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An Approach to the Formulation of Equations for Performance Indices

By

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Abstract

It is sometimes useful in comparing one simulation run with another to calculate a Performance Index for a System Dynamics Model. The construction of such indices using a weighted combination of Final Values and Instability Penalties is discussed. The method is illustrated using an example from a study of Mining Companies carried out by the author.

Introduction

Although it is usually the case that a close and painstaking study of the graphical and tabulated output is the best way of understanding the behaviour of an SD model, there are occasions when it is convenient to calculate a Performance Index (PI). This is usually a single number summarizing the whole performance of a run on the model. One advantage of this procedure is that it condenses a whole run into very simple form which may make for ease of presentation of the conclusions of a study to, say, a group of managers. A second advantage is that it gives a uniform comparison of one run with another which may be especially useful when one is 'fine-tuning' a model and the differences between runs are not dramatically evident from the graphical output. In practice this latter case may be less severe than it seems, as a careful choice of graphical scales, allied to the USESCALES facility in DYSMAP, will often magnify small differences. This will be particularly the case when comparative plotting is implemented in DYSMAP.

The third advantage of a PI is that it immediately suggests the use of a hill-climbing package for the design of 'optimal' controllers as argued by Sharp (1976), Winch (1976) and Keloharju (1976).

The advantages and disadvantages of optimal control, per se, are too numerous to discuss here. The disadvantage of the use of PIs will be treated below.

Form of a Performance Index

Generally, a PI reflects the balance between two factors; the virtues of specified variables attaining some values at some defined time point, usually the end of the run, and the penalties for the system of the magnitude of any instabilities in the trajectory of the same, or other, variables during the run. We shall denote these by FV for Final Value and IP for Instability Penalties respectively. The general form of the equation for the Performance Index will be

$$PI = \sum_{i=1}^{n} W_i FV_i - \left(\sum_{j=1}^{m} W_j \sum_{k=1}^{p} IP_{kj} \right) \qquad (1)$$

This means that there are n variables whose final values are used and each is accorded a weight of W_i to reflect its importance. There are m variables, whose instability penalties are to be measured, in each case at each of p points during the simulation, with weights W_j attached to them. The weights W_i and W_j reflect both the relative importance of the individual components of the FV and IP respectively and the relative importance attached to the FV as opposed to the IP, that is, how much instability we are prepared to tolerate for the sake of the attainment of final values.

It will be clear that we do not require the W_i or the W_j to add to 1.0. Similarly, the actual numerical value of the PI has no meaning and all that matters is the relative PI from one run to another. A PI constructed as in equation (1) will clearly be of the 'more means better' variety, but the converse may be used where appropriate.

To illustrate the first type of PI, consider a case where SALES is the instantaneous value of sales in £/month, and STREND is a smoothed, or trend, value of SALES. We might construct the equations

```
A PI.K  =  W1*STREND.K-W2*SVAR.K
L SVAR.K = SVAR.J+DT*((SALES.JK-STREND.J)**INT(2))
K SVAR  =  0
L STREND.K = STREND.J+(DT/TSST)(SALES.JK-STREND.J)
N STREND = SALES
```

The smoothing time TSST would be fairly long and W1 and W2 would be chosen by the method discussed below.

The purpose of the PI is to reward smooth growth in the level of SALES, as measured by STREND. Thus PI increases as STREND does but is reduced by variations in SALES as measured by SVAR. It contains therefore a term for the Final Value, STREND, and for the Instability Penalty, SVAR.

