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# DETERMINISTIC PRODUCTIVITY ACCOUNTING FOR ENGINEERS TO DECODE FINANCIAL SIGNALS

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## Abstract

Industrial engineers are making increasing use of a new approach which permits productivity decoding of financial signals by monitoring the financial impacts of productivity change. The approach makes use of volume and price data from the accounting system and transforms them to create a set of variances which explains change in financial measures of operating performance with reference to productivity variances and other price-related variances.

The approach is used by the national productivity centres of South Africa, the United States, Australia and Israel. It is referenced in the engineering and economics literature of the United States, is taught in the engineering and commerce faculties of major South African universities, and has been adopted by premier South African undertakings such as Vaal Reefs, Gencor, AECI, Iscor, Eskom and the Post Office.



## Abstrak

Bedryfsingenieurs maak toenemend gebruik van 'n nuwe metingsbenadering wat die produktiwiteitsdekodering van finansiële seine insluit, ten einde die finansiële impak van produktiwiteitsverandering te kan monitor. Die benadering maak gebruik van die volume- en prysdata van die rekeningkundigesisteem en skep 'n stel afwykings wat die verandering ten opsigte van bedryfsprestasie as 'n stel produktiwiteitsafwykings en ander prys-verwante afwykings weerspieël.

Die benadering word deur die nasionale produktiwiteitsentras van Suid Afrika, die Verenigde State, Australia en Israel gebruik. 'n Uiteensetting van die benadering het reeds in die tydskrifte van Bedryfsingenieurswese en Bedryfsekonomie in die Verenigde State verskyn, en kursusse wat die benadering insluit word in beide die fakulteite ingenieurswese en - handel aan die Suid Afrikaanse universiteite aangebied. Vooraanstaande Suid Afrikaanse ondernemings soos Vaal Reefs, Gencor, AECI, Yskor, Eskom en die Poskantoor maak gebruik van die benadering.


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## Background

Industrial engineers are trained to aim at improving operations (i.e. raising productivity). A commitment to improve productivity creates a need for productivity measurement. Without productivity measurement there would be no score-card to ascertain whether systematic efforts to raise productivity are bearing any fruit. Notionally defined, productivity is a quotient of a quantity of product (i.e. output of goods and/or services delivered) and a quantity pertaining to a subset of resources (i.e. input comprizing materials, labor and capital needed to make product).

The case for productivity measurement was put as follows by Peter Drucker, the noted management authority:

"Without productivity goals a business has no direction, and without productivity measurement a business has no control".

The purpose of productivity measurement is therefore control. Control is facilitated when measures of the extent of productivity change are used by those responsible for monitoring resource allocations to pose questions to those who allocate resources. It is noted that the productivity quotient has no necessary causal significance. Changes in productivity express effect and not cause. Causal insight can only be provided by those familiar with a given operation. Ongoing productivity measurement, otherwise known as productivity tracking, therefore poses rather than answers questions.

Productivity improvement has a "hard" (i.e. objective, tangible, robust) aspect and a "soft" (i.e. subjective, elusive) aspect. Productivity measurement is "hard". Its "soft" concomitants include management commitment to respond to signals generated by productivity measurement, and the more difficult process of modifying value systems and behaviour patterns at organizational and personal levels. Productivity measurement is hence necessary, but insufficient, for systematic improvement of productivity.

A primary feature of this work is the specification of productivity measures which offer a "bottom line" linkage, i.e. linkage to the financial accounting system of the producer. Experience shows that any measure of productivity which exists as a discrete measure unconnected to the financial system commands limited credibility since it sooner or later sends signals which conflict with signals from the financial accounting system. A classical example of such a conflict arises when the productivity measure signals improvement while the financial accounting system signals deterioration.

The work presented in this article is totally deterministic. The preference of the engineering and accounting communities for rigor, precision and freedom from ambiguity indicated at an early stage a need to develop, as far as possible, a deterministic methodology in lieu of a stochastic one.

