DYNAMICA ISSN 0306-7564 Volume 2, Part 2

The Role of Forecasts in System Dynamics

by

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Abstract

This paper attempts to explain a result that has been noted in several system dynamics studies, namely that the performance of a properly designed system that depends on a forecast is relatively insensitive to forecast error. This is shown for continuous linear systems to be a consequence of the design criteria used in system dynamics modelling.

The role of Perfect Forecasts in such systems is discussed and the means by which normal system dynamics design procedures produce systems that are sensitive to forecast error elucidated.

1.1. Introduction

System Dynamics models of business systems generally make use of forecasts of future values of input variables such as Order Rate. In the course of various studies carried out in the System Dynamics Research Group it has been noted that system behaviour is little changed if, instead of assuming that perfect forecasts of future values of the variable of interest are available, imperfect forecasts are used. Thus a study of the Chemical Plant Investment Cycle (Hill, 1972) showed that system behaviour was hardly changed if forecasts of future Chemical Demand were assumed to be liable to bias at certain stages of the investment cycle rather than being perfect. A study of Tanker Chartering (Coyle 1974) lead to similar conclusions with regard to forecasts of future Oil Demand. A study of a Production Planning System (Sharp and Coyle, 1976) where forecasts of future Order Rates were generated essentially be exponential smoothing showed that the advantage of perfect forecasts over forecasts generated by smoothing was slight, if suitable alterations were made to system policies when using the forecasts derived by smoothing. Various other instances of this phenomenon are described by Winch (1975).

Such results raise a number of interesting questions. Firstly, is it true that the use of System Dynamics methods for the redesign of certain types of system are likely to yield systems that are insensitive to errors in the forecast used and if so what are the distinguishing characteristics of such systems? Secondly, if such systems exist, what are the assumptions that are built into the system dynamics approach that lead to this insensitivity? Thirdly, what is the role of forecasts under these circumstances? The further question then arises as to whether the advantages derived from a perfect forecast can be attained in some other way. Answers to these questions should give not only insights into the applicability of system dynamics methods but also, in view of the relative paucity of discussions of other than the statistical characteristics of individual techniques in the literature, help to establish the role of forecasts in systems and the type of situation in which perfect forecasts are desirable.

The aim of this paper is to give a partial answer to these questions by examination of the effect of replacing perfect forecasts by biased forecasts or by forecasts generated by the exponential smoothing process commonly used in system dynamics models (Forrester, 1961). To render mathematical analysis possible the discussion will be confined to linear systems and even then will be somewhat heuristic. Various authors have shown however, that nonlinear system dynamic models can often be well approximated by linear ones (Fey, 1961) (Rademaker, 1974), (Sharp and Coyle 1976) so it seems plausible to assume that the conclusions have a wider validity.

1.2. The System to be Studied

In what follows, the assumption is made that a continuous linear system dynamics model is a satisfactory approximation to the actual system. For simplicity of exposition detailed discussion will be confined to the case where the system concerned has a single driving input $i(t)$. Such systems are very common in corporate modelling where the input is typically an exogenous Order Rate. It is assumed that a perfect forecast of the input at some time $f(t) \equiv i(t+a)$ $a \geqslant o$ is available for use within the system. For such a linear system the differential equation analogue of the usual DYNAMO model takes the form (Sharp, 1974)

$$\dot{\underline{x}} = A\underline{x} + B\underline{y} + \underline{a}\, f(t) + \underline{b}\, i(t) \qquad (1)$$

$$\underline{y} = C\underline{x} + D\underline{y} + \underline{c}\, f(t) \qquad (2)$$

Where the variables $\underline{x}$ correspond to LEVELS and SMOOTHED variables and the variables $\underline{y}$ are the RATES and AUXILIARIES determined within the system. By virtue of the Sortability requirement (Sharp, 1974) imposed on system dynamics models these equations can be rewritten (by suitable elimination)

$$\dot{\underline{x}} = F\underline{x} + \underline{d}f(t) + \underline{b}i(t) \qquad (3)$$

$$\underline{z} = G\underline{x} + \underline{h}f(t) \qquad (4)$$

where the variables $\underline{z}$ are the internally generated RATES within the system.

