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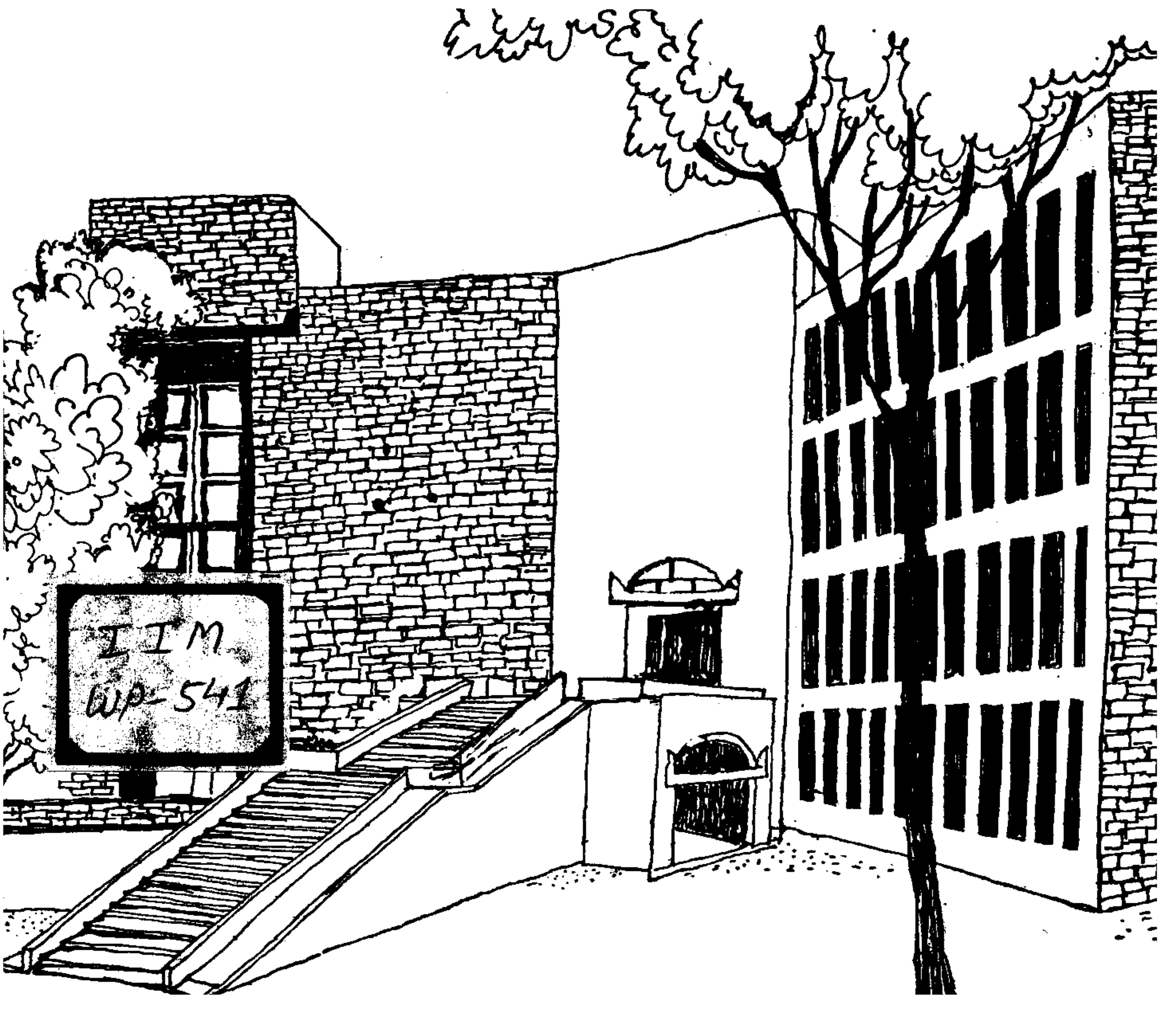

MODELS OF PRODUCTIVITY MEASUREMENT
A STUDY

By

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Models of Productivity Measurement – A Study