Note that:-

a) The IP term (SALES.JK-STREND.J) is calculated every DT i.e. in equation (1) p = LENGTH/DT

   This is not a requirement and is easily altered by multiplying by a PULSE function of the form
   PULSE(1,PERD,PERD) Where the pulsing interval, PERD, is some integer multiple of DT. This would be particularly important if the IP measured, not the variation about a trend, but the departures of SALES from DATA, where DATA would be a table function recording data about the system at time points PERD apart. This might arise in those rare situations where one tries to 'validate' a model against history.

b) INT(2) squares the deviations to eliminate negative values (see DYSMAP Users Manual, p12). There is no magic in squaring and a higher even power can be used. One might perhaps use the 6th power to penalise variations of more than, say, 10% by putting INT(POWER.K) and separate equations

```
A    ABS.K = CLIP(SALES.KL-STREND.K,STREND.K-SALES.KL,SALES.KL-STREND.K,0)
A    POWER.K = CLIP(6,2,ABS.K,0.1*SALES.KL)
```

   The first equation calculates the absolute value of the deviation.

c) The Instability Penalty can, if required, be expressed in terms of the departure relative to the trend by putting, e.g.,
   ((SALES.JK-STREND.J)/STREND.J)**INT(2)
   Note carefully the order of the brackets!

This takes us to the central question in this paper; how does one arrive at the weights W_i and W_j? A little thought, and, even better, a small simulation will readily convince the reader that poor choice of W_i and W_j will lead to ridiculous results.

An Approach to Choosing Weights

We may most easily consider the choice of weights by an example drawn from the mining company model discussed by Coyle (1977A and 1977B).

The essential point is that the weights represent someone's opinion of what is important, but they must also be numerically consistent with the model. We start, therefore by asserting that, since there is no significance to the numerical value of the PI, we may as well choose a value which is convenient and looks 'good'. We therefore aim for an overall PI of approximately 100. We can rewrite equation (1) as

$$PI = SFV - SIP$$

Where SFV and SIP denote the sums of the Final Values and the Instability Penalties respectively. If someone decides that the attainment of Final Values is r times as important as the avoidance of instability (and we discuss the meaning of this later) we shall have

$$PI = SIP(r-1) \tag{2}$$

which will immediately give the approximate numerical values of SFV and SIP which will leave PI at about 100. If it was decided that r is to be 2, the SFV will have to be about 200 and SIP will be in the region of 100.

In the mining model we need two PI's; one for the holding company, ACZ, and one for the operating subsidiaries. These are denoted by ACZPI and OCPI respectively and they will allow us to test the hypothesis that 'what is good for the subsidiaries is good for the holding company'.

We shall use the following variables, the names for trend variables being given in brackets where they apply.

TOVER (TTREND)	Group Turnover (£/year)
AGPR (PTREND)	Average Gross Profits at Operating Companies (£/m)
ACZRMI (ITREND)	ACZ's Rate of New Investment (£/m)
PR (STAPR)	Production Rate at the Mines (t/m)
CFGAM (CFTREN)	Cash Flow Generated at Mines (£/m)
EML (MLH)	Effective Remaining Mine Life (m) (MLH is a fixed target, not a trend value)

The foregoing are components of the IP's, the following variables are used only as FV's.

TINV	Total Investment (£)
NIACZ	Investment due to ACZ (£)
DISRES	Reserves of Metal discovered (t)
PRTREN	Trend Value of metal prices (£/t) used for valuation of DISRES after allowing £75 for certain costs
ROITREN	Trend Value for Return on Investment (%/year) Used as a rough FV indicator of ROI

In order to calculate the IP's we define IPTOV to be the Instability Penalty to be associated with variations in Turnover.

It is given by

```
L  IPTOV.K  =  IPTOV.J + DT*((TOVER.J-TTREND.J)**INT(2))
N  IPTOV  =  0
```

with similar equations for the other components of SIP.

Care must be taken to ensure that this formulation is only used for variables which do actually display instability. If, for example, TOVER increases smoothly then TTREND will always lag behind and below it, so that IPTOV would have a very large value even though there is no instability to penalise. This would be highly misleading to a Performance Index should <u>only</u> be constructed after one has enough experience with the model to know what to allow for.