2.1. Criteria for System Design

The aim of a system dynamics study is to ensure that the system (3), (4) fulfils certain requirements. These requirements appear either explicitly or implicitly in the literature c.f. (Forrester, 1961), (Coyle, 1974). They are:

a) That the system is stable

b) That the system has zero position error i.e. the vectors $\underline{x}$ and $\underline{y}$ take up certain desired final values $\underline{p}$ and $\underline{q}$, respectively when the system is submitted to a unit step input. For this to be the case we have from (4) that since $f(t) = i(t+a) = 1$

$$\underline{q} = G\underline{p} + \underline{h} \qquad (5)$$

and from (3) that

$$\underline{o} = F\underline{p} + \underline{d} + \underline{b} \qquad (6)$$

c) That the final velocity error for a unit step input be suitably small

d) That a low frequencies the amplitude of oscillation of the system states is given by $\underline{p}$, i.e. low frequency inputs are not undesirably amplified.

e) That the system cope satisfactorily with noise. Four major sources of noise can be recognised these are:

  i) random fluctuations in the exogenous input
  ii) measurement error
  iii) structural error due to the fact that some system relationships can be expected to be subject to considerable random error (Sharp, 1974)
  iv) errors associated with the forecasting process

In practice this means that the system (3), (4) must cope satisfactorily with noisy inputs and also noise terms that represent the effects of (ii), (iii) and (iv), (Sharp, 1974). Such noise terms generally contain high frequency components and it is generally a requirement of the System Design that the internal rates $\underline{z}$ are unresponsive to high frequency noise. Thus the internal rates $\underline{z}$ are required to act as a low pass filter so that their response to frequencies above some critical frequency ω_c is very highly damped. In a production planning system input order rates generally contain substantial components of frequency 1 year. The natural time unit for such a system is a week and the normal requirement is for a highly damped response to seasonality whence we have

$$\omega_c \geqslant \frac{2\pi}{52} \simeq \frac{1}{8}$$

In most business systems the week is a convenient time unit and we shall assume this in what follows. Business systems are generally required to damp out the effects of seasonality which shows itself in the presence of substantial high frequency components. On the other hand they are expected to respond satisfactorily to low frequency inputs corresponding to the Business Cycle with a period of roughly 4 years. Accordingly we take as a suitable value for ω_c in the following discussion.

$$\omega_c = \frac{1}{25}$$

The explicit spectral analysis of systems with regard to input noise appears frequently in the literature e.g. (Coyle, 1974). The analysis of the response of the system to additive noise terms appears less frequently probably because in practice a system that damps out high frequency input noise also damps out high frequency noise from other sources. The requirement that the system act as a low pass filter in the sense defined above is however crucial to the analysis that follows.

3.1. The Effect of Replacing Perfect Forecasts by Alternative Forecasts

We now assume that the system (3), (4) has been designed to satisfy the criteria of section 2.1. We wish to consider the effect of replacing the perfect forecast f(t) in equations (3) and (4) by an alternative forecast $f'(t)$. Specifically we wish to consider 2 types of alternative forecast

viz $f'(t) = \alpha f(t)$ (7) where $\alpha \neq 1$ is some bias factor representing optimism or pessimism in forecasting and a forecast generated by exponential smoothing

$$\dot{f}' = \frac{i(t)-f'(t)}{\tau} \qquad (8)$$

Thus the system we now wish to consider is

$$\underline{x}' = F\underline{x}' + \underline{d}f' + \underline{b}i \qquad (9)$$

$$\underline{z}' = G\underline{x}' + \underline{h}f' \qquad (10)$$

Our approach will be to consider the difference in response between the systems (3), (4) and (9), (10) to sinusoidal variations about some operating point $(i_o, \underline{x}_o, \underline{z}_o)$ where in accordance with (5) and (6) we have

$$\underline{x}_o = (I-F)^{-1} (\underline{d} + \underline{b}) i_o \qquad (11)$$

$$\underline{z}_o = G\underline{x} + \underline{h}i_o \qquad (12)$$

We thus assume that the variables $\underline{x}$, $\underline{x}'$, $\underline{z}$, $\underline{z}'$, i, f' and f are the relevant deviations from this operating point.

The State Matrix of the system (3), (4) is F as is that of the system (7), (9) (10) whilst that of the system (8), (9), (10) is the matrix

$$\begin{bmatrix} -\frac{1}{\tau} & (\underline{0})^T \\ (\underline{d}) & F \end{bmatrix}$$

whence since τ is >0 it is clear that the eigenvalues of this matrix are those of the matrix F plus an additional eigenvalue $-\frac{1}{\tau}$. Therefore if the system (3), (4) is stable so is that of (7), (9), (10) or (8), (9), (10). We thus conclude that the alternative forecasts have no effect on the stability of the system.

