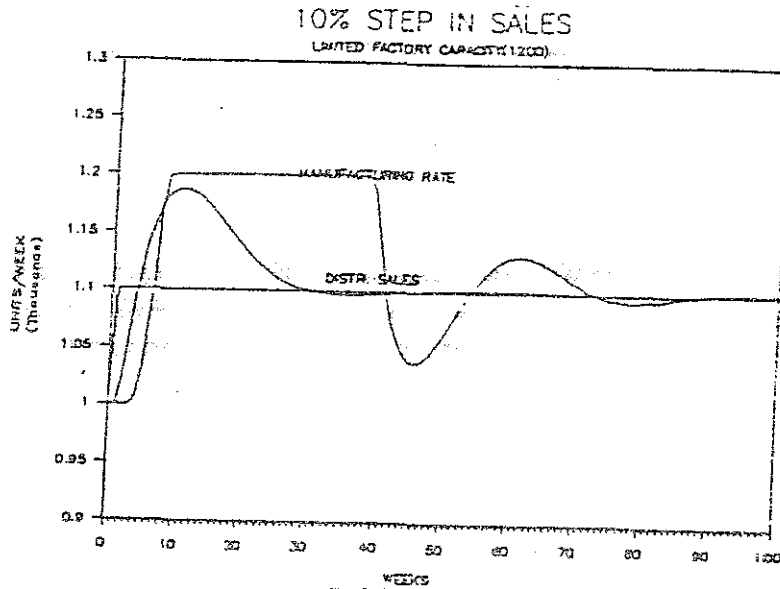


Figure 4

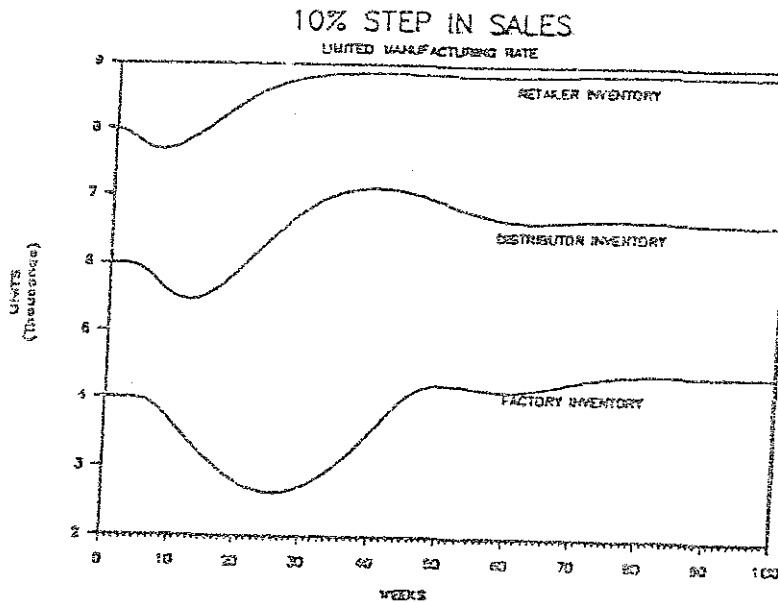


Figure 5

The factory limit has caused incoming orders and inventory at the factory to reach stability over a wider range than before. The factory inventory remains at a lower level than its initial level for longer than before while the limited manufacturing rate stays at a peak in order to satisfy increased demand.

These test results compare directly to results obtained under similar conditions using DYNAMO, thus proving a successful conversion. Furthermore we have shown positive conversion with other test conditions such as 1) 10% pulse in retail sales, 2) Random fluctuations in retail sales and 3) Gradual increase in retail sales. Further practical situation tests are needed to fully evaluate this success.

7. PROJECTED APPLICATION AREAS

The DYNAMO simulation program is merely a tool to investigate fluctuations in industrial activity, but before utilizing it in that field we must first understand its background.

The projected application areas are therefore divided into two categories namely theoretical and practical. The former investigating the underlying factors to Industrial Dynamics and the latter contributing to the understanding and utilization of Industrial Dynamics.

Once the proportions of Industrial Dynamics are well understood this program may be applied to a practical situation offering the user a vantage point from which to see inside the framework in which he is dealing, he may then use this information to streamline his ordering policies and delays to improve operating characteristics. The user may be anyone within the multi-echelon chain.

REFERENCES

1. Forrester, J.W. "Industrial Dynamics." Massachusetts Institute of Technology, Massachusetts, 1961.
2. Alexander, L.P. "Dynamo User's Manual" The MIT Press, Massachusetts, 1963.