TTREND is a smoothed value of TOVER. The IP's for Profit, IPPRO, Rate of Investment, IPRMI, Production, IPPR, Cash Flow, IPCF and Effective Mine Life, IPEML are defined similarly. We shall assume that the following equations adequately represent the respective managerial objectives of ACZ and the Operating Companies.

ACZPI = TINV*W1+NIACZ*W2+ROITREN*W3+DISRES*(PRTREN-75)*W4-(IPTOV*W5+IPPRO*W6+IPRMI*W7)

The PI therefore rewards high values of investment, ROI, and value of discovered reserves and penalises variation in turnover, profit and rate of investment.

The PI for the Operating Companies is

OCPI=TINV*W8+EML*W9-(IPPRO*W10+IPPR*W11+IPCF*W12+IPEML*W13)

This rewards increased investment in, and the maintenance of the life of, the operating mines, while penalising variability in mine profits, production, cash flow, and mine life. For the purpose of this paper we shall suppose that these are realistic in some sense and, for the moment, concentrate on a method for calculating the 13 values of W.

The first step is to run the model, using rough estimates for the values of W_i, but mainly observing the final values of the FV factors TINV, NIACZ, ROITREN, DISRES, PRTREN, and EML and the final values of the IP's IPTOV, IPPRO, IPRMI, IPPR, IPCF and IPEML, for a run on the model which can be regarded as a Base Case. The rough estimates of the W_i are reached by noting the order of magnitude of the inputs to the IP and setting the W value to the reciprocal of twice that order. Thus if CFGAM is in the order of 10^6, W12 could initially be set to 1E-12. This merely serves to keep the PI within reasonable bounds and provides numerical values for the W_i to get the program to run. The W_i can be amended to their correct values very easily, once we have used the initial run to calculate those values.

In this example we observe the following final values for the Base Case

$TINV = 73.460x10^{7}$ $NIACZ = 77.211x10^{6}$ $ROITREN = 5.4926$

$DISRES = 3.8653x10^{6}$ $PRTREN = 754.74$ $EML = 120.75$ $IPTOV = 99.543x10^{16}$

$IPPRO = 90.115x10^{14}$ $IPRMI = 10.376x10^{11}$ $IPPR = 67.413x10^{7}$

$IPCF = 17.040x10^{14}$ $IPEML = 45.629x10^{3}$

Calculation of Weights

We assume that for ACZ, the Final Values are twice as important as the Instability Penalties and we want the PI to be 100 for convenience. Thus we wish to have

ACZPI = 100

so

TINV*W1+NIACZ*W2+ROITREN*W3+DISRES*(PRTREN-75)*W4=200

and

IPTOV*W5+IPPRO*W6+IPRMI*W7=100

for the Base Case run only

If it is decided that the Instability Penalties are equally undesirable then we have

$IPTOV*W5 = IPPRO*W6=IPRMI*W7 = \frac{100}{3}$

Given the values for IPTOV, IPPRO and IPRMI quoted above, we immediately obtain

$W5=3.3486x10^{-17}$, $W6=3.699x10^{-15}$, $W7=3.2125x10^{-11}$

If we assume that the achievement of a high value of ROI is twice as important as the attainment of high values of the remaining three components of the Final Value measures we have

TINV*W1=NIACZ*W2=DISRES*(PRTREN-75)*W4=40

and ROITREN*W3=80

Whence we obtain

W1=5.4451x10^{-8},   W2=5.180x10^{-7},   W4=1.5224x10^{-8}

and W3=14.565

For the Operating Companies, we shall assume a more complicated pattern of relative importance, purely for the sake of illustrating the calculation. As before we need OCPI=100 with

TINV*W8+EML*W9=300

and

IPPRO*W10+IPPR*W11+IPCF*W12+IPEML*W13=200

to reflect an assumption that the Final Values are collectively only half as important again as the aggregate instability penalty, i.e. r=1.5 in equation (2). We shall assume that maintenance of the Final Value of mine life is twice as meritorious as the maximisation of the investment whence we have