We now denote in the usual way the laplace transform of x(t) as x(s) and set

$$\underline{m}(s) = \underline{x}(s) - \underline{x}'(s)$$
$$\underline{n}(s) = \underline{z}(s) - \underline{z}'(s)$$

Taking Laplace transforms we have from (3) and (8)

$$s\underline{m}(s) = F\underline{m}(s) + \underline{d}\left(f(s) - f'(s) \right) \quad (13)$$

$$\underline{n}(s) = G\underline{m}(s) + \underline{h}\left(f(s) - f'(s) \right) \quad (14)$$

or $$\underline{m}(s) = \underline{k}(s) \left(f(s) - f'(s) \right) \quad (15)$$

$$\underline{n}(s) \equiv \underline{l}(s) \left(f(s) - f'(s) \right) \quad (16)$$

where

$$\underline{k}(s) \equiv (sI - F)^{-1}\underline{d} \quad (17)$$

$$\underline{l}(s) \equiv Gk(s) + \underline{h} \quad (18)$$

We now proceed to examine the response of $\underline{m}$ and $\underline{n}$ to a harmonic input $e^{j\omega t}$. We denote the i th component of $\underline{m}$ by m_i we then have that the amplitudes of the steady state responses are given by

$$|m_i|^2 = |k_i(j\omega)|^2 \; |f(j\omega) - f(j\omega)|^2 \quad (19)$$

$$|n_i|^2 = |l_i(j\omega)|^2 \; |f(j\omega) - f(j\omega)|^2 \quad (20)$$

We now consider the values of (19) and (20) for frequencies above the cutoff frequency.

3.2. High Frequency $(\omega > \omega_c)$

In order to deal with this case we need first to consider the effect of a noise inputs $\underline{d}\, e^{j\omega t}$ and $\underline{h}\, e^{j\omega t}$ on the system (3), (4). Such noise inputs would arise naturally in connexion with forecast error, or might equally be regarded as a test noise signal. In either case as we remarked in section 2.1. the low pass filter assumption implies that the amplitude of response of the rate equations to such signals is negligible for $\omega > \omega_c$.

We therefore consider the system (3), (4) to be perturbed about the equilibrium point $\underline{x}_o$, $\underline{z}_o$, i_o, $f(t) = i_o$ by such noise signals. By virtue of equations (5) and (6) if $\underline{x}$ and $\underline{z}$ denote deviations from the equilibrium point the system becomes

$$\dot{\underline{x}} = F\underline{x} + \underline{d}\; e^{j\omega t} \quad (21)$$

$$\underline{z} = G\underline{x} + \underline{h}\; e^{j\omega t} \quad (22)$$

Preceeding to Laplace transforms we find

$$|x_i|^2 = |k_i(j\omega)|^2 \quad (23)$$

$$|z_i|^2 = |l_i(j\omega)|^2 \tag{24}$$

where $\underline{k}(j\omega)$ and $\underline{l}(j\omega)$ are as defined in (14) and (15)

By virtue of the assumption that the system acts as a low pass filter we have from (24) that

$$|z_i| = |l_i(j\omega)| \simeq 0 \text{ for } \omega > \omega_c \tag{25}$$

It is interesting to note that (25) can only be satisfied in a system using Perfect Forecasts if either the moduli of the coefficients of f(t) in equation (4) are considerably less than 1 or if the forecasts are filtered. In practice this filtering is secured in business systems by the use of forecasts of e.g. total demand for several months ahead which effectively removes high frequency components.

Turning to the factor

$|f(j\omega) - f'(j\omega)|^2$ in equations (19) and (20)

we find that for forecasts of the form (7)

$$|f(j\omega) - f'(j\omega)|^2 = (1-\alpha)^2 \tag{26}$$

whilst for those of form (8) where $f(s) = \dfrac{1}{1+\tau s}$

$$|f(j\omega) - f'(j\omega)|^2 = \left| e^{aj\omega} - \frac{1}{1+\tau j\omega} \right|^2 \tag{27}$$

$$= \frac{2-2\cos a\omega + 2\tau\omega\sin a\omega + \tau^2\omega^2}{1 + \tau^2\omega^2} \tag{28}$$

The maximum value of (28) is for $\tau\omega > 1$ equal to 2 whilst for $\tau\omega < 1$ it is 4.

