A SYSTEM DYNAMICS MODEL OF THE U.K. CONSUMER DURABLES MANUFACTURING INDUSTRY : SOME PRELIMINARY RESULTS

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ABSTRACT

The paper describes a system dynamics model of the consumer durables manufacturing industry in the United Kingdom. The model purpose is to analyse the causes and effects of cyclical fluctuations in the industry with a view to encouraging government or operational policies that might improve industry stability. The paper extensively examines the consumer durables industry and explains the model in detail, each equation being accompanied by an account of its construction. The results of simulation experiments conducted on the model using various test inputs are described. The paper appraises the technique of spectral analysis, which has served as one means of assessing model validity. The model, once validated, should form part of a larger model which will also represent the steel stockholding and steel manufacturing industries. Work on the larger model is in progress.

CONTENTS

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Appreciation of the financial support provided by H.M. Treasury and (in part) by the Institute of Purchasing and Supply is warranted because without these funds no fieldwork would have been possible, no initial descriptive report on the industry would have been prepared, and no spark would have been ignited to enflame my curiosity toward the system dynamics methodology.

I. THE FRAMEWORK OF THE STUDY

The work described here evolved from research commissioned by Her Majesty's Treasury into the reasons for and the effects of inventory fluctuations in manufacturing industry in the United Kingdom. Some earlier studies, mostly employing econometric techniques, were conducted at precisely that level of aggregation : the whole of the U.K. manufacturing industry. Our study is different in four major respects:

(a) Restricting the work to an examination of inventory fluctuations alone seemed undesirable. An approach which isolated inventory fluctuations from fluctuations in production, sales, and other factors could not be justified.

(b) A single, coherently defined industry was investigated. Models of the total industrial sector mask the common phenomenon that one industry may experience a cyclical reversal of its demand trend as much as 9-12 months or more before another separate industry.

(c) Our study relied upon system dynamics. System dynamics is better suited to modelling a complex closed-loop feedback system and to assessing the effects of alternative policy decisions by government, the industry, or both.

(d) Working at the industry level permitted extensive fieldwork, in the form of interviews with involved executives. These discussions helped provide a descriptive knowledge of the industry's structure and operational policies.

The consumer durables industry becomes more important as a developed economy expands. (The volume of total retail sales increased by 36.3 percentage points from 1958 to 1973, while the volume of durable goods shop sales and new car registrations increased by 74 and 90.8 percentage points, respectively, over the same period).[4] Therefore, to achieve greater stability in the economy generally, the government should move toward effectively stabilizing the apparent fluctuations in the consumer durables industry. Demand for many non-consumer products has its source in demand originating in the consumer durables industry (the well-known "accelerator effect" described by economists).[15] A reduction in fluctuations apparent in that industry would go far towards reducing fluctuations in other, interconnected industrial sectors.

Published applications of system dynamics to problems of instability at this level of aggregation are relatively few. Forrester's early work was largely concentrated at the level of the individual firm,[7] and more recently at the level of the national economy. However, attempts to reduce instability at the national level might be best carried out by a detailed examination of government policies toward the major constituent industries of the economy and toward the consumer durables industry in particular.

The consumer durables manufacturing industry in the U.K. consists of firms producing a variety of products ranging from expensive motor cars to small electric toasters. However, the nature of the particular firm's product is rather less important here than the fact that the industry as a whole is among the first to feel the effects of such government reactions to demand as changes in tax and/or credit controls.

Successive governments in the U.K., as part of their overall efforts to regulate the economy, have isolated the consumer durables industry for a succession of policy changes. (The increase in Value Added Tax to 25% for domestic electrical goods in the April 1975 Budget is typical)*. However, people familiar with the industry have persistently complained that this treatment in the long run does individual firms (and the economy) a great deal of harm.[3] Prices and income elasticity of demand for durables is significantly higher than for consumables, and consequently the frequent tax/credit changes generate fluctuations of considerable amplitude in the demand for durables.

H Ingham[9] provides an apt general description of the type of firm studied and visited during our research. Ingham refers to firms in the Type 1 category as follows:

> "Offering a small range of standard products of the firm's own choice, specification and design. The products are made for stock in anticipation of orders because a considerable current and probably continuing demand for them is assumed to exist".

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*To further illustrate this point, the same rate was halved to 12½% in the April 1976 Budget.

In terms of the Standard Industrial Classification (S.I.C.*) index, the firms visited during the fieldwork can be described as follows:

Table 1. Table of numbers of firms visited in relevant Minimum List Heading categories

Number of firms visited	S.I.C. Minimum List Heading	Description
8	368	Electric appliances primarily for domestic use
6	399/9	Domestic gas appliances
3	381	Motor vehicle manufacturing
3	365/2	Broadcast receiving equipment
1	339/4	Space heating, ventilating and air conditioning equipment
1	339/9	Other machinery
1	351	Photographic equipment
1	399/12	Miscellaneous metal goods
24		

In any system dynamics study, the initial phase must be devoted to acquiring knowledge of the structure and operational policies characterizing the system of interest. This initial phase, although all too often not accorded sufficient importance, can generate quite considerable difficulties.

In the project described here, considerable time was allocated to this particular initial aspect. Accordingly, several firms in the consumer durables manufacturing industry were invited to cooperate in the study. The response rate was low, but although our request entailed spending up to three days at each firm during a boom period in the cycle, within one year (January 1972-January 1973) 24 firms had been visited and 119 executives interviewed.

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*The Standard Industrial Classification index is a method of classifying activities that go on at places where people work; it is based on the types of products made or the service given at each place. Set up by U.K. government statisticians in 1948 it is revised every 10 years. The 1968 edition covers 181 Minimum List Headings which are written as 3(or 4) digits. Minimum List Headings for Vehicles (e.g.) are from 380-389 while those for Mechanical Engineering are from 331 to 349.

The interviews were structured around a preprepared questionnaire which served primarily as a catalyst for discussion. Such departments as Production Planning, Purchasing, Production Control, Marketing, and Distribution delegated their personnel and, although political factors appropriate to individual firms tended to taint some responses, by the end of the year a collective written description of how a typical firm in the consumer durables manufacturing industry operates had been prepared.[6] Much of the information obtained was qualitative, but such data has been especially useful in determining the broad shape of table functions contained in our model.

The reference mode which it is the purpose of the model to depict is an oscillating pattern of behaviour which conforms to the periodicity of the typical business cycle. The organising concepts which give rise to this type of behaviour are shown in Figure 1 which is a much-simplified influence diagram of the model as described in Section II.

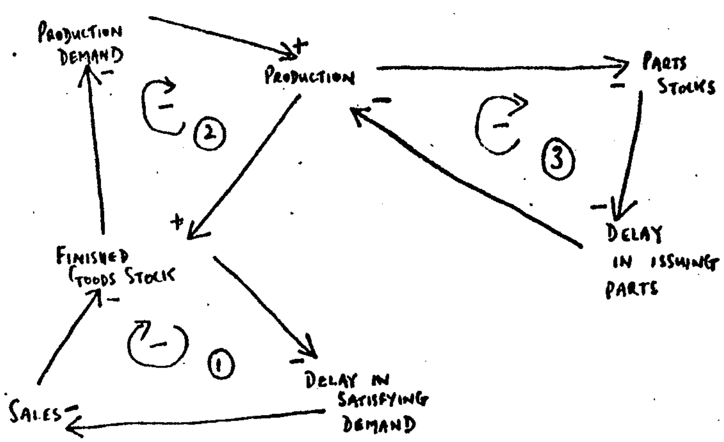

Figure 1. Influence diagram depicting organising concepts within the model

The interplay of three significant negative feedback loops is responsible for the observed oscillations. For example, an increase in the sales rate will lead to a decrease in the stock of finished goods and thereby an increase in the delay in satisfying demand. This in turn will cause a corresponding decrease in sales back towards the original rate.

The fall in the level of stocks of finished goods will cause an increase in production designed to correct the shortfall of stock. After a delay in manufacture these goods will be available to replenish the industry's finished goods stocks. The equations incorporating the variables in these negative feedback loops (loops 1 and 2: Figure 1) are discussed in Part A of the following section. Part A deals with the marketing and production planning sectors of the model.

Loop 3 in Figure 1 is covered in Part B which describes the materials management sector. This negative loop shows that an increase in production, designed to rectify the shortfall of finished goods stock, leads to a reduction in the stocks of available parts and materials with the result that the delay in issuing parts increases thereby in turn bringing about an eventual decrease in production.

II. DESCRIPTION OF THE MODEL

The model is designed to simulate the effect of changes in demand for industry products on production, stocks, and the derived demand for parts from supplying industries. Demand for industry products is an exogenous variable.

Appendix I provides a DYNAMO flow diagram of the model, showing the interrelationships in the consumer durables manufacturing industry. These interrelationships include variables and interactions commonly acknowledged in the literature, as well as others established by observation of the system through fieldwork at the 24 firms mentioned earlier. Particular numerical values, where quoted, are based on information obtained through the fieldwork. The model equations are written in the DYNAMO language, with units expressed as equivalent product units at constant prices. Time is expressed in months. A documentor listing of the current version of the model is presented in Appendix III, with an on-line listing in Appendix IV.

To understand the model, the logic underlying the important equations must be understood. The explanation offered here begins with the sales/demand input and works backwards to the purchasing of replenishment parts and materials from other industries.

A. The marketing and production planning sectors

The flow into the industry of orders, in this case originating from the distributive trades, has been designated the primary demand rate PDR in the model. The equation for this variable is:

R	PDR.KL	=	PDRI + STEP (STH,STT)
	PDR	=	Primary Demand Rate (units/month)
	PDRI	=	Primary Demand Rate Initially - 1000 (units/month)
	STH	=	STep Height = 200 (units/month)
	STT	=	STep Time = 12 (months)

This equation permits the modeller to introduce a STEP input function* to investigate the effects of an arbitrary 20% increase in primary demand.

*A STEP function in the DYNAMO language has the form

X = STEP (H,T) STEP = 0 if TIME <T
  STEP = H if TIME ≥T

While a real-world analogy is unlikely to be found, a change of this nature approximates the situation attendant upon significant reflationary action by the government such as the stimulation of consumer spending. On such occasions, although the consumer durables manufacturing industry experiences a sudden external shock, the actual change in demand is unlikely to be so abrupt. The primary reason for using a simple input signal to drive the system is to simplify the task of analyzing system behaviour.

The delay in satisfying primary demand DSPD is inversely proportional to the ratio of actual to normal finished goods stocks (AFGS/NFGS), and is assumed to vary as indicated in the table function* below. The delay is least, equal to the average time required to process orders (1 month), when actual stocks are 50% more than normal. However, when stocks diminish, as during the boom phase of the economic cycle, the delay in supplying goods from stock increases. For example, the table function shows that the industry takes, on average, 9 months to satisfy demand when the ratio of actual to normal stocks falls to 0.25.

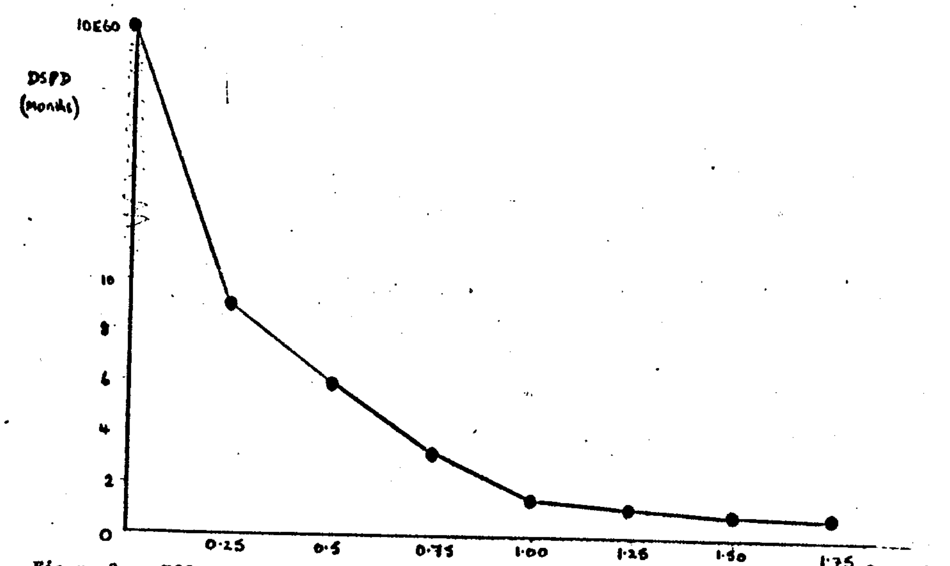

Figure 2. Effect of finished goods stock availability on the delay in satisfying primary demand

*Table functions are an extremely useful feature of the DYNAMO programming language. They enable the modeller to incorporate non-linear relationships in a model. Moreover, they frequently permit an interpretation of qualitative data, which otherwise might be neglected. But qualitative data can often at least indicate the overall shape of the function. Then even if the particular values of the function cannot be justified directly, the sensitivity of the system to changes in the assumed values can be tested prior to a substantial expense of effort on their accurate determination.

The value of 10E60, for the delay in satisfying primary demand when the ratio of actual to normal finished goods stock is zero, is used in the computer program to represent infinity. Although that portion of the curve is not usually operational, if the model is subjected to a large enough shock, low values for DSPD can cause AFGS to assume negative values through the operation of the equation for the sales rate SR.

A	DSPD.K	=	TABHL (TAB6, AFGS.K/NFGS.K, 0, 1.75, 0.25)
T	TAB 6	=	10E60/9/6/3.25/1.5/1.25/1/1
	DSPD	=	Delay in Satisfying Primary Demand (months)
	AFGS	=	Actual Finished Goods Stock (units)
	NFGS	=	Normal Finished Goods Stock (units)
	TAB6	=	Table of delay in satisfying primary demand (months)

The sales rate SR from the consumer durables manufacturing industry to their customers (almost wholly in the distributive trades) is shown as the primary demand rate backlog PDRB divided by the delay in satisfying primary demand DSPD. For a given backlog, as the delay in meeting demand increases, the sales rate decreases.

R	SR.KL	=	PDRB.K/DSPD.K
	SR	=	Sales Rate (units/month)
	PDRB	=	Primary Demand Rate Backlog (units)
	DSPD	=	Delay in Satisfying Primary Demand (months)

Production demand PRD, one of the most important decision functions in the system, expresses the rate of planned industry output. Our fieldwork suggests that PRD contains two components viz. an amount based on current forecasts which could be expected to be sold, and an amount to adjust any discrepancy in the finished goods stock. The delay in adjusting finished goods stock DAFGS increases as the ratio of actual to normal finished goods stock approaches 1.5 and thereafter is constant.

A	PRD.K	=	MFS.K + ((NFGS.K - AFGS.K) / DAFGS.K)
	PRD	=	Production Demand (units/month)
	MFS	=	Modified Forecast of Sales (units/month)
	NFGS	=	Normal Finished Goods Stock (units)
	AFGS	=	Actual Finished Goods Stock (units)
	DAFGS	=	Delay in Adjusting Finished Goods Stock (months)

In aggregate production planning, firms face a choice between keeping production steady while allowing finished goods stock to absorb any sales rate variations, or keeping tight control of finished goods stock levels while allowing production to fluctuate. In the consumer durables industry, firms unanimously opt for the former course of action. The preference for steady production is reflected in the increase in the finished goods stock adjustment delay, described in more detail below. The increased delay has the effect of mitigating any sharp downturn in planned production.

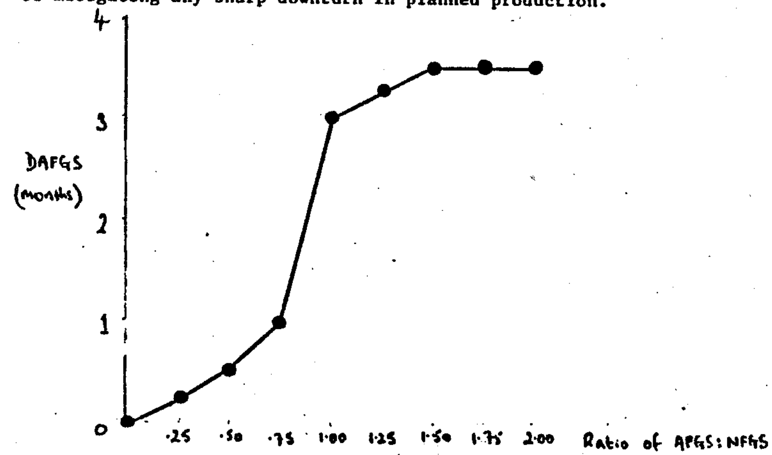

Figure 3. Effect of finished goods stock availability on the finished goods stock adjustment delay

The delay in adjusting finished goods stock DAFGS is shown in Figure 3. The table shows that DAFGS increases as the ratio of actual to normal finished goods stock increases to 1.5 and thereafter DAFGS is constant at 3.5 months. The delay increases sharply as the ratio of actual to normal finished goods stock increases from 0.75 to 1.0. This reflects the industry's desire to avoid sharp cuts in planned production as finished goods stock builds up when demand falls off.