Productivity and its measurement has occupied the attention of managers, bureaucrats, researchers, academicians and trade unions, the world over. Consequently a great deal has been said and written on the subject. Considerable efforts have been spent on the analysis of this vital ingredient of the success and well being of a business enterprise. These have resulted in development of a number of refined and rigorous methods of measuring productivity at enterprise level as well as strategies to improve the same. Thus a body of knowledge can now be said to have evolved on our understanding of productivity, its measurement and improvement. In the present work, an attempt is made to study some important models of productivity measurement, which have evolved in recent years. Problems of productivity measurement as well as current status regarding use of productivity indicators are also studied. The study, it is felt, would be of assistance to those interested in the implementation of productivity programmes in their respective organizations, as well as those intending to persue further research in this vital area. Our effort will be to concentrate on the more salient aspects of these models and their applications. A critical analysis of the models is made to identify areas requiring further attention.

The beginning of the productivity movement in manufacturing system dates back to the time of F.W. Taylor and even earlier. Understandably, the movement received impetus during and after World War II, because of the multiplicity of challenges the war posed. Apart from the United States, countries on the European and Asian sub-continents were amongst the first to recognize the need for increased productivity. There was deliberate attempt on the part of the governments of these countries to support productivity programmes and form national and regional productivity bodies. While the movement is percolating to more and more countries, it has gained national priority in developed countries. A nation's productivity is now unquestionably regarded as one of the two major determinants of the way of life of its people – the other being its socio-political system. A productive economic system of producing goods and services is necessary for a high standard of living.

1 Productivity Measurement - some key issues

Traditionally, productivity is defined as the ratio of output to input. Inputs are predominantly manpower, capital, materials, energy, etc. The output is variously expressed as the number of physical units, money value of production, money value of sales, value added by manufacture , etc. The inputs similarly could be expressed in terms of manhours, direct labour costs, total labour costs, total costs, capital costs, foreign exchange cost and so forth. The commonly used indicator of productivity rise or fall is 'productivity index'. Indices used in the past range from the intangible and comprehensive expression of GNP per capita to the precise engineering time analysis of manhours to perform a specific operation in particular factory. Between these extremes, other indices are possible like general industry index which is the aggregate output per manhour.

Quite often, output per manhour is used as a measure of productivity. Although this is appropriate for labour productivity, it may not reflect total productivity. Increase in labour productivity need not always imply corresponding increase in total productivity. Holt(1) illustrates this point very well by considering a situation in which higher labour productivity is achieved by replacement of an old equipment. Holt shows that increase in labour productivity increases total productivity, but increase in capital cost of new equipment works in the opposite direction and may, if it is large enough, result in decrease of total productivity.

The above simple illustration helps highlight some of the important issues which arise in productivity measurement. To summarise, these are in some way, associated with the following:

i) Purpose and objectives of productivity measurement
ii) Criteria for measuring productivity
iii) potential errors likely in measurement
iv) problems of measurement.

We shall consider these aspects in some detail, in the following discussions.

2 Purpose and objectives of productivity measurement

Eilon(2) provides an interesting elucidation of the reasons for productivity measurement. According to him, the guidelines as to how to measure productivity may be gained from an analysis of why we should wish to measure it. The reasons for this are four fold:

i) for strategic purposes - in order to compare the performance of the firm with that of its competitors or related firms, both in terms of aggregate results and in terms of major components of performance.

ii) for tactical purposes - to enable management to control the performance of the firm by identifying the comparative performance of the individual sectors of the firm, either by function or product.

iii) for planning purposes - to compare the relative benefits accruing from the use of different inputs or varying proportions of the same inputs, currently and over long periods, as the basis for considering alternative adjustments over future periods, and

iv) for other management purposes - such as collective negotiations with trade unions, assessing the effects of prospective governmental restrictions, etc.

The objectives of productivity measurement stem from the above stated purposes. Not all objectives, of course, may be of equal importance to a given firm. Thus in one firm, productivity measurement may be primarily dictated by the requirements of collective negotiations with trade unions. In another firm productivity might be the key to remain competitive. It is therefore essential that those objectives are clearly stated and persued by the productivity programmes.