Since we are generally interested in fairly limited amounts of bias i.e. $|\alpha| < 1$ we conclude that $(26) \ll 1$

Thus from (20) we have that the difference between the systems for a unit high frequency input

$$|n_i|^2 \leqslant 4 \, |l_i(j\omega)|^2 \tag{29}$$

In practice the amplitude of high frequency components of i(t) is generally less than 0.5 i_o. The amplitude of the difference n_i is accordingly given by

$$|n_i| \leqslant 0.5 \times 2\, i_o \, |l_i(j\omega)|$$

$$\leqslant |l_i(j\omega)| \, i_o \tag{30}$$

By virtue of (25) then we conclude that

$$|n_i| << i_o$$

Generally the RATES which correspond to $\underline{z}$ are of the same order of magnitude as i_o so we may conclude that for frequencies $> \omega_c$ there is negligible difference between the RATES generated by the system (3), (4) and those generated by the system (9), (10) whichever form of forecast $f'(t)$ is used. As far as those state variables that represent system states that we wish to control however such as stocks or cash are concerned, however changes in them are caused <u>only</u> by the interaction of the exogenous input and the internally generated RATES. We therefore conclude that for these state variables (as distinct perhaps from state variables representing SMOOTHS, etc.) there is negligible difference in the behaviour of the 2 systems. Thus in all essential respects the systems behave more or less identically for $\omega > \omega_c$.

4.1. Low Frequency Response $\omega < \omega_c$

For the purposes of low frequency analysis we assume that ω_c is small enough to permit the system transfer functions to be expanded as a power series in s and that terms of order s^2 and above can be neglected. This is equivalent to assuming that the parameters of the system particularly time delays are sufficiently small relative to $\frac{1}{\omega_c}$ to render this approximation valid. In general this does not appear to be a problem in actual systems except perhaps where unusually long time delays are encountered. In such cases the analysis given below is easily extended to higher order transfer functions.

We therefore assume that the transfer function corresponding to equation (3) takes the form

$$x(s) = A(s)\, i(s) + B(s)\, f(s) \qquad (31)$$

and that corresponding to equation (9)

$$x'(s) = A(s)\, i(s) + B(s)\, f'(s) \qquad (32)$$

Writing $A(s) = \underline{a}_o + \underline{a}_1 s + \ldots$

$B(s) = \underline{b}_o + \underline{b}_1 s + \ldots$

we have from (31) that, since $e^{as} = 1 + as + \ldots$

and $f(s) = e^{as} i(s)$ (since we are concerned only with the steady state response to sinusoids)

$$\underline{x}(s) = \left[\underline{a}_o + \underline{a}_1 s + \underline{b}_o + \underline{b}_1 as + O(S^2)\right] i(s) \qquad (33)$$

$$= \left[\left\{\underline{a}_o + \underline{b}_o\right\} + \left\{\underline{a}_1 + \underline{b}_1 + \underline{b}_o a\right\} s + O(s^2)\right] i(s) \qquad (34)$$

Application of the final value theorem shows that the steady state response of the system (3), (4) is given by $(\underline{a}_o + \underline{b}_o) = \underline{p}$ (35) by virtue of (6). Similarly the velocity error i.e. the difference $\underline{x}(t) - \underline{p}t$ when the system is subjected to a unit ramp input $i(t) = t$ is given by the coefficient of s, i.e.

$$\left\{\underline{a}_1 + \underline{b}_1 + \underline{b}_o a\right\} \qquad (36)$$

We thus see that by suitable choice of the forecast horizon a the velocity error of the system can be reduced-possibly to zero. In practice with simple linear systems it it indeed generally possible to secure this. A zero velocity error is desirable both because a unit ramp is a useful test input and also because we then have from (34) and (35)

$$\underline{x}(s) = \underline{p}\ i(s) \qquad (37)$$

i.e. the amplitude of the response of $\underline{x}(s)$ to low frequency noise is given by $\underline{p}$, i.e. there is no undesirable amplification of low frequency inputs.