## Basic Notions

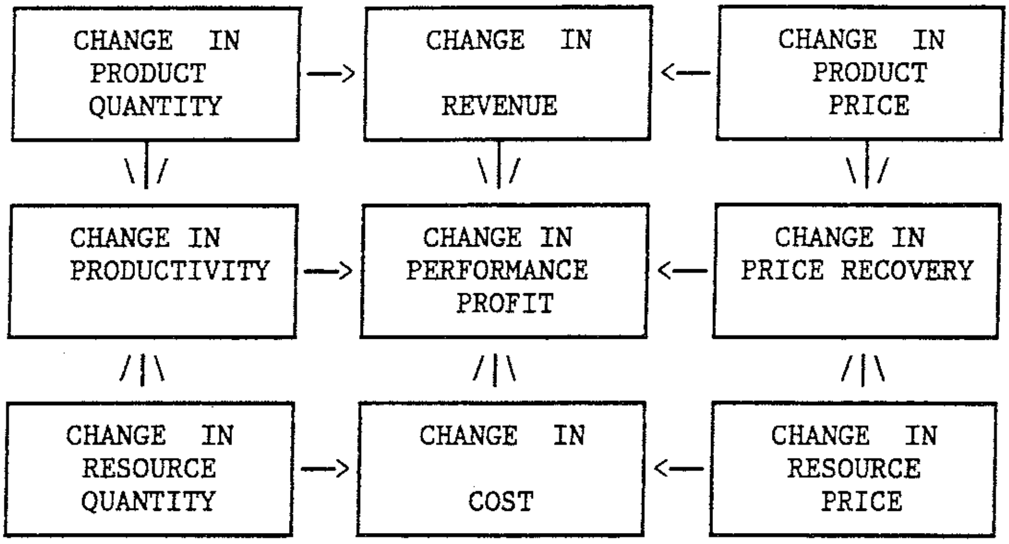
Each relation is specified below and refers to product (i.e. output comprizing the good or service produced) and resource (i.e. input comprizing material, labor and capital resources needed to make product).

$$\text{PRODUCTIVITY} = \text{PRODUCT QUANTITY} \,/\, \text{RESOURCE QUANTITY} \qquad (1)$$

PRICE RECOVERY = PRODUCT PRICE / RESOURCE PRICE (2)

The way in which change in the productivity and price recovery relations impact change in profit is explained in a notional manner in figure F1 as a prelude to the algebraic and geometric definitions specified below.

Figure F1 NOTIONS OF PERFORMANCE CHANGE




The above notions flow from the following accounting identity which is true for product and resource.

VALUE = QUANTITY x PRICE (3)
in $ in units in $/unit

The above identity is used to explain change in the profit of a business between two accounting periods. It is used to derive the following accounting variances for each cost resource and each capital resource used in an operation.

PERFORMANCE PROFIT VARIANCE in $ = CHANGE IN PRODUCTIVITY in $ + CHANGE IN PRICE RECOVERY in $ (4.1)

= CHANGE IN CAPACITY UTILIZATION in $ + CHANGE IN EFFICIENCY in $ + CHANGE IN PRICE RECOVERY in $ (4.2)

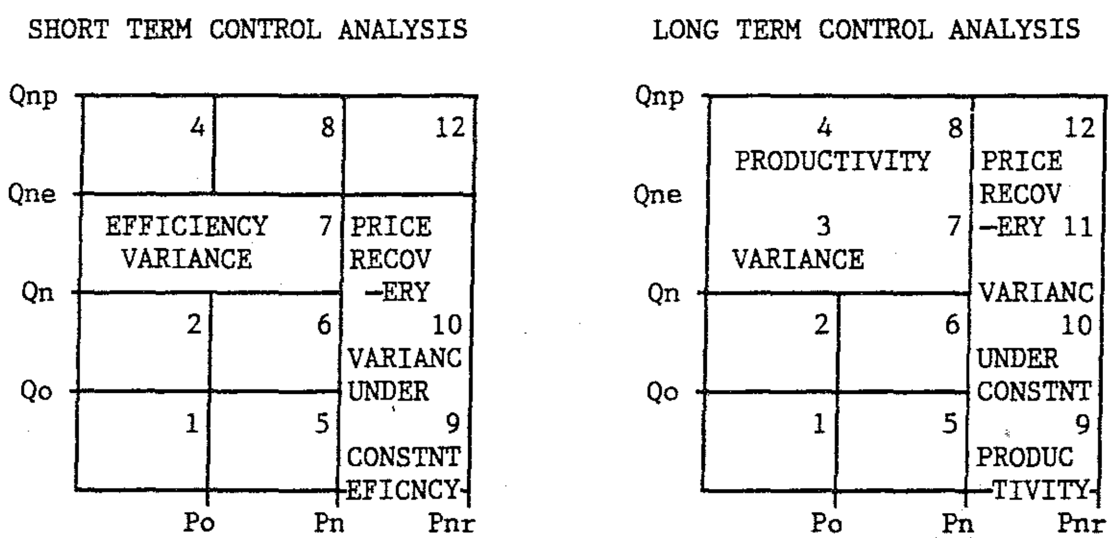
Change in profit usually refers to change in profit associated with change in return on investment or return on sales. Other profit variances needed for reconciliation with change in the income statement are also provided by the model. They are not germane to this article and are therefore omitted.