TINV*W8=100 and EML*W9=200

which gives

W8=1.3613x10^{-7},   and W9=1.6563

For the instability penalty we take instability of mine life, IPEML, and of profit, IPPRO, as being equally important, with instability of production, IPPR, being regarded as twice as serious and that of cash flow, IPCF, being taken as 3 times as disadvantageous. The total of 200 'points' has to be divided into 7 portions - one each for IPEML and IPPRO, two for IPPR and three for IPCF. Thus

IPEML*W13=IPPRO*W10= $\frac{200}{7}$

IPPR*W11 = $\frac{2}{7}$ x 200 and IPCF*W12 = $\frac{3}{7}$ x 200

With the numerical values from the model we find

W10=3.1706x10^{-15}, W11=8.4765x10^{-8}, W12=5.0302x10^{-14}, W13=6.2617x10^{-4}

In some cases, one might wish to take the growth in, say TINV rather than the final value. This can be done by subtracting the printed initial value from the final value or by putting

```
N START = TINV
A GROWTH.K = TINV.K-START
```

and reading GROWTH. This will obviously alter the weights somewhat.

The drawback to this procedure is that it can lead to apparently distorted results if the growth effects are small in the base case but fairly large in other runs. For example, the growth of EML in the base case is 0.75 and it would therefore have a weight of about 250 if used instead of EML. It is quite easy to produce growth in EML of 100 or more, so that OCPI becomes as high as 25000. This is consistent with the Base Case but it seems to be unreasonable and would be hard to explain to managers. An answer is to use non-linear weights which would have the value of 250 up to, perhaps, 10 units of growth in EML and a far lower weight above that level. The problem is really to make this look like anything more than science fiction to the managers who have to choose the weights.

Comment on the Method

The PI's we have used here are purely to illustrate the weight calculation and have no other objective significance for this paper. A PI can, however, be used as a check on the modelling process in the sense that there should clearly be some correspondence between the factors in the PI and the variables in the Model List in the List Extension procedure.

If the agreement between the two sets of variables is poor it may suggest that the purpose of the project has changed during the evolution of the model. In such a case one needs to verify that the model still meets its new purpose. It may also imply that the purpose was not clearly mastered in the first place, in which case rethinking is even more badly needed!

As far as the weight calculations are concerned, it is worth contrasting the method we have used with the more obvious approach. For simplicity in the example we consider the SFV component of OCPI as this contains the fewest terms, but the following comments are generally applicable.

The'obvious' approach is to put

$$P = f_8 * TINV + f_9 EML$$

where P denotes the 'reduced' PI and we use f_8 and f_9 to avoid confusion with W_8 and W_9. Since EML is taken to be twice as 'important' as TINV we could put $f_8 = 1/3$ and $f_9 = 2/3$ so that $f_8 + f_9 = 1$, or even $f_8 = 1$, $f_9 = 2$. Unfortunately, TINV is in the order of 10^8 and EML is in the order of 10^2. Such a difference of 10^6 orders of magnitude clearly means that EML would never have the least effect on P, and P, being in the order of 10^8, would be rather hard to explain to managers who are often more used to making comparisons in the form of percentages.

Large order of magnitude differences are very common in SD models. For example, IPTOV and IPEML, which might easily appear in the same PI, differ by 10^{13} orders of magnitude! Note also that the largest term in the IP for ACZPI is IPTOV and the largest in the FV for ACZPI is TINV, and these differ by 10^9 orders of magnitude in favour of the IP.

Clearly, unless an approach similar to that described here is used the resulting PI will be usually dominated by one term and will usually mean that the IP will completely swamp the FV.

It should, of course, be realised that the statement earlier that, for example, 'EML is twice as important as TINV' (to paraphrase) is a convenient form of words for saying that 'in the Base Case, EML provides 2/3 of the overall SFV and TINV provides 1/3'. This is better because it is more precise than the ambiguous work 'important'. In practice we would usually tend, however, to use the first version of the statement and it will be important for the analyst to be clear in his own mind about what is really implied and to make sure that the manager, whose views the PI is supposed to represent, also knows what is being put into the PI.