Turning to the low frequency response of systems using alternative forecasts we find that for those of type (7) we have

$$\underline{x}'(s) = \left[\{\underline{a}_o+\underline{b}_o\} + \{\underline{a}_1 + \underline{b}_1 + \underline{b}_o a\} s + (\alpha-1)\left[\underline{b}_o + \{\underline{b}_1+\underline{b}_o a\} s + O(s^2)\right]\right] i(s) \qquad (38)$$

and for those of form (8) we have

$$\underline{x}'(s) = \left[\{\underline{a}_o+\underline{b}_o\} + \{\underline{a}_1+\underline{b}_1+\underline{b}_o a\} - b_o\{\tau+a\} s + O(s^2)\right] i(s) \qquad (39)$$

where the coefficients of s^o and s^1 have the same interpretation as above.

For the system (38) we have therefore that

$$\underline{x}'(s) - x(s) = (\alpha-1)\left[\underline{b}_o + \{\underline{b}_1 + b_o a\} s\right] i(s) \qquad (40)$$

For low frequency inputs we have accordingly

$$\left| x'(j\omega)_i - x(j\omega)_i \right|^2 = (\alpha-1)^2 \left(b_{o,i}^2 + (b_{1,i}+b_{o,i}a)^2 \omega^2\right) \qquad (41)$$

where $b_{o,i}$ denotes the i th component of $\underline{b}_o$ etc.

Clearly if $\left| x'(j\omega)_i - x_i(j\omega) \right|$ is small compared with the equilibrium value $x_{o,i}$ it is reasonable to describe the behaviour of the alternative system as being little changed.

If we assume that a fairly extreme value for a low frequency component is say $0.5\ i_o$ and that a difference of up to 10% of the equilibrium value of the i th component is acceptable i.e. $0.1 \times p_i \times i_o$ and that $|\alpha-1| \leq 0.25$ we have from (41) that for there to be no significant difference between the systems

$$0.1 \times p_i \geq 0.25 * \sqrt{b_{o,i}^2 + (b_{1,i}+b_{o,i}a)^2 \omega_c^2}$$

i.e. $$p_i \geq 2.5 * \sqrt{b_{o,i}^2 + (b_{1,i}+b_{o,i}a)^2 \omega_c^2} \qquad (42)$$

In actual systems the values of p_i for variables of interest such as inventory are usually around 4 whilst the value of $b_{o,i}$ is usually not much greater than $1. \frac{1}{\omega_c}$ is generally about 25. Condition (42) is therefore likely to be satisfied in practice if

$$\frac{b_{1,i} + b_{o,i}a}{25} < 1 \qquad (43)$$

Assuming that the velocity error of the system with perfect forecasts is zero this is equivalent from (39) to

$$\left| a_{1,i} \right| < 25 \qquad (44)$$

If we consider the effect of low frequency structural noise on the system we find that the transfer function for such noise is $a_o + a_1 s$.

Since amplication of such noise is clearly undesirable we may conclude along the lines of section 3.2 that (44) is a desirable design criterion so we may expect it to be fulfilled in practice.

Turning to the system (39) we have that

$$\underline{x}(s) - \underline{x}'(s) = \underline{b}_o(a+\tau)s + O(s^2) \qquad (45)$$

It follows then that

$$\left| x'_i(j\omega) - x_i(j\omega) \right|^2 = b^2_{o,i}(a+\tau)^2\omega^2 \qquad (46)$$

Considering as above a sinusoidal disturbance of amplitude 0.5 i_o and assuming that difference between the systems of up to 10% of the equilibrium value of x_i is acceptable we find

$$0.1\, p_i i_o \geq 0.25\, i_o b_{o,i}(a+\tau)\omega_c \qquad (47)$$

Taking $\left| b_{o,i} \right| \simeq 1$, $p_i \simeq 4$, $\frac{1}{\omega_c} \simeq 25$ as before we have

$$40 \geq (a+\tau) \qquad (48)$$

We thus see that unless $(a+\tau) > 40$ there is likely to be little difference between a system using forecasts derived via exponential smoothing and a system using perfect forecasts.

In this case however it is clear that since at low frequency if terms of $O(s^2)$ are negligible the difference between the systems arises because a system with perfect forecasts can have negligible velocity error whereas a system using a forecast generated by exponential smoothing will usually have a finite velocity error. This suggests that a system using a forecast generated by exponential smoothing can be made to approximate even more closely to one in which perfect forecasts are used by altering the system so that it has negligibly velocity error whilst leaving its high frequency characteristics essentially unchanged. An obvious approach is the addition of integral control action to the proportional control normally used in most system dynamics work.