Profit stands on a productivity leg and on a price recovery leg.

producer's viewpoint, it is typically more controllable than price recovery.

Equation (4.2) shows that change in productivity is decomposed into a term for change in capacity utilization (which shows the effect of spreading a quantity of fixed resource over a change in production volume) and a term for change in efficiency (which shows the effect of change in the consumption of variable resource per unit of production and change in the level of fixed resource which is not justified by the change in production volume). At an industry level, business cycle change causes change in capacity utilization while change in efficiency typically expresses the commissions or omissions of management intervention. The breakdown of equation (4.2) by resource is valuable for control purposes.

Figure F2 – GEOMETRIC DEFINITION OF PERFORMANCE VARIANCES




The derivation of functions shown on vertical and horizontal axes of figure F2, and the concomitant performance variances, are specified below.

| | | | | |
|---|---|---|---|---|
| Qou | = | old (product) quantity | (given) | (5) |
| Qnu | = | new (product) quantity | (given) | (6) |
| Pou | = | old (product) price | (given) | (7) |
| Pnu | = | new (product) price | (given) | (8) |

$$B = \frac{\text{sigma over "u"} \quad [Qnu - Qou] * Pou}{\text{sigma over "u"} \quad Qou * Pou} \qquad (9)$$

= ratio of change in old-price-weighted total product quantities

= change in Laspeyres quantity relative for total product

$$C = \frac{\text{sigma over "u"} \quad Qnu * [Pnu - Pou]}{\text{sigma over "u"} \quad Qnu * Pou} \qquad (10)$$

= ratio of change in new-quantity-weighted total product prices

= change in Paasche price relative for total product

D = resource variability ratio (given) (11)

Qo = Old (resource) quantity (given) (12)

Qn = New (resource) quantity (given) (13)

Qne = Qo * [1 + B * D] (14)

= New (resource) quantity normalized for constant efficiency

Qnp = Qo * [1 + B] (15)

= New (resource) quantity normalized for constant productivity

Po = Old (resource) price (given) (16)

Pn = New (resource) price (given) (17)

Pnr = Po * [1 + C] (18)

= New (resource) price normalized for constant price recovery

δx = New interval − old interval (given) (19)

$$\text{PERFORMANCE PROFIT VARIANCE} = \frac{Qnp * Pnr - Qn * Pn}{\delta x} \quad (20)$$

$$\text{CAPACITY UTILIZATION VARIANCE} = \frac{[Qnp - Qne] * Pn}{\delta x} \quad (21)$$

$$\text{EFFICIENCY VARIANCE} = \frac{[Qne - Qn] * Pn}{\delta x} \quad (22)$$

$$\text{PRODUCTIVITY VARIANCE} = \frac{[Qnp - Qn] * Pn}{\delta x} \quad (23)$$

$$\text{PRICE RECOVERY VARIANCE NORMALIZED FOR CONSTANT EFFICIENCY} = \frac{Qne * [Pnr - Pn]}{\delta x} \quad (24)$$

$$\text{PRICE RECOVERY VARIANCE NORMALIZED FOR CONSTANT PRODUCTIVITY} = \frac{Qnp * [Pnr - Pn]}{\delta x} \quad (25)$$

To evaluate the direction and tradeoff of resource substitutions, short term analysis pairs the functions given in statements (22) and (24) while long term analysis pairs the functions given in statements (23) and (25).

Readers requiring more information on the application of the concept and its mathematical derivation are referred to the bibliography. Three notations have been published to reach audiences with differing levels of mathematical appreciation.

Notation 1 is the simplest articulation of the concept and is contained in the first reference in the bibliography. It is non-technical and provides managers with a description of the analytical tool and how it is used to improve the allocation of resources and hence profitability. This notation is used in courses in third year engineering, third year business economics and in graduate schools of business.

Notation 2 is algebraically more demanding than notation 1. It employs an index set comprizing 3 arguments to specify difference equations which range from ordinary differences of degree one and order one to partial differences of degree one and higher order. Notation 2 is contained in the second reference in the bibliography. It is used in courses in fourth year engineering.