A	DAFGS.K	=	TABHL (TAB1, AFGS.K/NFGS.K, 0, 2, 0.25)
T	TAB1	=	0/0.25/0.5/1.0/3.0/3.3/3.5/3.5/3.5
	DAFGS	=	Delay in Adjusting Finished Goods Stock (months)
	AFGS	=	Actual Finished Goods Stock (units)
	NFGS	=	Normal Finished Goods Stock (units)
	TAB1	=	Table of delay in adjusting finished goods stock (months)

All firms in the industry employ sales forecasts as a starting point for planning production. Therefore a forecasting routine has been built into the model. The equation for the raw forecast of sales RFS extrapolates by determining the slope of the smoothed (delayed) sales curve, and then uses this slope to calculate the change in sales over the forecasting horizon. This procedure is representative of the largely unsophisticated forecasting methods common within the industry. In certain situations in the model, the forecasting equation is subject to modification, as explained below.

A	RFS.K	=	SS.K + FH * ((SS.K - PSS.K)/CSPS)
	RFS	=	Raw Forecast of Sales (units/month)
	SS	=	Smoothed Sales (units/month)
	FH	=	Forecast Horizon = 3 (months)
	PSS	=	Past Sales Smoothed (units/month)
	CSPS	=	Constant for Smoothing Past Sales = 1 (months)

Modifications to the raw forecast of sales are treated by multiplying the raw forecast by the factor for adjusting raw forecast of sales FARFS.

A	MFS.K	=	RFS.K * FARFS.K
	MFS	=	Modified Forecast of Sales (units/month)
	RFS	=	Raw Forecast of Sales (units/month)
	FARFS	=	Factor for Adjusting Raw Forecast of Sales (dimensionless)

FARFS is represented by a table function (Figure 4) which is operational in the model when smoothed primary demand SPD exceeds smoothed sales SS or is less than 75% of smoothed sales. (Smoothed values of the variables are employed to reduce the magnitude of random disturbances in the ratio. Smoothing the variables ensures that only significant and continuing changes are taken into account in any adjustment of the raw sales forecast). Smoothed primary demand SPD can easily exceed smoothed sales SS when the government reduces personal taxation or eases credit controls. The consumer durables manufacturing industry knows from past experience that the effect of such a decision will be a fairly rapid increase in demand. They need not wait until a shift in the sales trend appears on the historical sales graph.

Governmental tightening of credit restrictions has the opposite effect, but the equation for FARFS assumes no modification to the raw forecast of sales RFS unless smoothed primary demand SPD is less than 75% of smoothed sales SS. In other words, any downward shift in the primary demand rate PDR will not be reflected in a modified forecast of sales MFS (and, therefore,

an altered production demand) unless the shift is relatively severe. This reasoning coincides with the industry's policy of delaying production cutbacks for as long as possible.

A	FARFS.K	=	TABHL (TAB2, SPD.K/SS.K, 0, 2, 0.25)
T	TAB 2	=	0/0.5/0.75/1/1/1.2/1.4/1.6/1.8
	FARFS	=	Factor for Adjusting Raw Forecast of Sales (dimensionless)
	SPD	=	Smoothed Primary Demand (units/month)
	SS	=	Smoothed Sales (units/month)
	TAB2	=	Table of factor for adjusting raw forecast of sales (dimensionless)

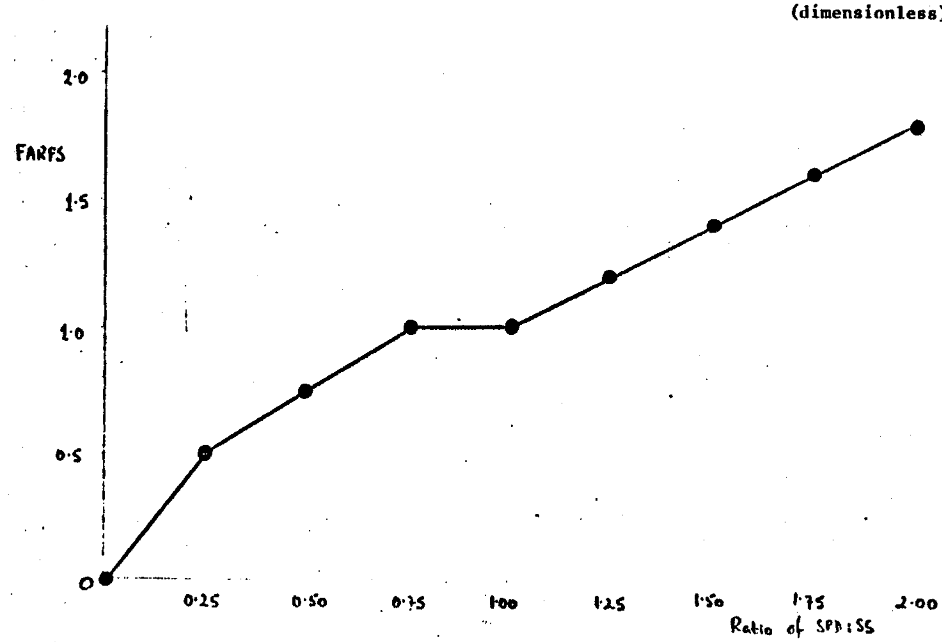

Figure 4. Factor for adjusting the raw sales forecast following a marked change in demand

The SMOOTH* function is employed to first delay the signal for the sales rate SR and then delay the smoothed sales SS. Alternatively, past sales smoothed PSS can be viewed as a "doubled-smoothed" version of the sales rate. The equations are smoothed because decisions in industry are based on information about rates which is averaged (smoothed) over a period of time, rather than on instantaneous rates which by their very nature would be impossible to measure anyway.

*The SMOOTH function has the form X = SMOOTH (IN,DEL) where IN = input and DEL = smoothing constant or delay. It provides a way to exponentially smooth a quantity.

A	SS.K	=	SMOOTH (SR.K,CSS)
A	PSS.K	=	SMOOTH (SS.K, CSPS)
	SS	=	Smoothed Sales (units/month)
	SR	=	Sales Rate (units/month)
	CSS	=	Constant for Smoothing Sales = 3 (months)
	PSS	=	Past Sales Smoothed (units/month)
	CSPS	=	Constant for Smoothing Past Sales = 1 (months)

The production rate PR is a delayed version* of the parts issuing rate PIR. All consumer durables firms manufacture their products by an assembly-type operation on the constituent parts. Thereby, the flow of products from the end of the assembly line can be viewed as a delayed version of the parts issued at the beginning of the production lines.

R	PR. KL	=	DELAY 3 (PIR.K, DPR)
	PR	=	Production Rate (units/month)
	PIR	=	Parts Issuing Rate (units/month)
	DPR	=	Delay in Production = 3 months

Our fieldwork showed that, averaged over all the investigated firms, desired finished product stocks were the equivalent of 6 weeks (1.5 months) average sales. Such stocks may not necessarily be held at the factory but may be dispersed among one or more distribution depots. For this reason the normal finished goods stock holding NFGSH was set at 1.5 months and the normal finished goods stock at the equivalent of 1.5 months long term sales rate LTSR. The long term sales rate was found to be a fairly long term average of the sales rate and has been represented by smoothing the sales rate using a 12 month smoothing constant.

A	NFGS.K	=	NFGSH * LTSR.K
A	LTSR.K	=	SMOOTH (SR.K,CLTS).
	NFGS	=	Normal Finished Goods Stock (units)
	NFGSH	=	Normal Finished Goods Stock Holding = 1.5 (months)
	LTSR	=	Long Term Sales Rate (units/month)
	SR	=	Sales Rate (units/month)
	CLTS	=	Constant for Long Term Sales = 12 (months)

*The DELAY 3 function performs much the same operation as the SMOOTH function. However, DELAY 3 is employed to delay physical flows, whereas SMOOTH is employed to delay information flows.

B. The materials management sector

Having described the main equations relating to sales and aggregate production planning, we can now move backwards in the manufacturing operation to the equations embodying materials management.

The majority of firms in the industry pursue a requirements planning procedure which involves exploding the aggregate production plan into all the constituent parts and materials required for assembly of finished products. The parts demand rate equation reflects this procedure: the parts demand rate PADR is a delayed version of production demand PRD. The model specifies a constant 1-month delay to allow for the clerical procedures entailed in receiving and exploding an aggregate plan and tabulating parts requirements. Obviously, some firms with computerised systems may be able to conduct this operation much more quickly, but an average delay of 1 month seems reasonable for the industry as a whole.

R	PADR.KL	=	DLINF 3 (PRD.K, DEXPRD)
	PADR	=	PArts Demand Rate (units/month)
	PRD	=	PRoduction Demand (units/month)
	DEXPRD	=	Delay in EXploding PRoduction Demand = 1 (month)

The equation for RDPR represents industry demand for parts and materials, and takes the same form as the equation for production demand. The replenishment demand for parts rate RDPR contains two components: the parts demand rate PADR satisfies current demand, and the variables ((NPS-APS)/DAPS) account for stock adjustment. The adjustment delay in the latter term increases as actual parts stocks APS exceeds normal parts stocks NPS.

The MAX function* employed in the RDPR equation prevents negative values for RDPR. In some preliminary runs, negative values of the stock adjustment term have exceeded the current demand for parts. Such negative values, when multiplied by -1.0, represent cancelled orders for parts and materials. However, although cancelled orders could be straightforwardly incorporated in the model, for the time being the model uses a value of zero whenever the RDPR equation goes negative. By implication then, in some time periods no orders for parts and materials are sent to suppliers.

*A MAX function in DYNAMO has the form

X = MAX (P,Q) where MAX = P if $P \geq Q$ and MAX = Q if $P < Q$

R RDPR.KL = MAX (0,PADR.JK + ((NPS.K - APS.K)/DAPS.K))

RDPR = Replenishment Demand for Parts Rate (units/month)
PADR = PArts Demand Rate (units/month)
NPS = Normal Parts Stock (units)
APS = Actual Parts Stock (units)
DAPS = Delay in Adjusting Parts Stocks (months)

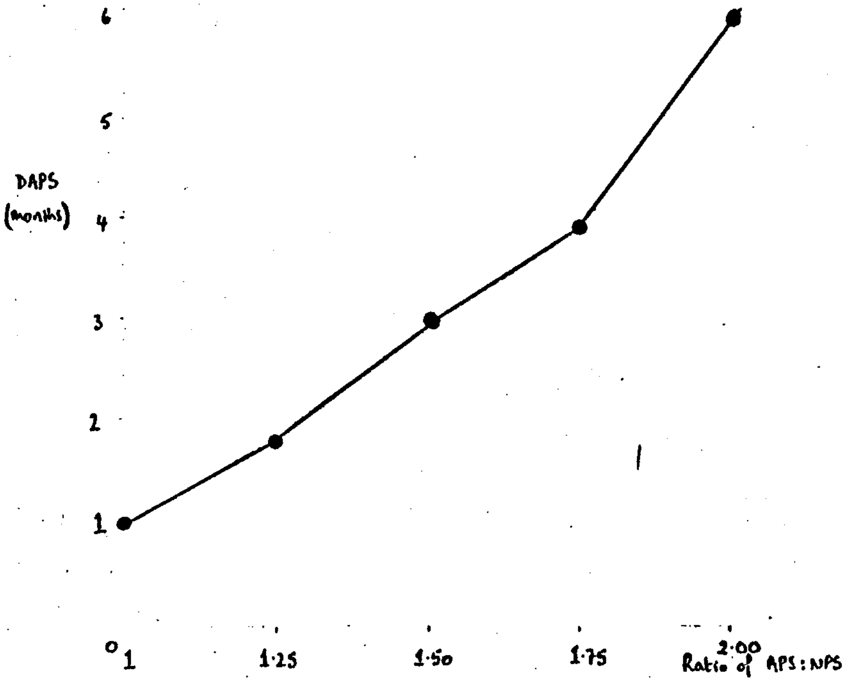

Figure 5. Effect of parts stock availability on the delay in adjusting parts stocks

From a minimum length of 1 month when actual parts stocks APS are less than or equal to normal parts stocks NPS, the delay in adjusting parts stocks DAPS increases to 6 months when actual parts stocks are twice the normal requirement. This is depicted in the table function in Figure 5.

Firms may actually be able to adjust stock deficiencies more quickly than the 1-month minimum figure used here. For example, they can contact their respective suppliers by telephone and so short-circuit the once-monthly requirements scheduling process. While acknowledging this practice, especially during the boom phase of the cycle, such a refinement has been omitted for the present, particularly since the model does not yet include a variable lead time for parts and materials.

The increase in the delay in adjusting parts stocks DAPS to 6 months reflects the fact that firms in the industry want to retain the goodwill of their suppliers when demand is depressed. Lengthening the adjustment delay prevents any marked reduction in demand for supplies.

A DAPS.K = TABHL (TAB3, APS.K/NPS.K, 1, 2, 0.25)
T TAB3 = 1/1.8/3.0/3.9/6.0

DAPS = Delay in Adjusting Parts Stocks (months)
APS = Actual Parts Stocks (units)
NPS = Normal Parts Stocks (units)
TAB3 = Table of delay in adjusting parts stock (months)

The equation for PRR may embody a shortcoming of the current version of the model. The equation below describes the parts receiving rate PRR as a delayed version of the replenishment demand for parts rate RDPR. The average delay is set at 3 months. Obviously, the lead time on parts/materials cannot be constant, especially since a characteristic of boom conditions in the economy is a lengthening of lead times with a consequent effect on order rates.

R PRR.KL = DELAY 3 (RDPR.JK, DRRP)

PRR = Parts Receiving Rate (units/month)
RDPR = Replenishment Demand for Parts Rate (units/month)
DRRP = Delay in Receiving Relenishment Parts = 3 (months)

Stocks of parts and materials held by firms are proportional to their use in production. Therefore, the normal parts stocks NPS equals a number of months of normal parts stockholding NPSH multiplied by the smoothed production demand SPRD. In other words, the industry tries to maintain a parts/materials stock that will cater for a certain number of months of average production.

A NPS.K = NPSH.K * SPRD.K

NPS = Normal Parts Stocks (units)
NPSH = Normal Parts Stock Holding (months)
SPRD = Smoothed PRoduction Demand (units/month)

Firms in the industry are galvanized into strict control of parts/materials stocks in times of tight liquidity. During such periods, in order to preserve cash flow, the growth of stock levels must be contained. Usually, as a result, senior management issues directives to reduce stock holdings. In the main, parts/materials stocks are the focus of attention, since attempts to cut finished goods stocks are inextricably bound up with aggregate production planning.

The particular mechanisms adopted to improve control of parts/materials stocks range from creating a more efficient data base on stock levels, purchases, and usage rates to the use of decision rules designed from operational research investigations. In most cases, improved procedures should have a lasting benefit on firms within the industry, although, no doubt, pressures to contain stock levels are very much less in the boom phase of the cycle when cash flow is usually healthy.

To incorporate this important stock control feature into the model, normal parts stockholding NPSH is related to the ratio of the smoothed parts receiving rate to smoothed sales (SPRR/SS) by means of a table function. According to the table, when sales are sufficient to generate cash to pay for purchases, normal parts stockholding is 3 months. However, if sales fall off for any reason, and parts/materials continue to be delivered, the pressures on cash flow reduce the normal parts stockholding. The table function is shown in Figure 6.