The advantage of this approach is that it can be extended to systems where at low frequency terms in $\frac{1}{s^2}$ cannot be neglected. In this case a system with perfect forecasts cannot necessarily be tailored to have negligible acceleration error without redesign of the system control structure in which case very little extra effort is requi: to redesign the system to function satisfactorily with forecasts derived via exponential smoothing.

It is perhaps worth noting that such redesign need not necessarily be carried out explicitly but is part and parcel of the usual redesign process which aims to produce, as noted in section 2.1, systems which have negligible velocity error and in which the amplitude of variation of the state variables at low frequencies is of the order p times amplitude of variation of the input. (Forrester, 1961), (Coyle, 1974).

5.1. Interpretation of the Results

The discussion above goes some way towards answering the questions posed in section 1.1. For linear systems at least the Design Criteria generally applied in a system dynamics study tend to make the system relatively insensitive to the types of forecast error considered. Thus at high frequencies as shown by section 3.2. the requirement that the system be insensitive to both high frequency inputs and high frequency noise implies that the system be more or less unaffected by the replacement of a Perfect Forecast either by a forecast with bias or by a forecast derived by smoothing.

At low frequencies it follows from the discussion of section 4.1. that, given the values of parameters that usually occur, the system is able to function acceptably with forecasts with substantial bias. Equally equation (48) shows that unless an accurate forecast can be made a considerable period ahead that there is little advantage to be gained by using it, rather than a forecast derived by smoothing.

Given the Design Criteria adopted the advantages of a perfect forecast boil down to allowing zero velocity error to be obtained. The importance of obtaining acceptably low velocity error at low frequencies is hopefully obvious from the discussion. As indicated in the previous section however an acceptably low velocity error may be obtaine by judicious choice of control laws for the system and the procedure can both be extended to obtain a suitably low acceleration error, if necessary, and also has the advantage of being an integral part of the usual SD approach to system redesign.

Since the forecasting process in industry is usually both time consuming and contentious, there are therefore benefits to be obtained by replacing the forecast thus derived by a simple smoothed average and carrying out any necessary system redesign to ensure acceptable performance. This is perhaps particularly desirable because in the real life situation forecasting error is rarely the pure statistical phenomenon of a random term with zero mean but also involves an often substantial bias due to the aspirations and fears of the forecaster. As we have seen a system designed according to the usual S.D. criteria can absorb considerable amounts of bias without serious effects, but the problem can be circumvented by use of a forecast derived by exponential smoothing Alternatively the selection of control laws so as to give satisfactory performance even with substantially biased forecasts may be possible if the control system is suitably designed, e.g. by the incorporation of a suitable integral control.

In summary then Perfect Forecasts offer little advantage even in theory for the type of systems considered because the system must strongly attenuate high frequency components of the forecast while at low frequencies the errors induced by imperfect forecasts are less serious and can anyway be reduced by careful design of the system in accordance with usual S.D. principles.

5.2 Applicability of Results

The results as derived are applicable only to single input linear systems in which a single forecast is made. Since superposition is valid for linear systems however the extension to systems with several inputs is straightforward. The reasons for considerin that linear systems provide satisfactory approximation to many non-linear models are given in section 1.1.

It is obvious however that the results depend crucially on the Design Criteria of section 2.1. particularly the low pass filter assumption and the assumption that a continuous linear model is a good approximation to the system. Since the sampling period in business systems is generally short by comparison with the settling time a continuous model is likely to be an acceptable approximation as long as there are not substantial discontinuities in the underlying decision process. Thus the results cannot be expected to apply to the type of capacity investment problem which involves large and infrequent investments in capacity, e.g. power stations.

Equally there are good reasons why the low pass filter assumption should have wide applicability. Within an organisation RATES involving physical flows cannot be rapidly varied (Forrester, 1961) whilst, even if the RATES concerned are the responsibility of outsiders such as suppliers, commercial prudence often dictates that the Company do as it would be done by.

The most obvious area in which the low pass filter concept does not apply would accordingly appear to be that in which the RATES involve money transactions that do not involve actual physical flows, i.e. transactions of a speculative nature in financial or commodity markets. In addition this analysis cannot be applied without further refinement to systems where goods are produced to order with short lead times, e.g. the manufacture of fashion fabrics.

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