Results of the Indices

To evaluate the weight-calculation method, we must show that it actually works and, in doing this it is useful to discriminate between the two components of the PI, i.e. the Final Value and the Instability Penalty. This is most easily done by writing two supplementary equations to give

FVACZ=W1*TINV+W2*NIACZ+*W3*ROITREN+W4*DISRES*(PRTREN-75)

and

FVOC=W8*TINV+W9*EML

and print these Final Values. The corresponding SIP's can be calculated readily from (ACZPI - FVACZ) and from (OCPI-FVOC)

The results of runs on the model to test several policies are given in Table 1. The policies themselves are not relevant to this paper, though they are discussed in Coyle (1977A).

Table 1 Values of the Performance Indices, Sum of Final Values and Sum of Instability Penalties for the Example

Policy	Values for					
	ACZ			Operating Companies		
	ACZPI	FVACZ	SIPACZ	OCPI	FVOC	SIPOC
A (Base Case)	100.00	200.00	100.00	100.00	300.00	100.00
B	118.14	229.71	111.57	39.95	296.71	256.76
C	112.41	236.29	123.88	56.60	264.61	208.01
D	81.21	197.99	116.78	138.40	326.27	187.87
E	72.19	191.71	119.52	118.40	323.40	205.0
F	58.07	155.21	97.14	0	279.49	279.49
G	128.22	227.66	99.44	165.08	319.70	154.62

For the Base Case, ACZPI and OCPI are actually 99.999 and 100.01 respectively to 5 significant figures. We have ignored the error. The other values are as printed by DYSMAP and have not been adjusted as the possible error of .01 is hardly important.

We note that the method of calculating the weights has indeed yielded PI's for the Base Case which are very close to 100. We should expect this, but it provides a useful, though not perfect, check, particularly on the exponents of the weights.

The value of the method is that the Table of PI's readily demonstrate the falsity of the proposition that 'what is good for the operating companies is good for ACZ'. Although this paper is not about mining companies we can usefully examine the consequences of the PI method by briefly discussing some of the results.

Policy B is one which can plausibly be argued to be good for the operating companies, when viewed in isolation from other policies. The PI shows that it is clearly worse, mainly because of the large increase in the SIP. A more detailed table would show which components of the SIP were responsible.

Policy E represents a switch from Policy C to D half way through the run. Within the limitations of the model, it represents a modern trend of the operating companies having a greater say in their own destinies. From the operating companies' viewpoint it produces results intermediate between those of policies C and D, which is plausible. For ACZ we see worse performance from E than from C or D and the reason for this counter-intuitive behaviour is the decline in Final Values rather than the rise in instability.

Policy F represents an alternative form of 'economic nationalism' in which the operating companies retain more of their earnings, but operate their control policies less severely than in Policy D. Predictably, this is worse for ACZ than either D, or E, because of the fall in Final Value. Surprisingly, it is catastrophic for the Operating Companies due to the huge increase in instability, the equality of Final Value and Instability Penalty being purely fortuitous. The control policies clearly do contribute to the reduction of instability and flattening the policies greatly reduces that contribution.

Finally, to complete the demonstration of what can be deduced from Table 1, we note that there are no policies in which both ACZ and the Operating Companies do better than they did in the Base Case apart from policy G. This is a variation of current political tendencies in that it represents the Operating Companies retaining less rather than more of their earnings with their policies being dominant, as in Run D. In this case, everyone does better and the Operating Companies attain the highest PI in the Table, even by PI's reflecting their own objectives and further, the Operating Companies get the greater improvement. Is this a case of 'Daddy knows best'? This apparently strange result is roughly equivalent to ACZ weakening the dominance by the Operating Companies by, as it were, changing the basic form which that dominance acts. It could represent an approach to bargaining by ACZ in the 'new world' of the 1980's.