A	NPSH.K	=	TABHL (TAB4, SPRR.K/SS.K, 1, 2, 0.25)
T	TAB4	=	3/2.75/2.5/2.0/1.0
	NPSH	=	Normal Parts StockHolding (months)
	SPRR	=	Smoothed Parts Receiving Rate (units/month)
	SS	=	Smoothed Sales (units/month)
	TAB4	=	Table of normal parts stockholding (months)

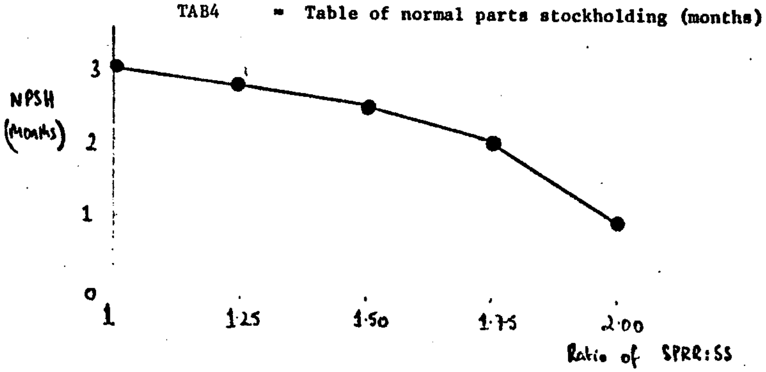

Figure 6. Effect of liquidity changes on normal parts stockholding

For a given parts demand rate backlog PADRB the parts issuing rate PIR is inversely proportional to the delay in issuing parts DIP. This equation, identical in form to that for the sales rate, represents the effect of changes in the delay in issuing parts (resulting from variations in stock availability) on the ability of the industry to issue parts for assembly into finished products.

R	PIR.KL	=	PADRB.K/DIP.K
	PIR	=	Parts Issuing Rate (units/month)
	PADRB	=	PArts Demand Rate Backlog (units)
	DIP	=	Delay in Issuing Parts (months)

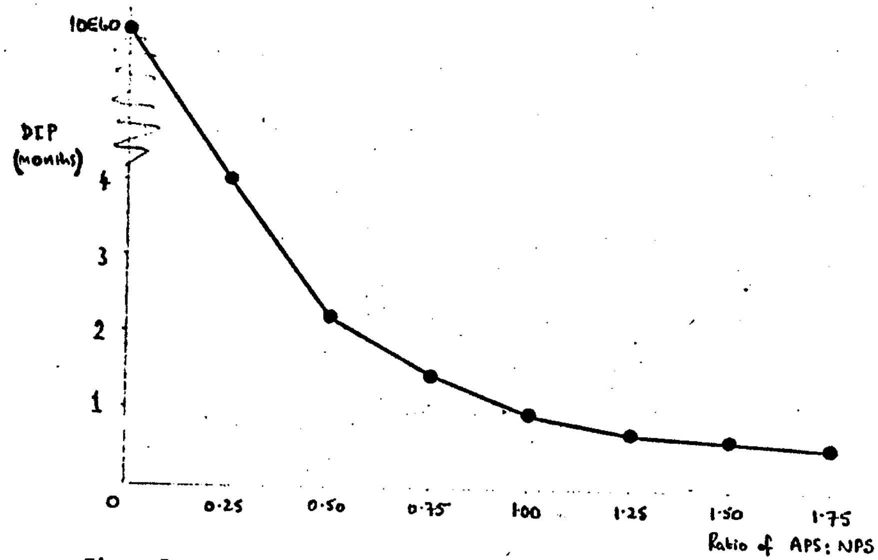

Figure 7. Effect of parts availability on the delay in issuing parts

The table function for DIP shows that, as actual parts stocks exceeds normal, the delay in issuing parts decreases from 1 month to a minimum of 0.5 months when actual parts stocks are 75% above normal. The curve for DIP continues to fall as the ratio of Actual Parts Stocks APS to Normal Parts Stocks NPS exceeds 1.0 because of the desire by firms in the industry to prevent sharp reductions in the parts issuing (and hence production) rate and enable the manufacture of finished goods for stock during recessions. The table function is shown in Figure 7.

As the ratio of APS to NPS decreases towards zero then the delay in issuing parts DIP increases toward infinity. As with the equation for the Delay in Satisfying Primary Demand DSPD described earlier, the value of 10E60 is used in the table function to represent infinity and thus ensure that the level of APS is not driven negative by any large shock imposed on the model.

A	DIP.K	=	TABHL (TAB 5, APS.K/NPS.K, 0, 1.75, 0.25)
	TAB5	=	10E60/4/2.25/1.5/1.0/0.75/0.65/0.5
	DIP	=	Delay in Issuing Parts (months)
	APS	=	Actual Parts Stocks (units)
	NPS	=	Normal Parts Stocks (units)
	TAB5	=	Table of delay in issuing parts (months)

III. SIMULATION EXPERIMENTS AND MODEL VALIDATION

A. Standard test inputs

As a preliminary experiment to reveal dynamic behaviour characteristics of the model, a 20% STEP input is inflicted on the model system in the 12th month. Figure 8* shows the effect of such a sudden increase in demand on some of the important endogenous variables. This particular signal clearly induces cyclical behaviour with a periodicity of between 30 and 34 months. Although the 20% increase occurs at the end of the 12th month, the fluctuations, albeit considerably damped, are still continuing after the 100th month. An explanation will be forthcoming shortly.

As expected, the finished goods stock exhibits peaks significantly greater than the production peaks. The former peaks show 43.12%, 28.14%, 22.33% and 20.48% increases on initial values, compared to 33.64%, 24.54%, 21.34% and 20.39% for the latter. This result is consistent with the stated industry policy of using finished goods stocks, rather than production, to counteract flunctuations in sales.

Production exhibits an interesting feature which is compatible with observations from our fieldwork: production momentum, once started, is difficult to arrest. As a result, after each cyclical peak in sales has passed, production continues to increase (or at least does not decrease simultaneously). Perpetual "overshooting" of production in this manner is a major problem for production planners in the industry.

The model has also been run with a demand signal incorporating data generated randomly from a normal distribution with a mean of 1000 units and a standard deviation of 40 units. The results, (shown in Figure 9), are quite interesting. Even with randomly generated demand, industry output sales and stocks still exhibit cyclical behaviour. Such a result implies that the system possesses characteristics which are sensitive to certain input frequencies, an entire spectrum of which would be found in normal random noise, for example. We must identify these characteristics and whether revised policies adopted by firms in the industry are likely to reduce amplification of the sensitive frequencies.

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* The figures on the following pages, which depict the time series plots, do not all exhibit the same scale, but where the reader is invited to compare two or more graphs their scales are consistent. All the values printed are in terms of percentages of initial values (i.e. index number form).

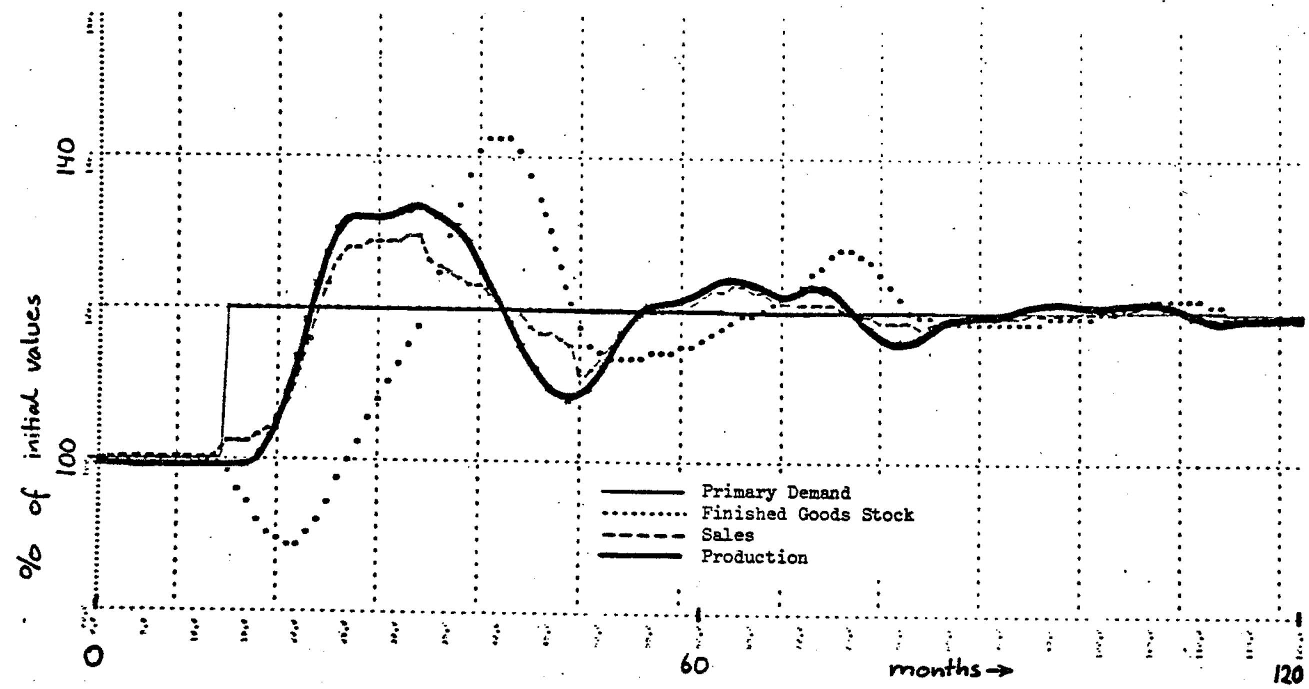

Figure 8. Fluctuations generated by a 20% step increase in primary demand in month 12

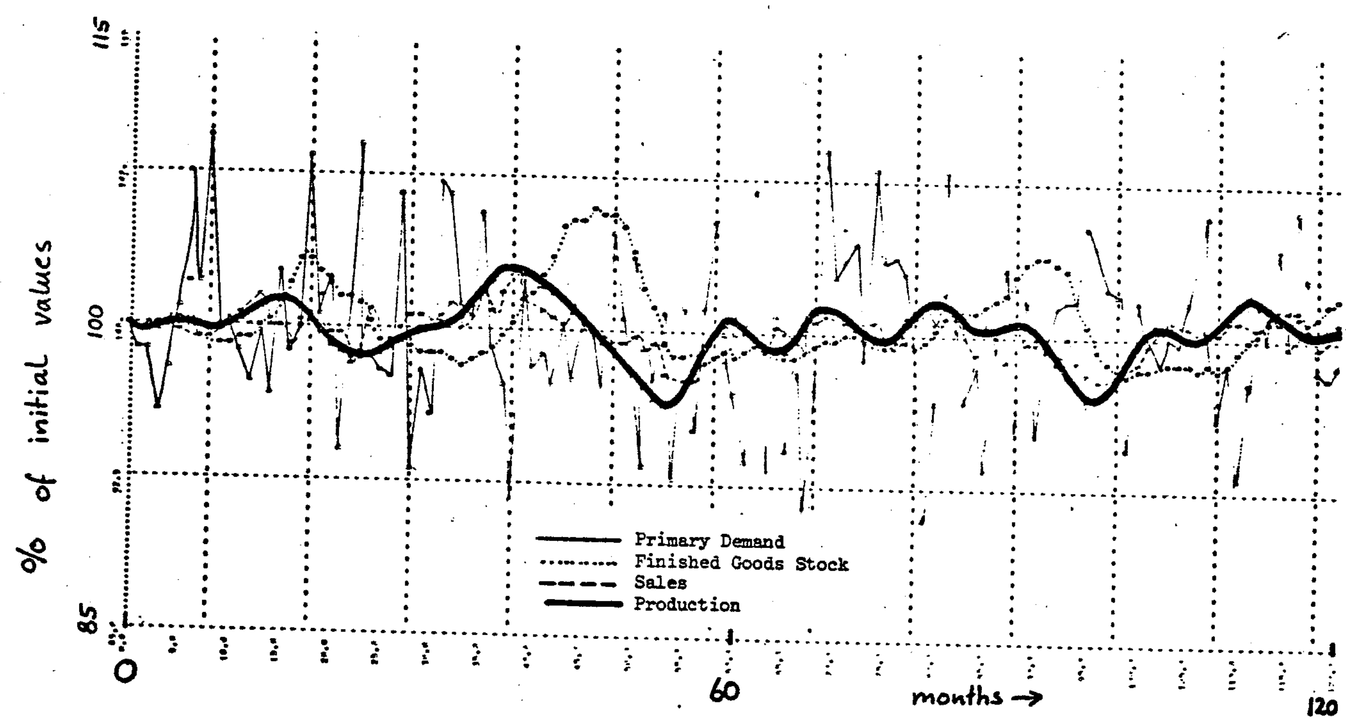

Figure 9. Model behaviour resulting from a normal random noise demand signal

To further illustrate the system's sensitivity to certain input frequencies, the model has been driven by a demand signal comprising a pure sine wave with an amplitude of 200 units and a periodicity which changes in successive runs. Figure 10 shows the resulting amplification in finished goods stocks and production. The figure anticipates a serious amplification when a signal with a periodicity of between approximately 15 and 55 months perturbs the system. The critical or natural frequency* of the system would appear to be elicited by a signal with a period of about 25 months.

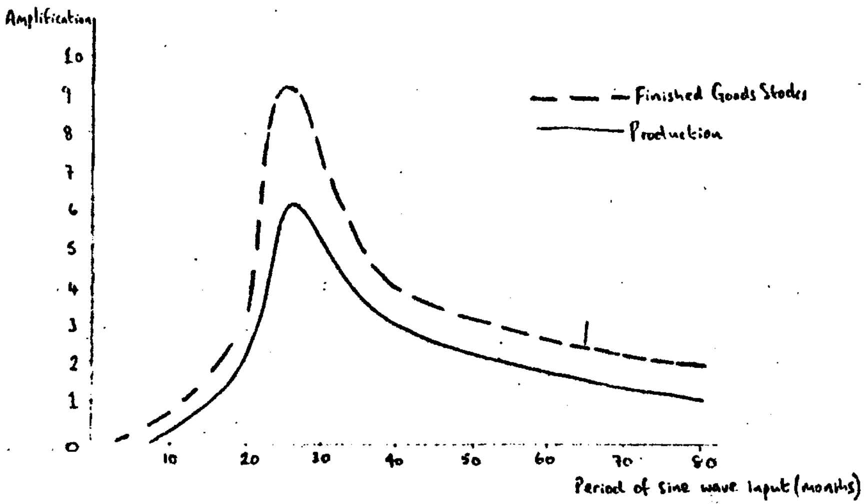

Figure 10. Graph of the degree of amplification of two system variables as a function of periodicity of a sine wave input

One factor contributing to instability in the industry appears to be the forecasting procedures adopted by the constituent firms. Few sophisticated procedures are in use, firms merely extrapolating from current trends and focusing on an excessively short forecasting horizon. To illustrate the impact of forecasting procedures, Figure 11 shows the response of the system to a 20% step input when the sales forecasting routine, which until now has been used to determine production demand, is replaced by a smoothing process on the only "hard" information available - the inflow of orders. The equation for production demand PRD now becomes:

*The natural frequency of a system is the frequency of a disturbance to which the system is most sensitive. In this case it is a frequency corresponding to an input signal with a period of about 25 months.