3 Criteria for productivity measurement

Nevertheless, it is useful to bear in mind that useful productivity measures should satisfy certain criteria. For instance, the measure should relate all significant inputs to the production of the organization's output. It should also remove the impact of inflation both in inputs as well as outputs. Among the other criteria, the following are noteworthy. (Balke 3, Stewart 4).

i) the measure should provide a clear understanding of the nature and causes of changes observed in measurements.

ii) It should trace the effects of observed changes on traditionally reported financial and operating results, i.e., costs, prices, profit and return on investment (ROI).

iii) It should provide a sound indication of operations adjustments required to improve results.

iv) It should provide a reasonable estimate of the impact of prospective changes in operations on the measures employed and in turn, on costs and profitability.

v) It should account for product mix and quality shifts and not give results with respect to productivity which are solely due to product mix phenomena.

4 Typical errors in productivity measurement

A number of errors are commonly made in productivity measurement. For instance, if output is measured in terms of money value of goods produced, it would hardly make sense to compare an output worth say Rs.1 crore, this year with an output of Rs.1 crore some ten years ago and argue that productivity was same these two years. An excellent analysis of the potential errors often made in measuring productivity is provided by Mundel(5). Quite apart from the errors caused by using indices which fail to measure what is otherwise defined as improvement, the following, more seriours, errors are commonly found:

i) Use of overly simplistic measures of output
ii) Suboptimization
iii) Counting outputs in a manner that related to goals
iv) Counting outputs which are not final outputs
v) Counting outputs in a manner not related to inputs.

To elaborate, consider a situation where only a few products instead of all the products in the product mix are counted as output merely because these account for bulk of say, labour input, in the current period. In subsequent periods, the production of other outputs may well increase at much faster rate. Similar examples could be cited to illustrat the other errors also. To mention but a few of these, consider the situations below:

4.1 Sub-optimisation: Use of unit laboratory cost as measure of productivity is common in hospital laboratories. This is achieved by matching manpower in the laboratory to the workload. Such close matching can well lead to patient backlogging, due to uneven arrival rate. This circumstance actually leads to system productivity loss as a whole due to wastage of hospital facilities, time of nurses, pharmacists, orderlies, etc.

4.2 Outputs which are not final: Again for measurement of hospital system productivity, cost per bed day is often used as a measure. However, a bed day is not a final output. A healedpatient is. But mere counting of healed patients is oversimplistic, as the type of diagnosis, nature of patients (in patients or out-patients, etc.) need to be taken into account.

4.3 Unrelated outputs: It will be erroneous for a quality assurance department to measure its productivity in terms of number or value of defective products found. Clearly defective product is not the objective, avoiding it is.

4.4 Unrelated labour resources: The productivity of a metereological department should not be measured by the number of say cyclones it tracked. The department does not make the cyclones. The real output of the department is 365 days in a year of carefully monitored and reported weather.

5 Problems of productivity measurement

Even if productivity measures were based on sound criteria and devoid/the errors of the type discussed above, there still remain /of some difficult problems of productivity measurement, in the context of a particular firm. These include:

i) Measuring outputs whose characteristics change over time.

ii) Defining and measuring real capital stocks and 'inputs' as well as labour inputs when the characteristics of both factors are diverse and changing.

iii) Problems of aggregating heterogeneous units of output and input

iv) Determining which particular input output relationships are most important.