The politically more realistic policy for the Operating Companies, D, actually reduces instability there and the reason for ACZ's poor performance with this policy is the rise in instability rather than a fall in Final Value. This at once suggests that further work should be in the area of reducing their instability by redesigning policies they control. In this way, the PI can suggest, by a more detailed examination of its components than we have space for, quite specific policy design tasks for the analyst. In this case, since IPTOV and IPPRO are components of ACZPI which also appear in OCPI one might hope, by reducing their instability components, to improve the performance of both ACZ and the Operating Companies. However, both these measures are essentially controlled by Operating Company policies which may not be accessible to an analyst working for ACZ. His task might therefore be to concentrate on IPRMI.

Problems with the Use of Performance Indices

The output from a Performance Index is so compellingly simple that one is tempted to overlook the real problems, both technical and in principle, of using them.

The first problem is that the weights calculated depend on the run chosen as the Base Case. If, for example, we took the run representing policy D as the Base Case we should find different Final Values and Instability Penalties and thereby calculate different weights, as shown in Table 2, in which the data and results given earlier are restated for convenience.

The only 'data' value which is the same is PRTREN which depends on an exogeneous input, but the rest are only moderately different.

With these new weights we can recalculate the performance figures and obtain Table 3. The values for policy D indicate that the weights have been properly calculated for the new Base Case.

The first feature of Table 3 is that several of the PI's have gone negative, and the results are, in general, very different from Table 1. This is not surprising, in itself, but becomes so when we use Tables 1 and 3 to create Table 4 in which the policies are ranked from 1 - 7 according to the 6 possible measures and compared between the Tables, recalling that, for SIPACZ and SIPOC the smallest value is the best.

The two sets of weights only give the same answer for the Final Value for the Operating Companies and this leads to a fair degree of matching between the policies as measured by the OCPI. This result is essentially accidental and it can be seen from the form of Equation (1) that it will, in general, be very rare that the choice of Base Case will not affect the rank order of the eventual answer. This means that PI's have to be viewed with great caution unless it is manifestly obvious what the Base Case is to be. In general, it will be 'present' system but that is, in practice, sometimes not easy to identify.

The real cause of the problem is that the PI's, as we have calculated them, are dimensionally suspect in that they mix up dimensions such as £, months, $£^2$/Year (for the Instability Penalty on Turnover), and so on. The weights then act in three ways, i.e. as indicators of 'importance', as scaling factors, and as dimensional transformations. This difficulty could be avoided if we could express, say, OCPI purely in financial terms. This could be done for a factor such as IPPR as one could calculate the cost of varying the mine production level providing one was bold enough to make the necessary assumptions but it would be very hard to assign any kind of 'cost' to factors such as Effective Mine Life, other than in very arbitrary terms.

In practical modelling, the answer overall is probably to put a lot of effort into establishing a very closely agreed and specified Base Case and not to pay too much attention to the Performance Index beyond using it as a convenient comparator. This will be even more the case when we have considered the 'philosophical' aspects of PI's.