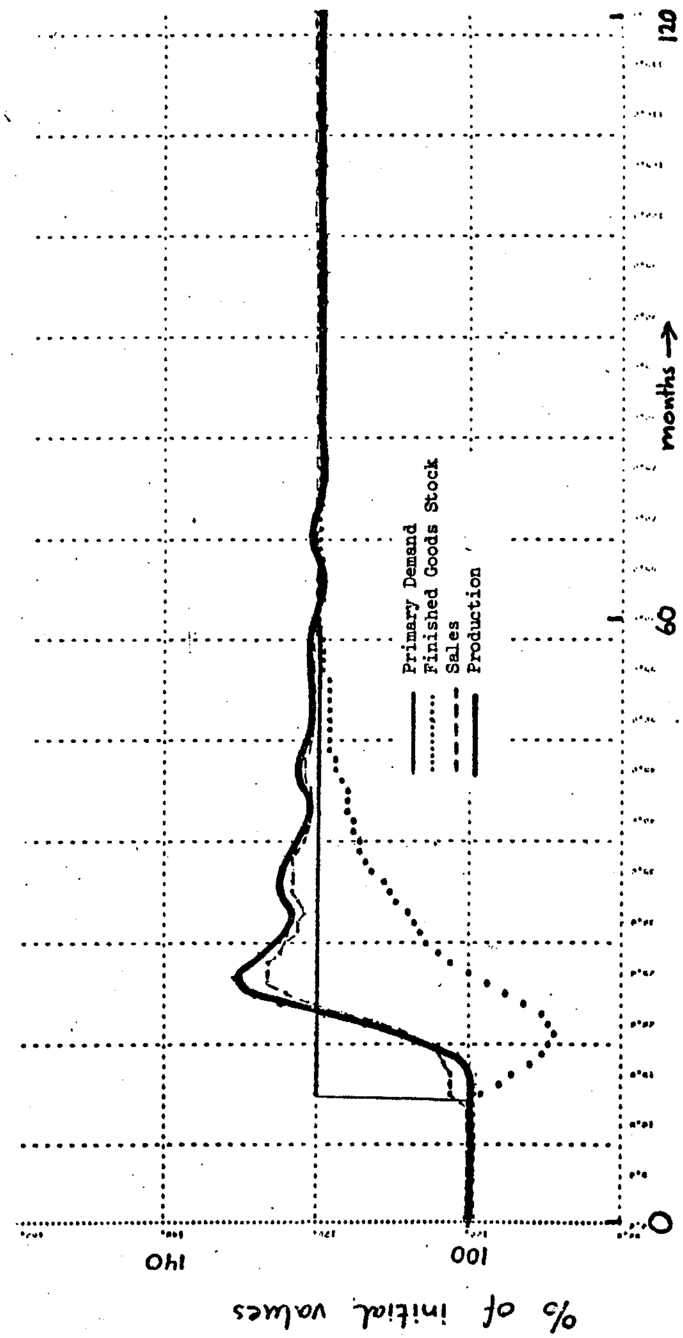

Figure 11. Results of a 20% step increase in primary demand in month 12 when smoothing of incoming orders, as opposed to forecasting sales, is used to determine production demand

A PRD.K = SPD.K + ((NFGS.K - AFGS.K)/DAFGS.K)

[PRD.K = MFS.K + ((NFGS.K - AFGS.K)/DAFGS.K] (previous equation)

SPD = Smoothed Primary Demand (units/month)

NFGS = Normal Finished Goods Stock (units)

AFGS = Actual Finished Goods Stock (units)

DAFGS = Delay in Adjusting Finished Goods Stock (months)

MFS = Modified Forecast of Sales (units/month)

Comparing Figure 8 with Figure 11 clearly shows the reduction in instability. Indeed, fluctuations of any significance disappear after 50 months or so when the smoothing of incoming orders is used to determine future production demand, whereas they continue through the 100th month when sales forecasts are used for the same purpose. The continuation of fluctuations in Figure 8 must therefore be the direct result of the sales forecasting procedures adopted by the firms in the consumer durables manufacturing industry. Nothing else but these procedures have changed between the two figures.

Figures 12 and 13 further illustrate the differential effect of alternative modes of determining production demand. Both depict the behaviour of the system when driven by an input signal composed of random fluctuations superimposed upon a sine wave. This type of input signal more nearly approximates the effects on demand of periodic stimuli applied to consumer spending by the government in its overall management of the economy. Figure 12 illustrates the effects in a system practicing forecasting, while Figure 13 shows the effects in the same system when orders are smoothed instead. Once more, the smoothing policy has the effect of damping fluctuations in comparison with the sales forecasting policy.

Inevitably such results raise the question of why firms in the consumer durables manufacturing industry bother with forecasts at all. Yet every firm of those visited pays attention to such forecasts when formulating their aggregate production plans. Perhaps fear of competition motivates individual firms. Smoothing of data, as opposed to extrapolation of the same data, inevitably means that the information obtained will lag a change in trend. Therefore, a firm that adopts a smoothing system for aggregate production planning could discover during an expansion phase of the demand cycle that its delivery dates were extended compared to competing firms using forecasting systems. As a result, its market share could shrink. However, whether the adverse affects of a reduction in market share outweigh the negative effects of instabilities (such as the inefficiencies introduced by fluctuating workloads) is open to question. Actually, most firms probably do not even consider the costs associated with instabilities beyond saying that, given a choice between fluctuations in production and fluctuations in finished goods stocks, they would prefer the latter.

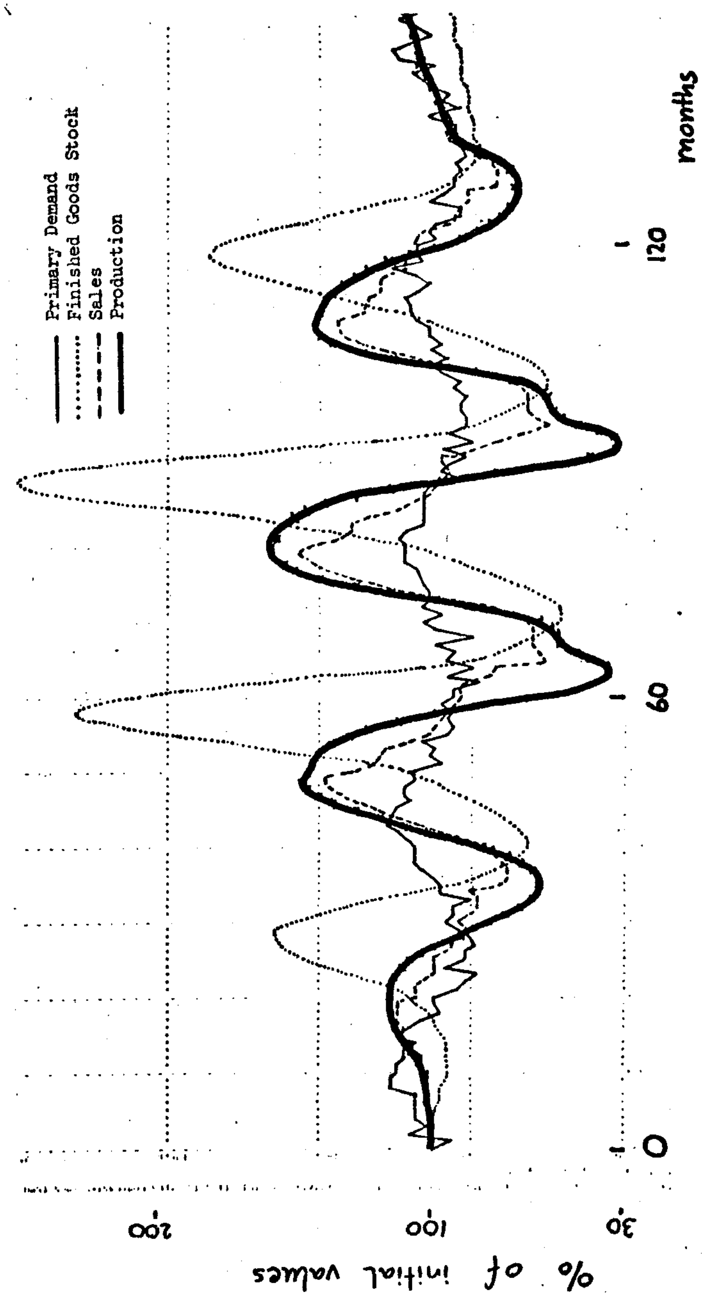

Figure 12. Effect of sales forecasts as a determinant of production demand when primary demand is a composite of normal random noise and a sine wave

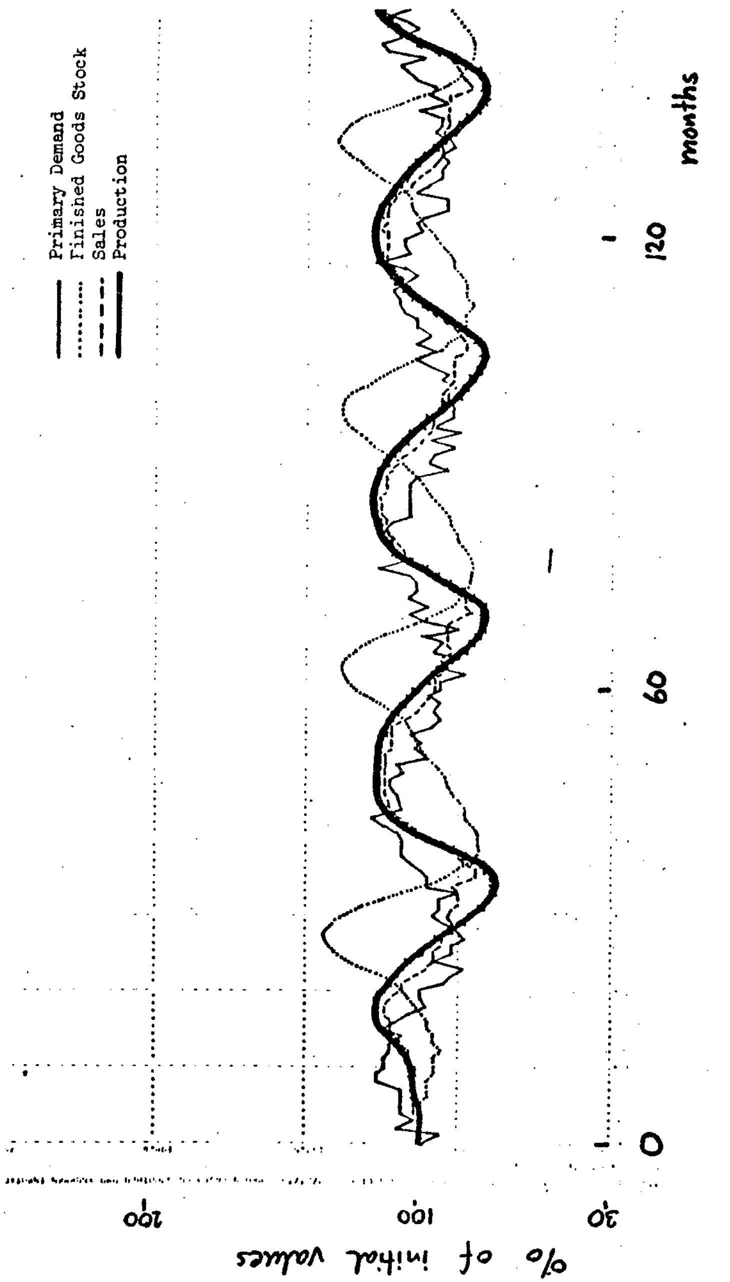

Figure 13. Effect of smoothed incoming orders as a determinant of production demand when primary demand is a composite of normal random noise and a sine wave

A firm which replaced its production planning system based on forecasting by one based on the smoothing of incoming orders would probably remove the need to have to make such a choice.

A second experiment has been undertaken to assess the effect of removing the modification to the raw forecast of sales. For this test, forecasts consist only of an extrapolation of past movements in the sales rate. The system ignores further information from changes in incoming orders. Figure 14 displays the results of this experiment.

The effect of removing the forecast modification can be seen by comparing the percentage increases on initial values of the successive peaks in actual finished goods stock, production rate, and sales rate series in Figures 14 and 8, respectively. The figures are tabulated below:

20% Step Increase in Demand

	No Modification to Forecast Figure 14 (% increases)			Modification to Forecasts Figure 8 (% increases)		
	1st peak	2nd peak	3rd peak	1st peak	2nd peak	3rd peak
Finished Goods Stock	55.85	36.90	28.71	43.12	28.14	22.33
Production	38.11	29.47	24.82	33.64	24.54	21.34
Sales	33.70	27.31	23.65	30.14	23.39	20.99

Not modifying the sales forecasts increases the system instability. The implication is that, when account is taken of rapid changes in demand, the industry responds in advance of changes in sales, thereby eliminating information delays and preventing the destabilisation induced by excessive adjustments to output.

Two experiments have been conducted to assess the sensitivity of the modelled system to variations in delay times. First, the delay in adjusting finished goods stock DAFGS is increased to two, and then to four times, its original value. As a result, the delay function ranges up to between 0 and 14 months, instead of between 0 and 3.5 months originally.

With a pure sine wave for input, the periodicity of fluctuations in production does not change, but the amplification of the input signal is considerably reduced as the delay increases. Figure 15 illustrates the results of this experiment.

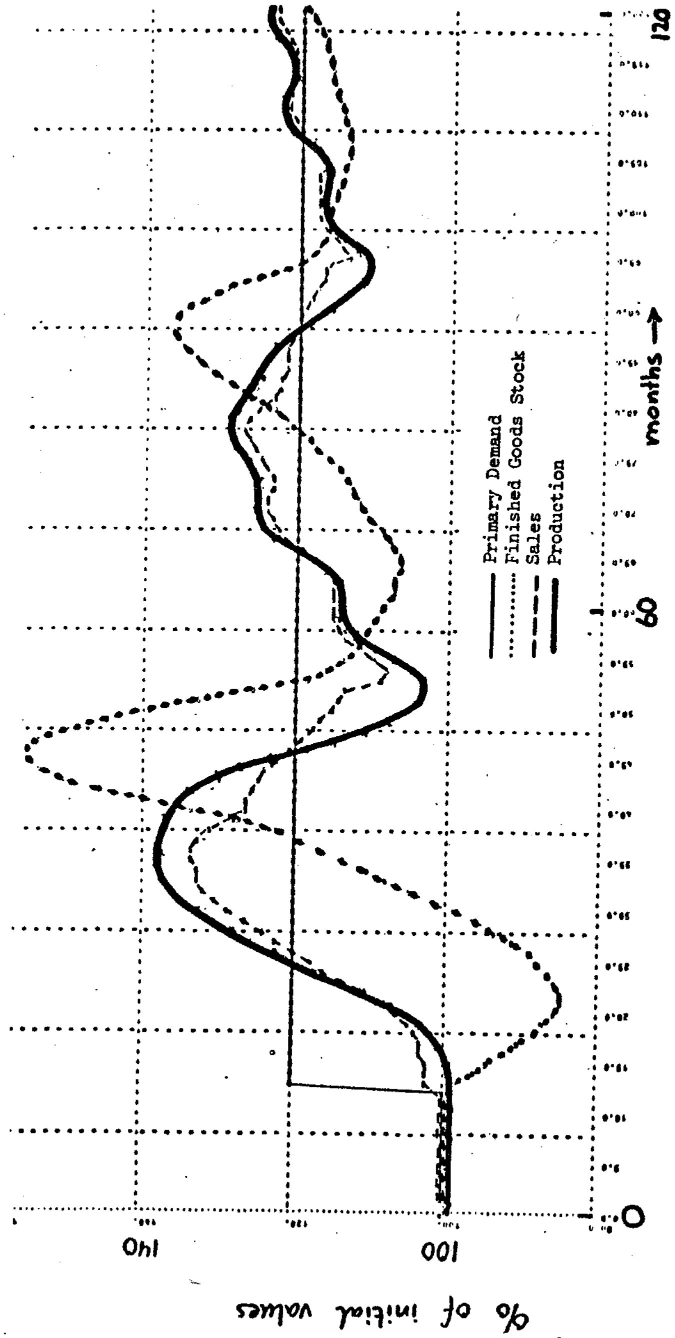

Figure 14. Fluctuations generated by a 20% step increase in primary demand in month 12 when sales forecasts, without modification, are used to determine production demand

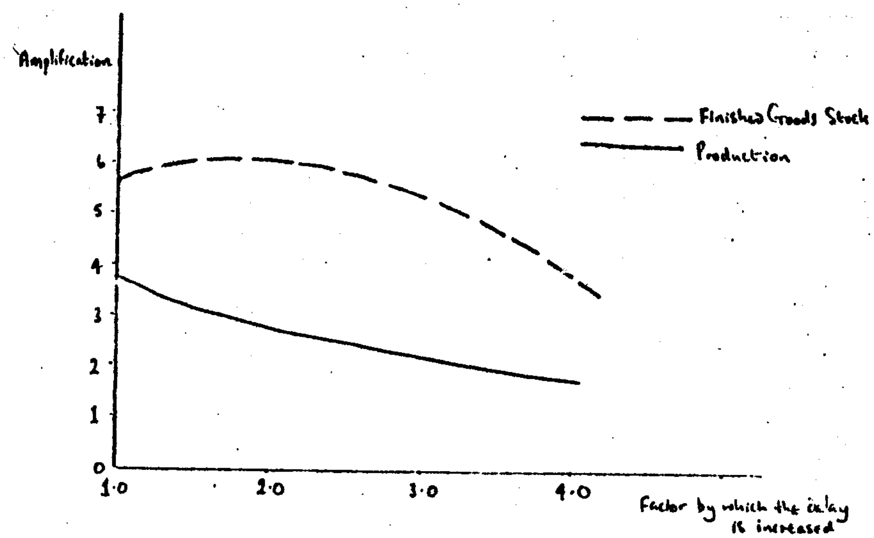

Figure 15. Amplification of two system variables as the delay in adjusting finished goods stock increases

The finished goods stock is amplified at first up to the point where the delay in adjusting finished goods stocks is 1.75 times as great as the original delay, and then progressively decreases. In effect, up to that maximum point, delaying the adjustment of discrepancies between normal and actual finished goods stock leads to a reduction in production fluctuations only at the expense of greater fluctuations in the finished goods stock. If the delay increases still further, oscillations in both production and finished goods stock are diminished.