For instance, output measurement necessitates the choice of a weighting system to aggregate heterogeneous output. In addition, problems resulting from changing quality levels over time, the production of capital goods by the firm for its own use, handling of returns from intangible capital outlays require specific attention. In 'Job shop' environments, physical counts are meaningless. Thus one approach has been to estimate the 'aggregate price' of goods and services produced in a time frame of reference. On the input measures, it is customary to combine labour, capital, materials costs and costs associated with intermediate purchases. It is generally desirable to deflate the cost estimates by the approximate indices. A systematic and detailed study of these problems has been reported by Kendrick and Creamer(6). Their findings are briefly summarised below:

5.1 Outputs and intermediate inputs

The important questions here pertain to the following:

i) What is being measured

ii) Variable purchased goods and interplant transfers

iii) Production of own machinery

5.2 i) What is being measured - since the interest is in total current production and not physical volume of shipments, the estimates of net sales billed or the value of shipments must be adjusted for inventory change. Goods in process are also to be valued. To deflate the value of inventories, weighted index numbers of average hourly earnings of labour and of the prices of raw materials are required. The finished goods inventories would be deflated by a price index in accordance with relative values of various goods in stock.

5.3 ii) Variable purchased goods and interplant transfers: Intermediate goods, components or services not wholly integral to the operation, but subject to purchase from outside in varying ratio to internal production, should be counted separately and weighted according to the unit cost or value assigned in interplant transfers. The weights given to the company's final outputs should be reduced accordingly.

5.4 iii) Production of own machinery: Capital goods produced by the firm for its captive use should be accounted for. The expenditures charged to capital input, should be deflated and added to other current production.

5.5 Intangible Capital outlays: Typical examples include long range R&D expenditures, outlays for educational training programs, advertising and public relations, etc. The outlays are charged to current expense. Their output is extraordinarily difficult to measure. One way to treat them is to compute productivity changes after excluding the real costs of intangible investments both from input and output, and then impute the estimated productivity changes in current production to the real costs of intangible investment.

5.6 Quality Change: In case changes in average quality of output take place, as a result of relative shifts of production among co-existing 'qualities', output can be separately measured in terms of each type or 'quality' of the product. Difficulties arise when a change in quality is introduced in the same product type. When the change is significant, some adjustment is called for. A simple method is to count the entire price increase due to quality as an increase in quantity. Another method is to estimate the 'pure' price change accompanying the introduction of new model. The difference in cost of bill of materials (at constant prices) and labour to produce a new model compared to the old one is estimated. Thus, if there was a 3% increase in such costs while prices rose 5% the pure price increase will be set at 2% when models are constructed from essentially the same parts and components as the old, the total cost of producing this new model can be deflated by a composite index of unit cost of components.

5.7 New Products. The main problem here is that the new product isintroduced after the base year. An usual convention is to extrapolate the initial period price back to the base period by the price movement of a closely related product or product group. An alternative procedure is to cost the new item in terms of standard costs of the base period.

5.8 Custom built products: If the custom built products are constructed from more or less standardised components, the cost of producing the components is deflated by an index of unit costs. If the proportion of custom built output is small, same price index as used for standardised products could be used. When bulk of output is non standard, the problem is attacked directly as in the case of construction, ship-building, aircraft manufacture, etc. One method is to aggregate the prices of parts and components. Another method is to find a physical common denominator of output, for ex: square feet of floor space in building construction. So output may be measured in square feet for significant categories within which shifts in product mix over time would not be ex-pected to cause significant changes in real price per square feet.

5.9 Intermediate product inputs: Materials and contractual services purchased by firms represent the output of other firms. The methods of estimating these inputs at constant price terms are exactly the same as the methods of estimating physical outputs. It is necessary to break down the direct materials and the indirect supplies and contractual service costs of goods sold by type. In some cases, there will be records of physical units consumed. In other cases, the cost estimates will have to be deflated by the appropriate price indices.

5.10 Labour input: Manhours actually worked, weighting of manhours and total average hourly compensation are the three main issues here. Man hours should be measured as those actually worked rather than those paid for, because productivity measures/concerned with real /are input-output relationships. Manhours as a whole are a diverse collection. Even if total manhours worked do not change but there is a shift in the distribution of manhours towards higher paying occupations, weighted manhour input will rise. The weights by which manhours of various types are combined should be average hourly labour compensation of all types including fringe benefits. The same result may be obtained by deflating total labour compensation by an index of average hourly compensation including fringe benefits.