Table 2 Comparison of Weights from Alternative Choices of Base Case

'Data' from Model			Weights Calculated		
Variable	Run A	Run D	Weight	Run A	Run D
TINV	73.460×10^{7}	72.968×10^{7}	W1	5.4451×10^{-8}	5.4819×10^{-8}
NIACZ	77.211×10^{6}	77.536×10^{6}	W2	5.1806×10^{-7}	5.1589×10^{-7}
ROITREN	5.4926	5.6019	W3	14.565	14.2809
DISRES	3.8653×10^{6}	3.5270×10^{6}	W4	1.5224×10^{-8}	1.6684×10^{-8}
PRTREN	754.74	754.74	W5	3.3486×10^{-17}	3.5231×10^{-17}
EML	120.75	132.01	W6	3.699×10^{-15}	3.8724×10^{-5}
IPTOV	99.543×10^{16}	94.611×10^{16}	W7	3.2125×10^{-11}	2.0106×10^{-11}
IPPRO	90.115×10^{14}	86.078×10^{14}	W8	1.3613×10^{-7}	1.3705×10^{-7}
IPRMI	10.376×10^{7}	16.578×10^{11}	W9	1.6563	1.4597
IPPR	67.413×10^{7}	65.397×10^{7}	W10	3.1706×10^{-15}	3.3192×10^{-15}
IPCF	17.040×10^{14}	18.022×10^{14}	W11	8.4765×10^{-8}	8.7379×10^{-8}
IPEML	45.629×10^{3}	23.145×10^{3}	W12	5.030×10^{-14}	4.7561×10^{-14}
			W13	6.2617×10^{-4}	1.2344×10^{-3}

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Table 3 Values of Performance Indices, Sums of Final Values and Sums of Instability Penalties with Revised Weights

Policy	Values for					
	ACZ			Operating Companies		
	ACZPI	FVACZ	SIPACZ	OCPI	FVOC	SIPOC
A	111.55	202.38	90.88	50.76	276.94	226.18
B	163.47	237.10	73.63	-148.41	272.67	421.08
C	134.27	239.58	105.31	- 26.84	245.02	271.86
D (Base Case)	100.00	200.00	100.00	100.00	300.00	200.00
E	91.85	193.75	101.90	62.92	297.18	234.26
F	139.48	244.98	105.50	- 0.29	247.31	247.60
G	143.77	230.81	87.04	124.36	293.40	169.04

Table 4 Comparison of Rank Order Given by Different Base Cases

Position	Run Holding that Position, According to Attribute, as expressed in Tables 1 and 3											
	ACZPI		OCPI		FVACZ		FVOC		SIPACZ		SIPOC	
	1	3	1	3	1	3	1	3	1	3	1	3
1	G	B	G	G	C	F	D	D	F	B	A	G
2	B	G	D	D	B	C	E	E	G	G	G	D
3	C	F	E	E	G	B	G	G	A	A	D	A
4	A	C	A	A	A	G	A	A	B	D	E	E
5	D	A	C	F	D	A	B	B	D	E	C	F
6	E	D	B	C	E	D	F	F	E	C	B	C
7	F	E	F	B	F	E	C	C	C	F	F	B

By far the more serious problem is the meaning, if any, to be ascribed to the PI in managerial terms. There are three aspects to this; revision of objectives, form of equation (1), and the managerial preferences.

In the first place, managers may change their objectives as the system design improves. It is argued in Coyle (1977C), Chapter 1, that improvements in system behaviour lead us to realise that the system can do better and thereby to demand still better performance from it. This may lead management to introduce more and more Final Values and Instability Penalties into the PI as the design evolves. The labour of recalculating the weights is trivial compared to the fact that there is no guarantee that the system design which has evolved will be the preferred one with the new PI as compared to some other route which one might have taken.

Secondly, it is rather unlikely that complex managerial objectives can really be represented all that well by a fixed mathematical function, still less by the particularly simplistic linear combination function used in equation (1). This leads, thirdly, to the issue of whether the relative importances assigned by managers really reflect anything other than their desire that the analyst should stop asking them apparently naive and oversimplified questions.

In theory, both of these objections can be overcome to some extent by careful education of managers. In practice, it is very unlikely to be so simple and one may, in fact, be dragooning the manager into a method of presentation of objectives which is even more foreign and artificial to him when he understands it than it was before he became 'educated'.

Some advantage may be obtained by trying to formulate a PI almost as an incident in the careful examination of the model output by trying to catch the managerial nuances as the model performance is compared and discussed. In summary, however, we much conclude that, although PI's have advantages, in practical modelling they must only be used with extreme caution and any conclusions based mainly on PI's would have to be viewed with considerable scepticism.

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