For a second experiment, the delay in satisfying primary demand is successively increased to two and then four times its original value, in the same way as the delay in adjusting finished goods stocks was changed for the preceding experiment. This means that the delay, when the system is in equilibrium, increases from 1.5 months to 3 and then 6 months respectively. A pure sine wave provides the demand input. The resulting amplification of production and finished goods stock is shown in Figure 16. This time the effect is to considerably reduce the amplification in both series as the delay increases.

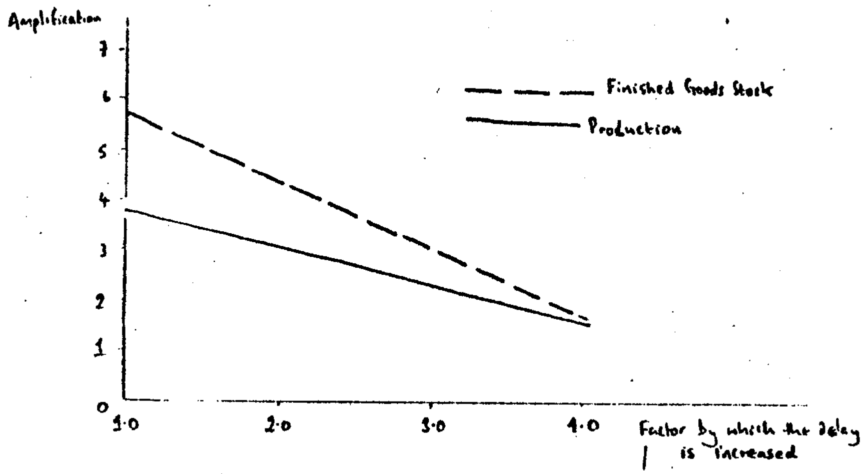

Figure 16. Amplification of two system variables as the delay in satisfying primary demand increases

Although both increases in the delay in adjusting finished goods stock and in the delay in satisfying primary demand have beneficial effects on system behaviour, the likelihood of their being implemented in a practical situation is certainly questionable. No firm would readily implement a policy of lengthening the delay in fulfilling customer orders, a strategy the latter case requires. Even given general agreement among individual firms, a most unlikely event, any significant delay in supplying customer requirements would lead to orders being switched to foreign competitors in the consumer durable goods field.

There is slightly more scope for delaying adjustments to finished goods stocks. Such a policy is already extensively used during a cyclical downturn. However, during an upturn, competitive pressures strongly impinge on policy-making because the sales departments of consumer durable goods firms continually insist on healthy stock levels in order to be able to offer goods for supply off-the-shelf. Any policy which was seen to create a negative free stock situation - that is, creating a larger backlog of orders than stock available - for any length of time would bring heavy protests from the sales people.

In 1965, Brechling and Wolfe published a paper containing a closely reasoned account of why the U.K. economy experiences such severe "stop-go" cycles.[2] One important conclusion was that the speed of the cyclical upswing is a primary determinant of ensuing fluctuations. To throw further light on this point, which has important implications for governmental control of the economy, the model has been tested with a demand input in the form of a ramp. This ramp drives demand up from 1000 units per months to 1200 units per month over periods ranging from one to three years. With this addition, the model can be viewed as a microcosm of the entire economy - the increase in demand being analogous to a general increase in consumer spending.

The behaviour shown in Figures 18 (a-c) supports Brechling and Wolfe's viewpoint. The figures show the effects of a 20% demand increase spread over one, two and three years, respectively. Fluctuations are diminished as the slope of the demand signal decreases. Figure 17 embodies the general principle exhibited by Figures 18 (a-c). The decline in the amplitude of fluctuations in finished goods stocks and production is graphed against the lengthening of the period of time over which the demand increase is spread. On the basis of Figure 17, the considerable destabilising effect of the extremely fast expansion of consumer demand in the U.K. economy in 1971/1972 is perhaps not surprising.

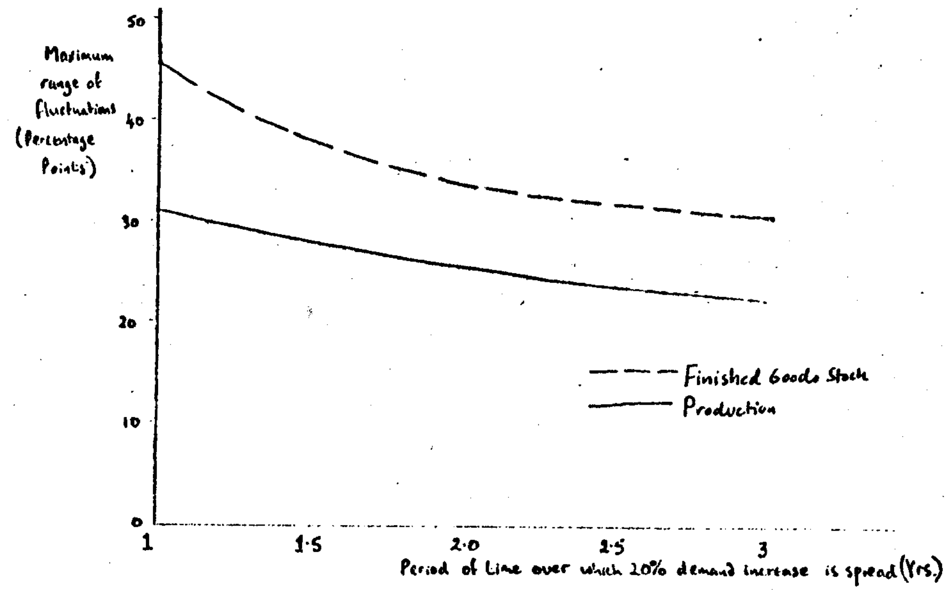

Figure 17. Decline in the range of fluctuations of finished goods stock and production as a 20% demand increase is spread over a longer period

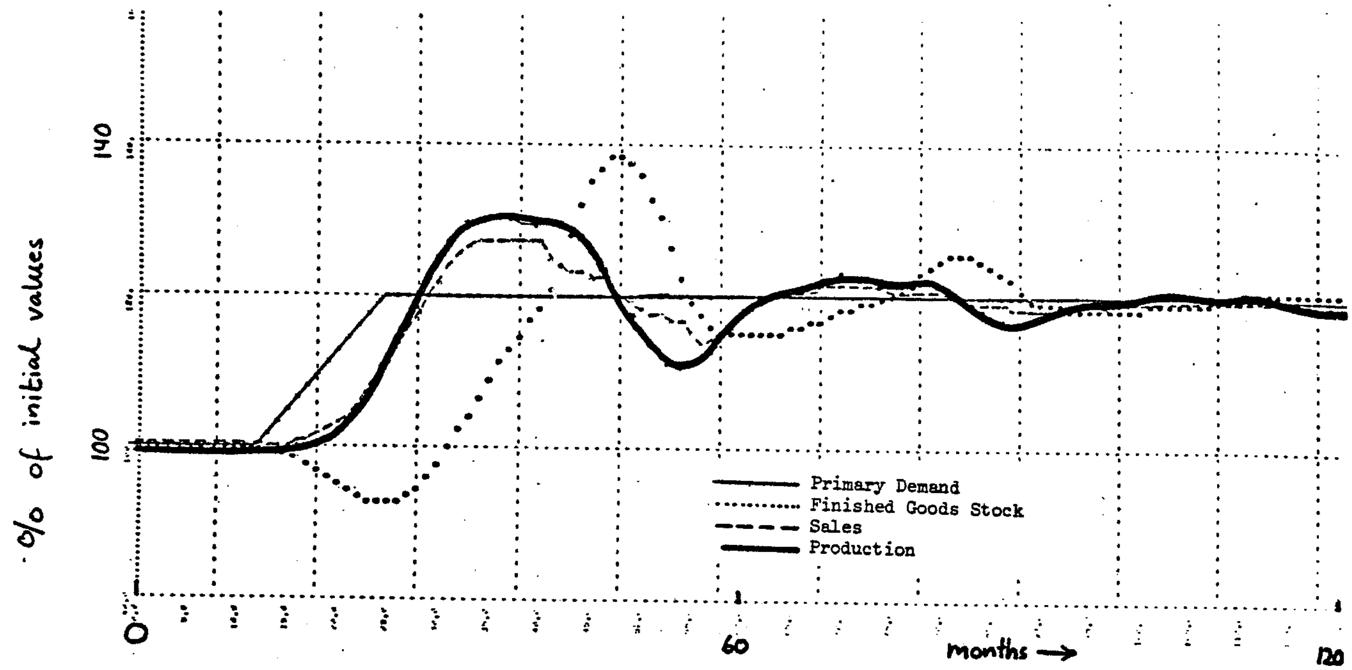

Figure 18(a). Fluctuations generated by a 20% increase in primary demand spread over 12 months starting at month 12

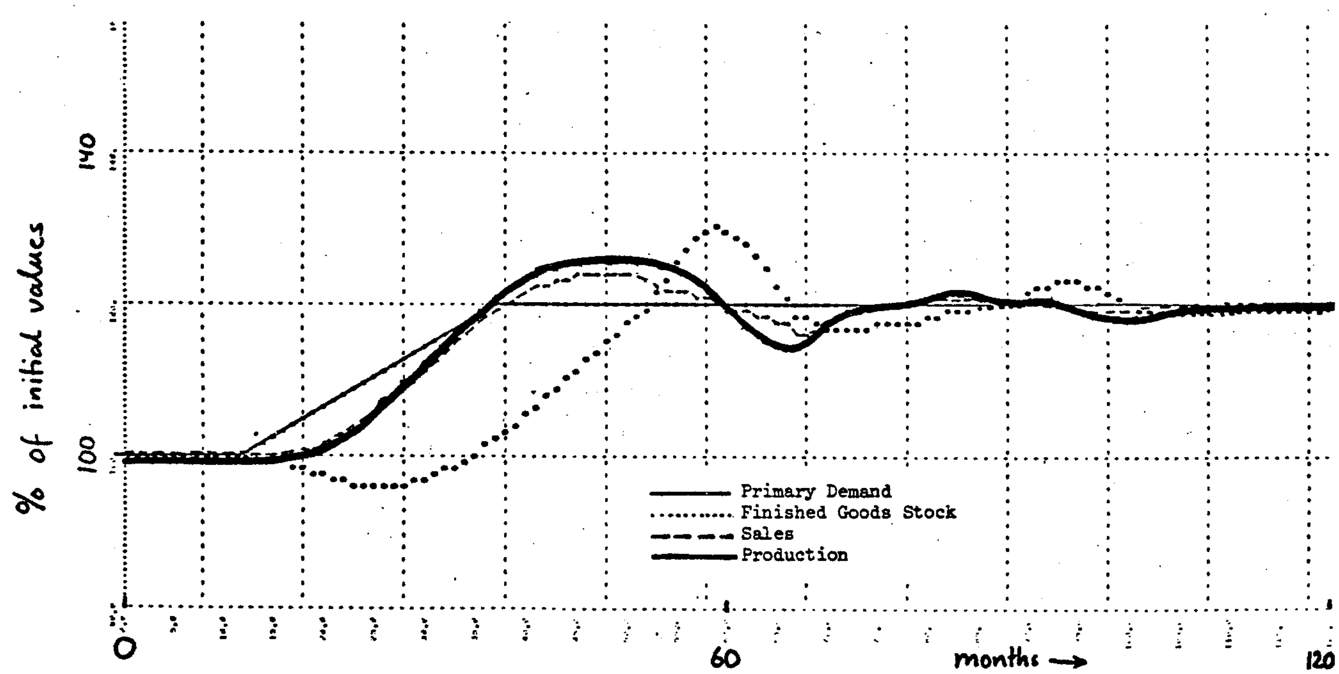

Figure 18(b). Fluctuations generated by a 20% increase in primary demand spread over 24 months starting at month 12

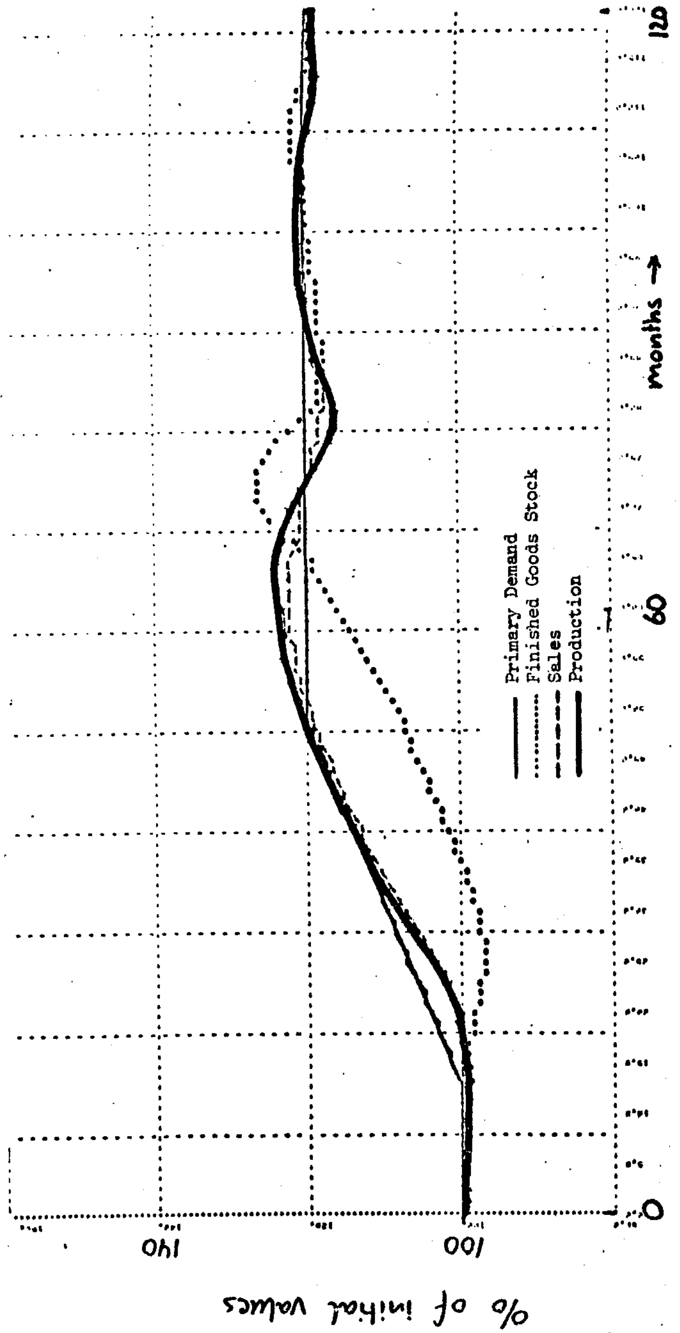

Figure 18(c). Fluctuations generated by a 20% increase in primary demand spread over 36 months starting at month 12

B. Historical time series inputs

A recurring controversy in system dynamics is model validation. Some practitioners argue against attempts to ascertain the ability of a model to re-create observed dynamic behaviour embedded in published statistics. However, if past data is available (something that for sufficient model variables may not be the case) why neglect it entirely? Good agreement between the simulated and actual behaviour of important variables would give the modeller greater confidence in his model. The question then becomes: What represents "good"?

Usually, a comparison between simulated and actual behaviour takes into account periodicity, amplitude, time of occurrence of turning points and phase relationships among variables. In many ways this approach is somewhat subjective and unscientific. Moreover, with highly variable data series, statements about turning points, amplitude and periodicity may be uncertain if not completely indeterminate.

Spectral analysis, a technique commonly employed in modern statistical practice and with origins in the physical sciences, may be able to play a useful role in helping to validate system dynamics models where the behaviour of the variables is such that visual inspection of the series may prove unreliable. However, there are no reported accounts of the use of spectral analysis in this way. Therefore, a review of the advantages and difficulties of the technique, by reference to an actual case study, should throw some light on the admittedly huge problem of model validation.