5.11 Capital input: All capital resources used by the firm must be included both in the form of equity funds and debts. The capital measurement should parallel output measurement. Thus, if output measure excludes R&D activities, the plant and equipment supporting these activities should also be excluded from capital input. If conventional accounting procedures are followed, fixed capital net of depreciation could be used.

In the case of working capital, the balance sheet values at purchase prices are virtually identical with values at current prices. A series of indices have to be found to relate the current period prices to those in the base period. Thus, in case of cash, the appropriate deflator is a composite index of average hourly earnings, prices of operating materials and other supplies and a construction cost index for industrial structures. To form the composite index, each should be weighted by its relative importance in the production process. In case of accounts receivables, the appropriate deflator is the price index of its own sales. The same is used to deflate finished goods inventories. For raw material inventories, the price index of purchased materials is most suitable. For work-in-process inventories, the relevant index is a composite of the purchased materials prices and average hourly earnings weighted by the relative contribution of each to the cost of semi finished inventories.

As for fixed capital the starting point is either the balance sheet or the accumulation of annual expenditures on structures and machinery, less depreciation charges. A price index is used to deflate net book values to base period prices. These measures result in real net capital (i.e., capital after depreciation at constant prices). Finally the investor's input is calculated. This is real net capital weighted by the rate of return in the base period. The rate of return is equal to net income before tax and interest payments, but after depreciation in the base period divided by the total of working and fixed capital revalued in the prices of base period. The base period rate of return is applied to total capital of the measured period expressed at base-period/to obtain investor's inputs. /prices

6 Survey of productivity measures: To understand the status with regard to the adoption of productivity measures, it will be beneficial to review the results of a survey carried out by Sumanth(7,8) on productivity indicators used by major U.S. industrial and non-industrial corporations. In this survey the organizations were asked to list two most useful productivity indicators they used in 17 functional departments, namely: manufacturing, sales, marketing, purchasing, personnel, finance/accounting, legal, engineering, research and development, quality assurance, maintenance, industrial engineering, data processing, administration, word processing, distribution warehousing and planning.

The productivity indicators were classified into 4 major categories, namely: partial productivity indicators, total factor productivity indicators, total productivity indicators and other non-standard indicators. The partial productivity measures included: labour productivity, capital productivity, materials productivity, and energy productivity. Total factor productivity(TFP) is the ratio of net output (excluding materials from gross output)to the sum of labour and capital inputs. Total productivity (TP) is the ratio of gross output to all inputs which included human, material, capital, energy and other expense inputs. The non-standard category included all those indicators which do not qualify to be categorised in the first three.

In the case of industrial corporations, questionnaires were addressed to 1000 largest corporations based on Fortune magazine's 1978 ranks. Out of these, 61 industrial corporations responded. These represented a cross section of the leading industrial companies, in U.S. In the case of non-industrial corporations, questionnaires were addressed to 300 largest non-industrial corporations based on Fortune's 1978 ranks. Responses were obtained from 29 of these. The responding companies included five of the six types of non-industrials (commercial banking, life insurance diversified financial, retailing, transportation and utilities). These represented a cross-section of leading non industrial companies in U.S. Tables 1, 2, and 3 summarise the results of the survey.

It was found that in case of both industrial and non industrial corporations, in almost all functions, the frequency with which non-standard indicators are mentioned outnumbers that of standard productivity measures. On an average, partial productivity measures are listed 19.3% time for industrials and 19.5% time for non industrials. TFP and TP measures are listed 0.5% time for industrials and 1% time for non industrials. Non-standard indicators are reported 80.4% time for industrials and 79.5% time for nonindustrials. Clearly the trends in both types of corporations are similar. In case of industrial corporations, highest number of indicators were reported for manufacturing function followed by sales, quality assurance and maintenance functions. In case of non industrial corporations, highest number of indicators were reported for sales, followed by operations, finance, accounting, data processing and word processing.