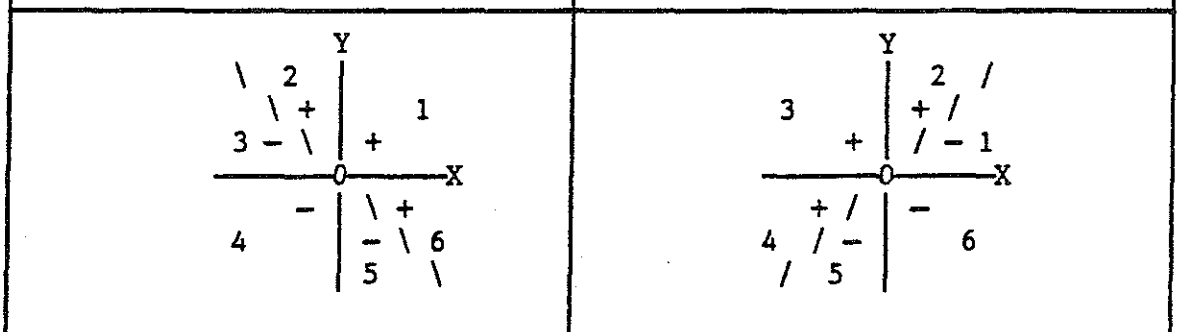
Notation 3 is algebraically more demanding than notation 2. It employs a more generalized index set, comprizing 3 arguments and several sub-arguments, to specify difference equations which range from ordinary differences of degree one and order one to partial differences of higher degree and higher order. This notation is contained in the third and fourth references in the bibliography. It is used in postgraduate courses in engineering and specifies the highly generalized deterministic mathematical structure which underpins the model.

G r i d s

A family of grids is employed to depict in graphic form the relationships uncovered by the partial difference equations specified above. In each of the following grids the 5 segments above the diagonal are financially favorable, the 3 segments on the diagonal are financially neutral, and the 5 segments below the diagonal are financially unfavorable. For a comprehensive discussion of each segment in each grid, see the first reference in the bibliography.

Figure F3 – GRIDS DEPICTING SPECIAL CASES OF PERFORMANCE MEASURES

| FUNCTION = Y + X | FUNCTION = Y – X |
|---|---|



| PROFIT GRID | PRODUCTIVITY GRID | QUANTITY GRID | PRICE GRID |
|---|---|---|---|
| Y = PRODUCTIVITY | CAP UTILZTN | PRODUCT QUANTITY | PRODUCT PRICE |
| X = PRICE RECOVERY | EFFICIENCY | RESOURCE QUANTITY | RESOURCE PRICE |
| 0 CENTER | 0 CENTER | 0 CENTER | 0 CENTER |
| 1 AWAKEN | 1 WIN | 1 LIFTOFF | 1 TRAIL |
| 2 PURSUE | 2 GAMBLE | 2 ORBIT | 2 SPURT |
| 3 FINETUNE | 3 SQUANDER | 3 DISCHARGE | 3 GOUGE |
| 4 SCUTTLE | 4 LOSE | 4 OVERREACT | 4 SHAVE |
| 5 SALVAGE | 5 RECOUP | 5 HOARD | 5 PARE |
| 6 SCRAMBLE | 6 EXCEL | 6 DESTRUCT | 6 SLASH |

## S o f t w a r e

Two commercial implementations of deterministic productivity accounting have been made for microcomputers. They offer the 1984 and 1987 specification of the author's work. The latter software release also contains an expert system which implements all the explanatory text which supports the grids defined in the first item in the bibliography. The expert system attracts strong interest from users as it reduces the upfront intellectual investment users are required to make when no expert system is available.

## C o n c l u s i o n

Industrial engineeers are better able to identify and evaluate opportunity to improve operations using deterministic productivity accounting to decode financial signals. Although the engineer who masters the mathematical and analytical structure acquires expert insight into the measures generated by this new approach, his communication with management is considerably facilitated by the expert system which offers a stand–alone reporting system to simplify the presentation of expert information to the non–expert. The prospect for improving operations (i.e., raising productivity) is favourable if the "hard" inferences regarding effect which are measured by deterministic productivity accounting are supported by the "soft" inputs which are described in this article and which are necessary for engineers to proceed beyond effect and to uncover the cause of productivity change so that remedial action can be taken where necessary.

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