This paper will not go into the theory of spectral analysis in depth. The reader can refer to other sources for a detailed description of the technique.[5,8,13] However, its essentials, as well as the procedure used in the spectral analysis computer program, are described in Appendix II.

Even though some attempt should be made to assess the model by its ability to re-create the dynamic behaviour of the industry as depicted in published statistics, problems still abound in the case of the consumer durables industry. First, the government does not publish statistics which can be identified with a definition of "consumer durables manufacturing industry"; second, the existing statistical coverage extends to only one or two of the important variables in the study. Nevertheless simulation runs have been conducted with the model driven by an exogenous historical time-series. The results, together with comments on the usefulness of spectral analysis as a model validation technique, are reported below.

The exongenous input to the model is the flow of orders which emanate largely from the distributive trades. However, no government-published statistics are available on the flow of orders; indeed, only one major firm of the 24 visited during our fieldwork kept data on orders booked. This omission from U.K. economic statistics does seem significant,and not only from the modelling point of view. A cyclical upturn in the flow of orders from distributive trades to the consumer durables manufacturing industry would be a useful leading indicator of improvement in the business confidence of retailers/wholesalers. Such a trend would normally be coincident with the restocking phase of the cycle.

Since data on orders booked is not available, the series for retail sales in durable goods shops[4] has been taken as a proxy. However, there are grave dangers in using proxy variables not least being the lack of any assurance that the variable is a suitable proxy. The choice of retail sales here has the major disadvantage in that sales lag orders by several months. The characteristic behaviour of the two series may not be similar because over-ordering is common during a boom phase of the cycle. Nevertheless, the retail sales series should at least reflect the respective periods of boom and slump in the durable goods industry, as suggested by Figure 19 which uses retail sales to drive the model. (The series consisted of 70 quarterly observations from 1958(1) to 1975(2). Unless otherwise stated, all actual data series used here take this form).

A significant point to be drawn from this figure concerns the peaks in finished goods stock. Statistics are not available for finished goods stocks disaggregated into the consumer durables manufacturing industry. However, a finished goods stocks-to-production ratio series for the U.K. manufacturing industry in aggregate[4] is available from 1959. Each peak in finished goods stocks in the model occurs shortly after a boom phase in the U.K. economic cycle. While this pattern is encouraging, since finished goods stocks would be expected to build up as a boom comes to an end, the behaviour is not in exact agreement with the occurrence of finished goods stocks peaks in the historical ratio series. Figure 20 below shows the relevant quarter of each year that exhibited peaks in the model series and the actual historical series, respectively.

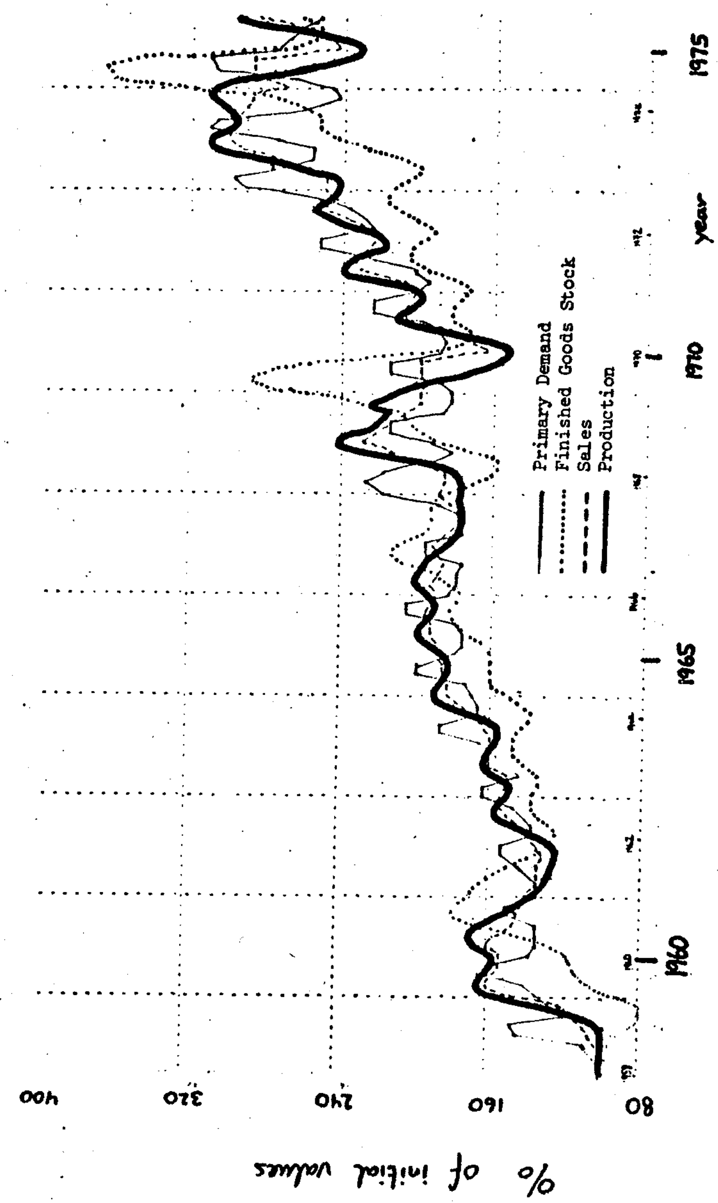

Figure 19. Behaviour resulting when the model is driven by a historical data series of retail sales in durable goods shops

MODEL OUTPUT SERIES	ACTUAL RATIO SERIES
1960 (3)	1961 (4)
1966 (3)	1966 (4)
1969 (2)	1971 (4)
1974 (3)	1975 (2)

Figure 20. Comparison of peaks in finished goods stocks series in the model with those published in the finished goods stock : output ratio series for manufacturing industry in aggregate

The greatest discrepancy occurs where the 1969 peak in the model output series falls 10 quarters away from the peak in the actual ratio series. However, given the unavailability of relevant data for the actual series and the fact that a proxy is being used as an input signal in the model, the overall result of producing the same number of peaks as the published data is relatively satisfactory.

The motor industry is one of the most important homogenous sectors of the U.K. consumer durables manufacturing industry. Therefore, available data series on new car production for the home[4] market would be useful in helping to assess the validity of the production series given by the model. Since retail sales would not be a suitable proxy to drive the model in this instance, the motor industry's counterpart to retail sales, new car registrations[4], has been adopted instead.

The results* of spectral analysis of the historical data series on new car registrations and car production for the U.K. market are shown in Figures 21 and 22, respectively. As expected, the power spectrum shows large peaks corresponding to high frequencies and also to a seasonal cycle. However, there is also a peak corresponding to a cycle of about 52 months -- the generally accepted periodicity of the business cycle in the U.K. This periodicity agrees with research reported elsewhere[11,17] as well.

The plots of the spectral density functions for the simulated production and finished goods stock series (Figures 23 and 24) do not lend much support

*The graphs of the spectral density functions reproduced below are read as as power (expressed on a logarithmic scale) as a function of frequency. The values x_i across the bottom are the exact points on the logarithmic y-axis, represented as e^{x_i}. The significance of peaks at certain frequencies is indicated by an arrow together with the periodicity of the corresponding cycle.

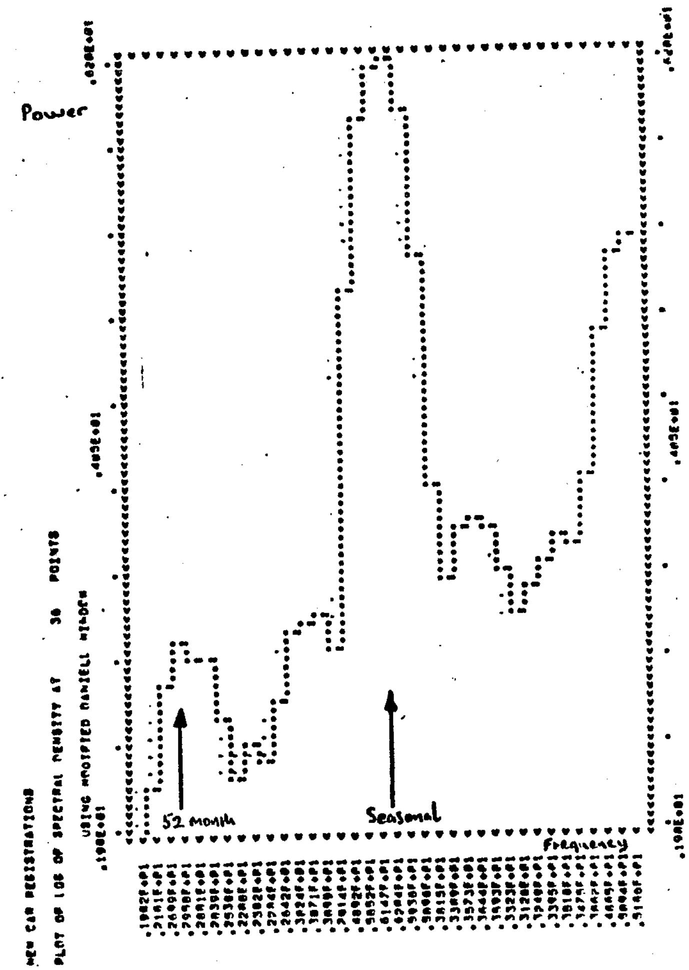

Figure 21. Power spectrum of new car registrations 1959-75

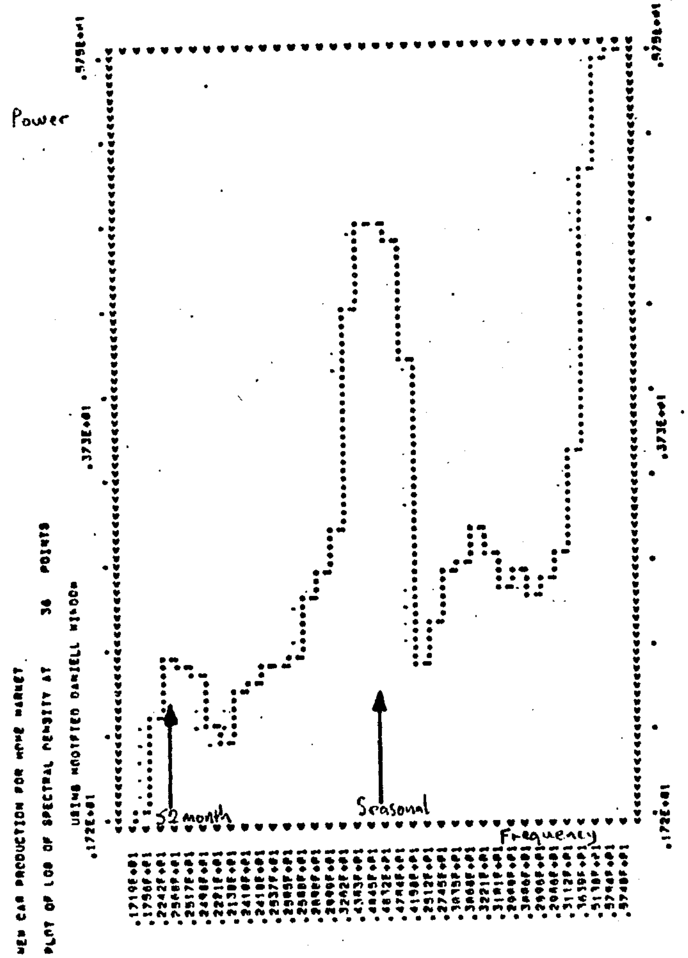

Figure 22. Power spectrum of new car production for the U.K. market 1959-75

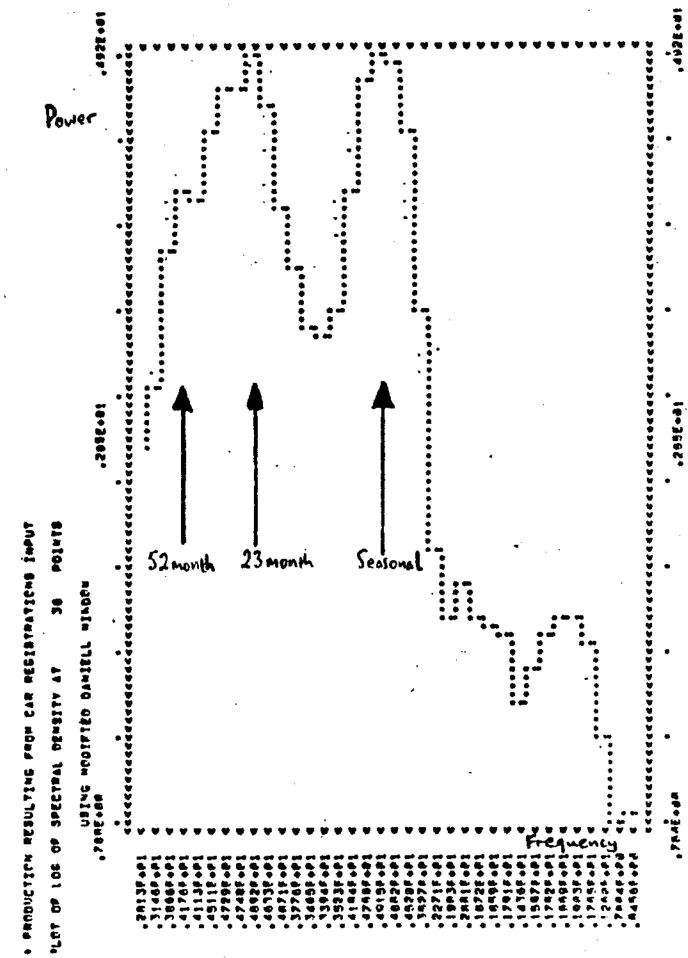

Figure 23. Power spectrum of the simulated production series when the model is driven by new car registrations

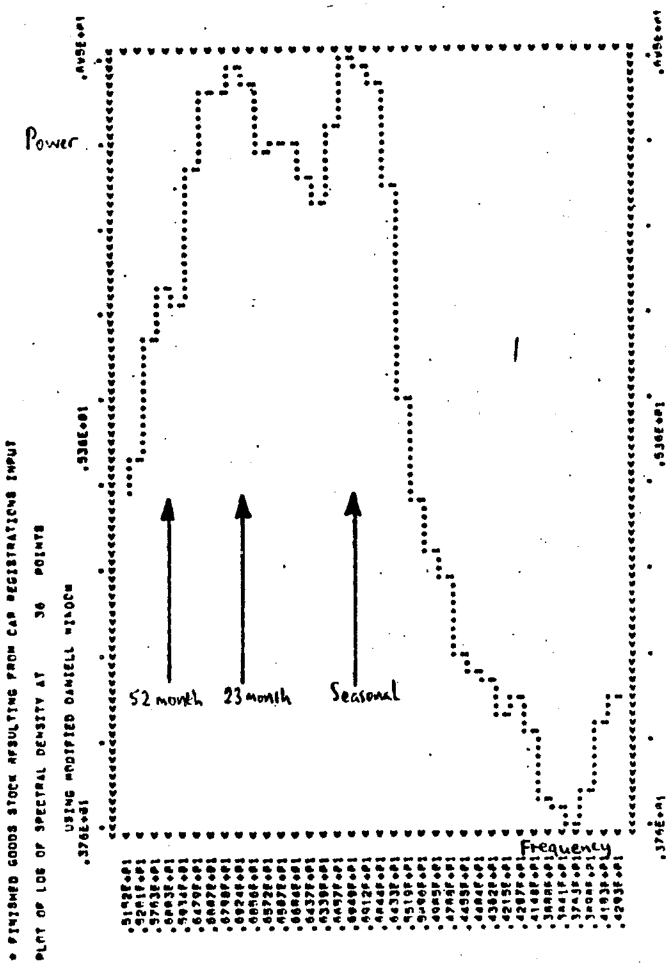

Figure 24. Power spectrum of the simulated finished goods stock series when the model is driven by new car registrations

to the existence of a 52-month cycle. Indeed, although there seems to be a peak corresponding to such a cycle, it is minor compared to the peaks corresponding to a 23-month cycle and to the seasonal cycle. The significant 23-month cycle does not appear in either of the power spectra of new car registrations or car production for the home market. In fact, a comparison of the power spectrum for car production for the home market (Figure 22) with the power spectrum for simulated production (Figure 23) generates no conviction that the two series are in any agreement, apart from seasonality influences.

Data obtained from firms participating in our fieldwork is generally unsuitable for spectral analysis because the data series are not of a significant length. To produce evidence for a 52-month cycle would ideally require something like a minimum of 200 monthly observations. An unfortunate fact of economic life is that industrial firms see no need to retain monthly data for several successive years. Consequently, the modeller hoping to acquire statistical information from such a source is unlikely to meet with much success. The longest series obtained from an individual firm consisted of 92 monthly observations. These observations have been subjected to spectral analysis with some misgivings, and, as expected, the plots of the power spectra are not very useful for detecting cycles with a periodicity corresponding to the business cycle.

The results reported in this section have to be viewed in the light of the fact that proxy variables have been used for the primary demand input. This expedient distorts what in other circumstances might be a reasonably successful method of testing dynamic models of industrial or economic systems.

One possibility which might be tried, in order to avoid the need to employ proxy variables for demand input in this model, is to add a retail/distributive sector. This would then mean that the primary demand flow to the industry would be determined endogenously as the distributive trades reacted to exogenous changes in customer sales. Certainly it would seem to be premature at this stage to reject either the model itself or spectral analysis as a means of testing it given our inability to obtain the necessary demand input data.

IV. CONCLUSION

The work reported in this paper has attempted to serve two important purposes. First, it has stressed the importance of the consumer durables manufacturing industry in the national economy, and explained why efforts to control instability in the economy should ideally start with a close examination of government policies toward, as well as managerial policies adopted by, this industry. From recent indications, this view is apparently beginning to be taken seriously.[12]

Second, and perhaps more importantly, our work has served notice of the usefulness of system dynamics for conducting such an examination. Indeed, system dynamics could prove to be a far more valuable tool for policy evaluation at the macro-economic level than the large-scale econometric models which consume such a large proportion of economic research efforts today. Econometric models are primarily forecasting models. Morever, although some attention is now being given to their use in simulating the effects of alternative economic policies[1],the primary characteristic of current econometric models is an ability to forecast the symptoms of economic problems rather than to identify the root causes which are almost certainly connected with the structure of the economic system and the policies adopted by the system managers.

Attempts to validate our model have unfortunately been inconclusive. However, given the non-availability of relevant data, especially that on orders booked by the consumer durables manufacturing sector, the results are perhaps not surprising. Nevertheless, the use of spectral analysis to compare an actual and a simulated series seems to offer considerable advantages in situations where the behaviour of the simulated and actual time series is such that,if a visual comparison was made, it could result in disagreement as to whether or not the two series were actually the same. The technique is, in effect, a quantitative way of assessing qualitative behaviour. However, it has a significant disadvantage in that, to produce a power spectrum which highlights business cycle behaviour, a fairly lengthy data series is required. Such lengthy data series are not commonplace in the U.K.

Finally, we are planning an enlargement of the model to incorporate the steel and steel stockholding industries. This work is being conducted in pursuit of the major objective of viewing the economy as an interconnected network of major industries. With a finished composite model, policy-makers should be able to assess the simultaneous effects of cyclical demand fluctuations on three major industries in the U.K. economy.

DECEMBER 1976

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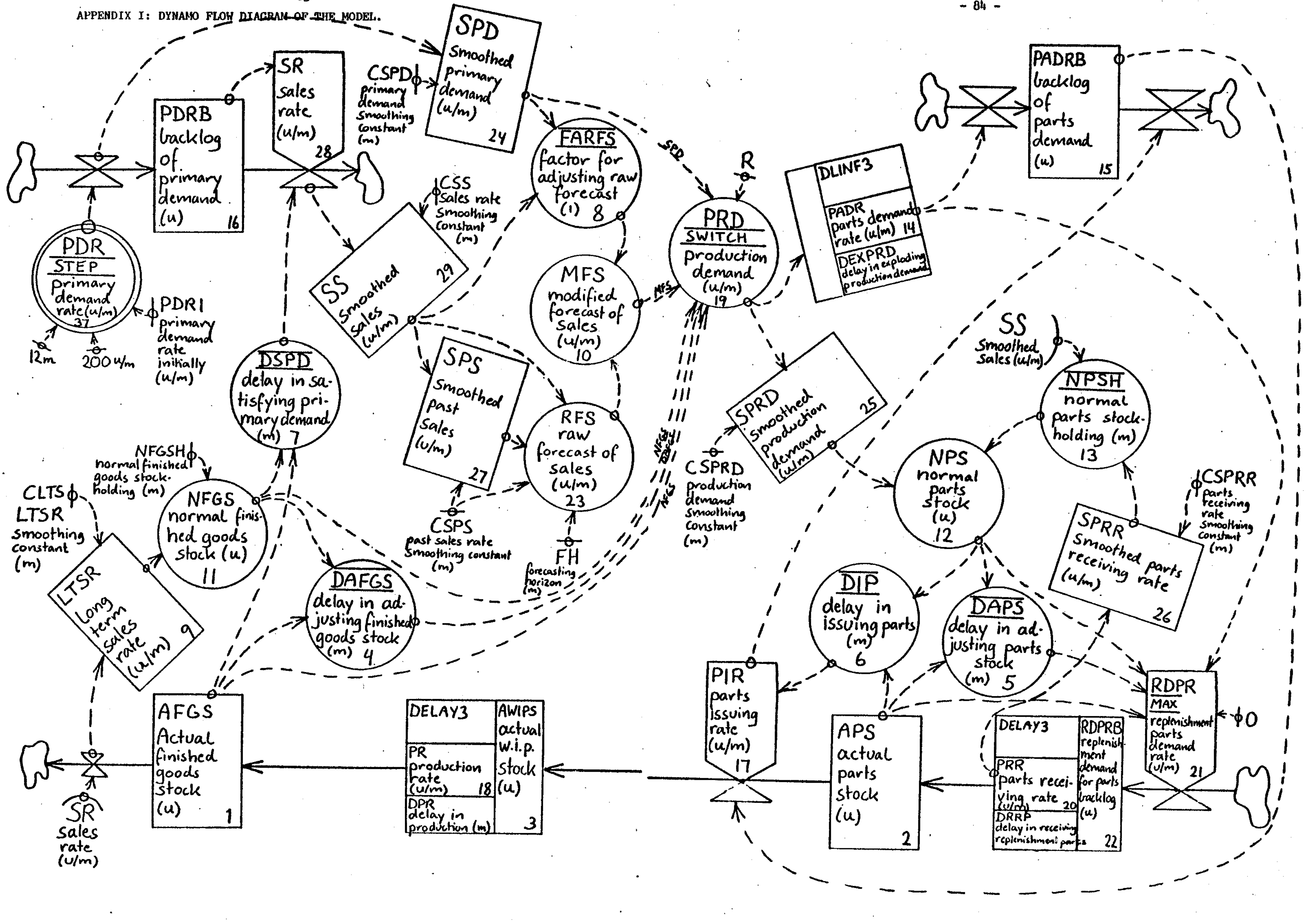
APPENDIX I: DYNAMO FLOW DIAGRAM OF THE MODEL.



APPENDIX II

Spectral Analysis

The spectral analysis method essentially breaks down a given time series into its component frequencies and estimates the relative strengths of these frequencies. A plot of component frequencies against component strengths - called the power spectrum (or spectral density function) - provides a convenient means of comparing two or more time series. In other words, two series are compared in the frequency domain, where a time series is the sum of many sine waves of differing frequencies, rather than in the more commonly employed time domain. If the spectral density function of an actual and a corresponding simulated time series of a variable exhibit similar profiles, the simulated and actual series must be in agreement with regard to that particular variable.

The computer program adopted here estimates the spectral density function by smoothing the periodogram, following a method suggested by P J Daniell (and described by R H Jones)[10] which incorporates a fast Fourier transform. Daniell's approach is generally viewed as an advance on earlier methods which operate by transforming a truncated autocovariance function. Such methods require the choice of a suitable lag window such as those suggested by Parzen[14] and Tukey[16]. The program incorporates a routine for pre-whitening the data by extracting any trend in mean and then taking first differences of the residuals.

APPENDIX III: DOCUMENTOR LISTING OF THE MODEL.

```
DYSMAP DOCUMENTOR.

L AFGS.K=AFGS.J+DT*(PR.JK-SR.JK)                                   1. 0,L
N AFGS=NFGS                                                        1. 1,N
                  AFGS    =(U) ACTUAL FINISHED GOODS STOCK
                  PR      =(U/MTHS) PRODUCTION RATE
                  SR      =(U/MTHS) SALES RATE

L APS.K=APS.J+DT*(PRR.JK-PIR.JK)                                   2. 0,L
N APS=NPS                                                          2. 1,N
                  APS     =(U) ACTUAL PARTS STOCK
                  PRR     =(U/MTHS) PARTS RECEIVING RATE
                  PIR     =(U/MTHS) PARTS ISSUING RATE

L AWIPS.K=AWIPS.J+DT*(PIR.JK-PR.JK)                                3. 0,L
N AWIPS=DPR*PIR                                                    3. 1,N
                  AWIPS   =(U) ACTUAL W.I.P. STOCK
                  PIR     =(U/MTHS) PARTS ISSUING RATE
                  PR      =(U/MTHS) PRODUCTION RATE

A DAFGS.K=TABHL(TAB1,AFGS.K/NFGS.K,0,2,0.25)                       4. 0,A
T TAB1=0/0.25/0.5/1.0/3.0/3.3/3.5/3.5/3.5                          4. 1,T
                  DAFGS   =(MTHS) DELAY IN ADJUSTING FINISHED GOODS STOCK
                  TAB1    =(MTHS) TABLE OF DELAY IN ADJUSTING FINISHED GOODS STOCK
                  AFGS    =(U) ACTUAL FINISHED GOODS STOCK
                  NFGS    =(U) NORMAL FINISHED GOODS STOCK

A DAPS.K=TABHL(TAB3,APS.K/NPS.K,1,2,0,25)                          5. 0,A
T TAB3=1/1.8/3.0/3.9/6.0                                           5. 1,T
                  DAPS    =(MTHS) DELAY IN ADJUSTING PARTS STOCK
                  TAB3    =(MTHS) TABLE OF DELAY IN ADJUSTING PARTS STOCK
                  APS     =(U) ACTUAL PARTS STOCK
                  NPS     =(U) NORMAL PARTS STOCK

A DIP.K=TABHL(TAB5,APS.K/NPS.K,0,1.75,0.25)                        6. 0,A
T TAB5=10E60/4/2.25/1.5/1/0.75/0.65/0.5                            6. 1,T
                  DIP     =(MTHS) DELAY IN ISSUING PARTS
                  TAB5    =(MTHS) TABLE OF DELAY IN ISSUING PARTS
                  APS     =(U) ACTUAL PARTS STOCK
                  NPS     =(U) NORMAL PARTS STOCK

A DSPD.K=TABHL(TAB6,AFGS.K/NFGS.K,0,1,75,0.25                      7. 0,A
T TAB6=10E60/9/6/3.25/1.?/1.25/1/1                                 7. 1,T
                  DSPD    =(MTHS) DELAY IN SATISFYING PRIMARY DEMAND
                  TAB6    =(MTHS) TABLE OF DELAY IN SATISFYING PRIMARY DEMAND
                  AFGS    =(U) ACTUAL FINISHED GOODS STOCK
                  NFGS    =(U) NORMAL FINISHED GOODS STOCK
```

```
A FAREF.K=TABHL(TAB2,SPD.K/SS.K,0,2,0.25)                             8. 0,A
T TAB2=0/.5/.75/1/1/1.2/1.4/1.6/1.8                                    8. 1,T
            FAREF   =(1) FACTOR FOR ADJUSTING RAW FORECAST
            TAB2    =(1) TABLE OF FACTOR FOR ADJUSTING RAW FORECAST
            SPD     =(U/MTHS) SMOOTHED PRIMARY DEMAND
            SS      =(U/MTHS) SMOOTHED SALES

A LTSR.K=SMOOTH(SR.JK,CLTS)                                            9. 0,A
C CLTS=12                                                              9. 1,C
            LTSR    =(U/MTHS) LONG TERM SALES RATE
            SR      =(U/MTHS) SALES RATE
            CLTS    =(MTHS) LONG TERM SALES RATE SMOOTHING CONSTANT

A MFS.K=RFS.K*FAREF.K                                                 10. 0,A
            MFS     =(U/MTHS) MODIFIED FORECAST OF SALES
            RFS     =(U/MTHS) RAW FORECAST OF SALES
            FAREF   =(1) FACTOR FOR ADJUSTING RAW FORECAST

A NFGS.K=NFGSH*LTSR.K                                                 11. 0,A
C NFGSH=1.5                                                           11. 1,C
            NFGS    =(U) NORMAL FINISHED GOODS STOCK
            NFGSH   =(MTHS) NORMAL FINISHED GOODS STOCKHOLDING
            LTSR    =(U/MTHS) LONG TERM SALES RATE

A NPS.K=NPSH.K*SPRD.K                                                 12. 0,A
            NPS     =(U) NORMAL PARTS STOCK
            NPSH    =(MTHS) NORMAL PARTS STOCKHOLDING
            SPRD    =(U/MTHS) SMOOTHED PRODUCTION DEMAND

A NPSH.K=TABHL(TAB4,SPRR.K/SS.K,1,2,0.25)                             13. 0,A
N NPSH=3.0                                                            13. 1,N
T TAB4=3/2.75/2.5/2.0/1.0                                             13. 2,T
            NPSH    =(MTHS) NORMAL PARTS STOCKHOLDING
            TAB4    =(MTHS) TABLE OF NORMAL PARTS STOCKHOLDING
            SPRR    =(U/MTHS) SMOOTHED PARTS RECEIVING RATE
            SS      =(U/MTHS) SMOOTHED SALES

R PADR.KL=DLINF3(PRD.K,DEXPRD)                                        14. 0,R
N PADR=1000                                                           14. 1,N
C DEXPRD=1                                                            14. 2,C
            PADR    =(U/MTHS) PARTS DEMAND RATE
            PRD     =(U/MTHS) PRODUCTION DEMAND
            DEXPRD  =(MTHS) DELAY IN EXPLODING PRODUCTION DEMAND

L PADRB.K=PADRB.J+DT*(PADR.JK-PIR.JK)                                 15. 0,L
N PADRB=DIP*PAIR                                                      15. 1,N
            PADRB   =(U) BACKLOG OF PARTS DEMAND
            PADR    =(U/MTHS) PARTS DEMAND RATE
```



```
L PDRB.K=PDRB.J+DT*(PDR.JK-SR.JK)                                     16. 0,L
N PDRB=DSPD*PDR                                                       16. 1,N
            PDRB    =(U) BACKLOG OF PRIMARY DEMAND
            PDR     =(U/MTHS) PRIMARY DEMAND RATE
            SR      =(U/MTHS) SALES RATE

R PIR.KL=PADRB.K/DIP.K                                                17. 0,R
N PIR=1000                                                            17. 1,N
            PIR     =(U/MTHS) PARTS ISSUING RATE
            PADRB   =(U) BACKLOG OF PARTS DEMAND
            DIP     =(MTHS) DELAY IN ISSUING PARTS

R PR.KL=DELAY3(PIR.JK,DPR)                                            18. 0,R
C DPR=3                                                               18. 1,C
            PR      =(U/MTHS) PRODUCTION RATE
            PIR     =(U/MTHS) PARTS ISSUING RATE
            DPR     =(MTHS) DELAY IN PRODUCTION

A PRD.K=SWITCH(MFS.K+((NFGS.K-AFGS.K)/DAFGS.K),SPD.K+((NFGS.K-AFGS.K)/ 19. 0,A
X DAFGS.K),R)                                                         19. 0,A
C R=0                                                                 19. 1,C
            PRD     =(U/MTHS) PRODUCTION DEMAND
            MFS     =(U/MTHS) MODIFIED FORECAST OF SALES
            NFGS    =(U) NORMAL FINISHED GOODS STOCK
            AFGS    =(U) ACTUAL FINISHED GOODS STOCK
            DAFGS   =(MTHS) DELAY IN ADJUSTING FINISHED GOODS STOCK
            SPD     =(U/MTHS) SMOOTHED PRIMARY DEMAND
            R       =(1) CONSTANT TO PERMIT EVALUATION OF 2 POLICIES

R PRR.KL=DELAY3(RDPR.JK,DRRP)                                         20. 0,R
N PRR=1000                                                            20. 1,N
C DRRP=3                                                              20. 2,C
            PRR     =(U/MTHS) PARTS RECEIVING RATE
            RDPR    =(U/MTHS) REPLENISHMENT PARTS DEMAND RATE
            DRRP    =(MTHS) DELAY IN RECEIVING REPLENISHMENT PARTS

R RDPR.KL=MAX(0,PADR.KL+((NPS.K-APS.K)/DAPS.K))                       21. 0,R
N RDPR=1000                                                           21. 1,N
            RDPR    =(U/MTHS) REPLENISHMENT PARTS DEMAND RATE
            PADR    =(U/MTHS) PARTS DEMAND RATE
            NPS     =(U) NORMAL PARTS STOCK
            APS     =(U) ACTUAL PARTS STOCK
            DAPS    =(MTHS) DELAY IN ADJUSTING PARTS STOCK

L RDPRB.K=RDPRB.J+DT*(RDPR.JK-PRR.JK)                                 22. 0,L
N RDPRB=DRRP*RDPR                                                     22. 1,N
            RDPRB   =(U) REPLENISHMENT DEMAND FOR PARTS BACKLOG
            RDPR    =(U/MTHS) REPLENISHMENT PARTS DEMAND RATE
            PRR     =(U/MTHS) PARTS RECEIVING RATE
```

```
A RFS.K=SS.K+FH*((SS.K-SPS.K)/CSPS)                                23. 0,A
C FH=3                                                             23. 1,C
C CSPS=1                                                           23. 2,C
                 RFS      =(U/MTHS) RAW FORECAST OF SALES
                 SS       =(U/MTHS) SMOOTHED SALES
                 FH       =(MTHS) FORECASTING HORIZON
                 SPS      =(U/MTHS) SMOOTHED PAST SALES
                 CSPS     =(MTHS) PAST SALES RATE SMOOTHING CONSTANT

A SPD.K=SMOOTH(PDR.JK,CSPD)                                        24. 0,A
C CSPD=3                                                           24. 1,C
                 SPD      =(U/MTHS) SMOOTHED PRIMARY DEMAND
                 PDR      =(U/MTHS) PRIMARY DEMAND RATE
                 CSPD     =(MTHS) PRIMARY DEMAND RATE SMOOTHING CONSTANT

A SPRD.K=SMOOTH(PRD.K,CSPRD)                                       25. 0,A
C CSPRD=6                                                          25. 1,C
                 SPRD     =(U/MTHS) SMOOTHED PRODUCTION DEMAND
                 PRD      =(U/MTHS) PRODUCTION DEMAND
                 CSPRD    =(MTHS) PRODUCTION DEMAND SMOOTHING CONSTANT

A SPRR.K=SMOOTH(PRR.JK,CSPRR)                                      26. 0,A
C CSPRR=1                                                          26. 1,C
                 SPRR     =(U/MTHS) SMOOTHED PARTS RECEIVING RATE
                 PRR      =(U/MTHS) PARTS RECEIVING RATE
                 CSPRR    =(MTHS) PARTS RECEIVING RATE SMOOTHING CONSTANT

A SPS.K=SMOOTH(SS.K,CSPS)                                          27. 0,A
C CSPS=1                                                           27. 1,C
                 SPS      =(U/MTHS) SMOOTHED PAST SALES
                 SS       =(U/MTHS) SMOOTHED SALES
                 CSPS     =(MTHS) PAST SALES RATE SMOOTHING CONSTANT
R SR.KL=PDRB.K/DSPD.K
N SR=PDRIN                                                         28. 0,R
                                                                   28. 1,N
                 SR       =(U/MTHS) SALES RATE
                 PDRB     =(U) BACKLOG OF PRIMARY DEMAND
                 DSPD     =(MTHS) DELAY IN SATISFYING PRIMARY DEMAND

A SS.K=SMOOTH(SR.JK,CSS)                                           29. 0,A
C CSS=3                                                            29. 1,C
                 SS       =(U/MTHS) SMOOTHED SALES
                 SR       =(U/MTHS) SALES RATE
                 CSR      =(MTHS) SALES RATE SMOOTHING CONSTANT

S AFGSPC.K=(AFGS.K*100)/(PDRI*NFGSH)
C PDRI=1000                                                        30. 0,S
C NFGSH=1.5                                                        30. 1,C
                 AFGSPC   =(%) ACTUAL FINISHED GOODS STOCK PERCENTAGE CHANGES 30. 2,C
                 AFGS     =(U) ACTUAL FINISHED GOODS STOCK
                 PDRI     =(U/MTHS) PRIMARY DEMAND RATE INITIALLY
                 NFGSH    =(MTHS) NORMAL FINISHED GOODS STOCKHOLDING
```



```
S PDRPC.K=(PDR.JK*100)/PDRI                                        31. 0,S
C PDRI=1000                                                        31. 1,C
                 PDRPC    =(%) PRIMARY DEMAND RATE PERCENTAGE CHANGES
                 PDR      =(U/MTHS) PRIMARY DEMAND RATE
                 PDRI     =(U/MTHS) PRIMARY DEMAND RATE INITIALLY

S PRDPC.K=(PRD.K*100)/PDRI                                         32. 0,S
C PDRI=1000                                                        32. 1,C
                 PRDPC    =(%) PRODUCTION DEMAND PERCENTAGE CHANGES
                 PRD      =(U/MTHS) PRODUCTION DEMAND
                 PDRI     =(U/MTHS) PRIMARY DEMAND RATE INITIALLY

S PRPC.K=(PR.JK*100)/PDRI                                          33. 0,S
C PDRI=1000                                                        33. 1,C
                 PRPC     =(%) PRODUCTION RATE PERCENTAGE CHANGES
                 PR       =(U/MTHS) PRODUCTION RATE
                 PDRI     =(U/MTHS) PRIMARY DEMAND RATE INITIALLY

S SRPC.K=(SR.JK*100)/PDRI                                          34. 0,S
C PDRI=1000                                                        34. 1,C
                 SRPC     =(%) SALES RATE PERCENTAGE CHANGES
                 SR       =(U/MTHS) SALES RATE
                 PDRI     =(U/MTHS) PRIMARY DEMAND RATE INITIALLY

S TFSPC.K=((APS.K+AWIPS.K)*100)/6000                               35. 0,S
                 TFSPC    =(%) TOTAL FACTORY STOCKS PERCENTAGE CHANGES
                 APS      =(U) ACTUAL PARTS STOCK
                 AWIPS    =(U) ACTUAL W.I.P. STOCK

S TFS.K=APS.K+AWIPS.K                                              36. 0,S
                 TFS      =(U) TOTAL FACTORY STOCKS
                 APS      =(U) ACTUAL PARTS STOCK
                 AWIPS    =(U) ACTUAL W.I.P. STOCK

R PDR.KL=PDRI+STEP(200,12)                                         37. 0,R
N PDR=PDRIN                                                        37. 1,N
C PDRI=1000                                                        37. 2,C
                 PDR      =(U/MTHS) PRIMARY DEMAND RATE
                 PDRI     =(U/MTHS) PRIMARY DEMAND RATE INITIALLY
```

APPENDIX IV


```
DYSMAP WHITE,USESCALES
DOC
* CONSUMER DURABLES MANUFACTURING SECTOR
NOTE
NOTE EQUATIONS OF THE MODEL
NOTE
L AFGS.K=AFGS.J+DT*(PR.JK-SR.JK)
L APS.K=APS.J+DT*(PRR.JK-PIR.JK)
L AWIPS.K=AWIPS.J+DT*(PIR.JK-PR.JK)
A DAFGS.K=TABHL(TAB1,AFGS.K/NFGS.K,0,2,0.25)
A DAPS.K=TABHL(TAB3,APS.K/NPS.K,1,2,0.25)
A DIP.K=TABHL(TAB5,APS.K/NPS.K,0,1.75,0.25)
A DSPD.K=TABHL(TAB6,AFGS.K/NFGS.K,0,1.75,0.25)
A FARFS.K=TABHL(TAB2,SPD.K/SS.K,0,2,0.25)
A LTSR.K=SMOOTH(SR.JK,CLTS)
A MFS.K=RFS.K*FARFS.K
A NFGS.K=NFGSH*LTSR.K
A NPS.K=NPSH.K*SPRD.K
A NPSH.K=TABHL(TAB4,SPRR.K/SS.K,1,2,0.25)
R PADR.KL=DLINF3(PRD.K,DEXPRD)
L PADRB.K=PADRB.J+DT*(PADR.JK-PIR.JK)
L PDRB.K=PDRB.J+DT*(PDR.JK-SR.JK)
R PIR.KL=PADRB.K/DIP.K
R PR.KL=DELAY3(PIR.JK,DPR)
A PRD.K=SWITCH(MFS.K+((NFGS.K-AFGS.K)/DAFGS.K),SPD.K+((NFGS.K-AFGS.K)/
X DAFGS.K),R)
R PRR.KL=DELAY3(RDPR.JK,DRRP)
R RDPR.KL=MAX(0,PADR.KL+((NPS.K-APS.K)/DAPS.K))
L RDPRB.K=RDPRB.J+DT*(RDPR.JK-PRR.JK)
A RFS.K=SS.K+FH*((SS.K-SPS.K)/CSPS)
A SPD.K=SMOOTH(PDR.JK,CSPD)
A SPRD.K=SMOOTH(PRD.K,CSPRD)
A SPRR.K=SMOOTH(PRR.JK,CSPRR)
A SPS.K=SMOOTH(SS.K,CSPS)
R SR.KL=PDRB.K/DSPD.K
A SS.K=SMOOTH(SR.JK,CSS)
T TAB1=0/0.25/0.5/1.0/3.0/3.3/3.5/3.5/3.5
T TAB2=0/0.5/0.75/1/1/1.2/1.4/1.6/1.8
T TAB3=1/1.8/3.0/3.9/6.0
T TAB4=3/2.75/2.5/2.0/1.0
T TAB5=10E60/4/2.25/1.5/1/0.75/0.65/0.5
T TAB6=10E60/9/6/3.25/1.5/1.25/1/1
NOTE
NOTE INITIAL VALUE EQUATIONS
NOTE
N AFGS=NFGS
N APS=NPS
N AWIPS=DPR*PIR
N PIR=1000
N RDPR=1000
N PADR=1000
N NPSH=3.0
N PADRB=DIP*PADR
N PDR=PDRIN
N PRR=1000
N PDRB=DSPD*PDR
```



```
N RDPRB=DRRP*RDPR
N SR=PDRIN
N PDRIN=1000
NOTE
NOTE SUPPLEMENTARY OUTPUT EQUATIONS
NOTE
S AFGSPC.K=(AFGS.K*100)/(PDRI*NFGSH)
S PDRPC.K=(PDR.JK*100)/PDRI
S PRDPC.K=(PRD.K*100)/PDRI
S PRPC.K=(PR.JK*100)/PDRI
S SRPC.K=(SR.JK*100)/PDRI
S TFSPC.K=((APS.K+AWIPS.K)*100)/6000
S TFS.K=APS.K+AWIPS.K
NOTE
NOTE CONSTANTS OF THE MODEL
NOTE
C R=0
C CLTS=12
C CSPD=3
C CSPRR=3
C CSPRD=6
C CSPS=1
C CSS=3
C DEXPRD=1
C DPR=3
C DRRP=3
C FH=3
C NFGSH=1.5
C PDRI=1000
NOTE
NOTE DOCUMENTOR EQUATIONS
NOTE
D  AFGS=(U) ACTUAL FINISHED GOODS STOCK
D   APS=(U) ACTUAL PARTS STOCK
D AWIPS=(U) ACTUAL W.I.P. STOCK
D DAFGS=(MTHS) DELAY IN ADJUSTING FINISHED GOODS STOCK
D  DAPS=(MTHS) DELAY IN ADJUSTING PARTS STOCK
D   DIP=(MTHS) DELAY IN ISSUING PARTS
D  DSPD=(MTHS) DELAY IN SATISFYING PRIMARY DEMAND
D FARFS=(1) FACTOR FOR ADJUSTING RAW FORECAST
D  LTSR=(U/MTHS) LONG TERM SALES RATE
D   MFS=(U/MTHS) MODIFIED FORECAST OF SALES
D  NFGS=(U) NORMAL FINISHED GOODS STOCK
D   NPS=(U) NORMAL PARTS STOCK
D  NPSH=(MTHS) NORMAL PARTS STOCKHOLDING
D  PADR=(U/MTHS) PARTS DEMAND RATE
D PADRB=(U) BACKLOG OF PARTS DEMAND
D  PDRB=(U) BACKLOG OF PRIMARY DEMAND
D   PIR=(U/MTHS) PARTS ISSUING RATE
D    PR=(U/MTHS) PRODUCTION RATE
D   PRD=(U/MTHS) PRODUCTION DEMAND
D   PRR=(U/MTHS) PARTS RECEIVING RATE
D  RDPR=(U/MTHS) REPLENISHMENT PARTS DEMAND RATE
D RDPRB=(U) REPLENISHMENT DEMAND FOR PARTS BACKLOG
D   RFS=(U/MTHS) RAW FORECAST OF SALES
D   SPD=(U/MTHS) SMOOTHED PRIMARY DEMAND
```

```
D  SPRR=(U/MTHS) SMOOTHED PARTS RECEIVING RATE
D  SPRD=(U/MTHS) SMOOTHED PRODUCTION DEMAND
D   SPS=(U/MTHS) SMOOTHED PAST SALES
D    SR=(U/MTHS) SALES RATE
D    SS=(U/MTHS) SMOOTHED SALES
D  TAB1=(MTHS) TABLE OF DELAY IN ADJUSTING FINISHED GOODS STOCK
D  TAB2=(1) TABLE OF FACTOR FOR ADJUSTING RAW FORECAST
D  TAB3=(MTHS) TABLE OF DELAY IN ADJUSTING PARTS STOCK
D  TAB4=(MTHS) TABLE OF NORMAL PARTS STOCKHOLDING
D  TAB5=(MTHS) TABLE OF DELAY IN ISSUING PARTS
D  TAB6=(MTHS) TABLE OF DELAY IN SATISFYING PRIMARY DEMAND
D AFGSPC=(1) ACTUAL FINISHED GOODS STOCK PERCENTAGE CHANGES
D PDRPC=(1) PRIMARY DEMAND RATE PERCENTAGE CHANGES
D PRDPC=(1) PRODUCTION DEMAND PERCENTAGE CHANGES
D  PRPC=(1) PRODUCTION RATE PERCENTAGE CHANGES
D  SRPC=(1) SALES RATE PERCENTAGE CHANGES
D TFSPC=(1) TOTAL FACTORY STOCKS PERCENTAGE CHANGES
D   TFS=(U) TOTAL FACTORY STOCKS
D  CLTS=(MTHS) LONG TERM SALES RATE SMOOTHING CONSTANT
D  CSPD=(MTHS) PRIMARY DEMAND RATE SMOOTHING CONSTANT
D CSPRD=(MTHS) PRODUCTION DEMAND SMOOTHING CONSTANT
D CSPRR=(MTHS) PARTS RECEIVING RATE SMOOTHING CONSTANT
D  CSPS=(MTHS) PAST SALES RATE SMOOTHING CONSTANT
D   CSS=(MTHS) SALES RATE SMOOTHING CONSTANT
D DEXPRD=(MTHS) DELAY IN EXPLODING PRODUCTION DEMAND
D   DPR=(MTHS) DELAY IN PRODUCTION
D  DRRP=(MTHS) DELAY IN RECEIVING REPLENISHMENT PARTS
D    FH=(MTHS) FORECASTING HORIZON
D  PDRI=(U/MTHS) PRIMARY DEMAND RATE INITIALLY
D NFGSH=(MTHS) NORMAL FINISHED GOODS STOCKHOLDING
D     R=(1) CONSTANT TO PERMIT EVALUATION OF 2 POLICIES
D   PDR=(U/MTHS) PRIMARY DEMAND RATE
D    DT=(MTHS) SOLUTION INTERVAL(0.2)
D  TIME=(MTHS) MONTHS
NOTE
NOTE INPUT VARIABLES AND CONSTANTS
NOTE
R PDR.KL=PDRI+STEP(200,12)
NOTE
NOTE OUTPUT INSTRUCTIONS
NOTE
PRINT AFGSPC,PDRPC,PRDPC,PRPC,SRPC,TFSPC
PLOT PDRPC=D,PRPC=P,AFGSPC=G,SRPC=S(80,160)
SPEC DT=0.200/LENGTH=156/PRTPER=1/PLTPER=1
RUN STEP INCREASE IN PRIMARY DEMAND
+
EJ
```