Some of the non standard indicators used are quite misleading, such as 'direct manhours' or 'total hourly payroll hours'. It is clear that reduction in direct manhours need not necessarily imply improved productivity. Similarly indiscriminate use of partial productivity measures can be extremely misleading. For instance, output/manhour may increase because of use of more technologically advanced equipment for a particular machining operation. After all in any company's productivity effort, the major attempt must be to reduce total manufacturing and selling cost, so that prices could be made competitive to gain a greater market share, without sacrificing profits. Thus, the true test of productivity improvement effort must be to increase returns without creating inflationary forces in the market. In this respect total productivity indicators are ideal. It is therefore clear from Sumanth survey that even in U.S., there is an imperative need for educating the industrial and non industrial corporations about the usefulness of total productivity measurement.

Certain specific measures being currently adopted in different sectors are also reported by Aggarwal(9). Among these are the following:

i) manufacturing sector - total factor productivity and profit/ total investment index.

ii) Government - A commonly used measure in government department is

$$\text{Productivity} = \frac{\text{Aggregate output in std. manhours earned by employees}}{\text{Man hours actually spent}}$$

The productivity of a government fundamentally needs to focus on increasing services at a given cost. If the most desirable service/ services being provided by each department can be identified, then measuring departmental productivities becomes a simple affair since in most departments, the major portion of costs can be directly attributed to personnel.

iii) Service industry - measures used are goal-oriented. One such measure is revenue generated per man day. For different services, specific measures are also in use. For instance, in hospitals a recommended measure is weighted number of patients healed per man year.

iv) Office work - Percentage of time spent by each person on useful and desirable activities is in use. The overall productivity measure for the office is similarly percentage time spent on such activities by the office as a whole.

v) Bank and Insurance companies - In case of banks, a preferred measure is the number of transactions processed per manday. For an insurance company, a similar measure is the number of premiums or claims processed per man year.

Table 1: Most Commonly Used productivity indicators in Manufacturing function(7) (Industrial Corporations)

Commonly Used productivity Indicators	No. of times mentioned	%
1) Partial productivity		
Human productivity indicators - Output/man hour, units/manhour, value added/labour hour, pounds/work hour, output/direct labour hour, yards/work hour, production/hour, production/no. of hour worked, tons/manshift, brl/man, output/man, No./manhour, Real output/employee, sales value of production/person, unit output/employee, value added/person, Net income/dollars of pay-roll; production value/labour dollar, value added/labour dollar, shipments/labour cost.	30	41.1
Machine productivity: output/machine hour, tons/machine hour.		
Energy productivity : production value/energy consumed, barrel production/barrel fuel.		
Space productivity : Units/dollars factory space,		
Fixed capital productivity: Barrel production/plant replacement value.		
2) TFP Measure. Value added/(labour + capital) input	1	1.4
3) TP measure. Output/input (constant dollars)	2	2.7
4) Non-Standard measures. manhour/unit, manpower/unit, cost/unit, factory cost/unit, •units of production, assembly hour/structure pound, direct man hour, total hourly payroll hour manufacturing expense/direct labour dollars, percent down time, plant utilization, per cent deliveries on time, labour efficiency, standard hour produced, standard hour reduced, standard hour, manpower efficiency, labour standard hour/$ 1000 sales actual labour hour/standard hour, actual units/standard units and performance to standard, hr earned/production hour, net allowed hour/elapsed hour. Volume produced, cost, schedules, yield, weight, dollars/100 lb. labour, material. % of on-time deliveries.	40	54.8

INDUSTRIAL ENGINEERING FUNCTION:

Non-Standard Indicators

Manpower/Unit, net production/machine, reduction in labour, methods savings, return on IE dollar, savings/year, return on investment, IE index, IEs %/sales billed, IE expense/ $ 100 production, incentive dollars/net sales ratio, income improvement dollars/cost of manufacturing, no. of new parts routed, actual/standard performance, cost improvements/person, method variance, labour standard/man hour.	18	100

Table 2 Productivity Indicators on Industrial Companies: A Summary (Industrial Corporations) (7)

FUNCTION	Partial Productivity Indicators		TFP Indicators		TP Indicators		Other Non-Std. Productivity Indicators	
	No. of times reported	%	No.of times reported	%	No.of times reported	%	No. of times reported	%
Manufacturing	30	41.1	1	1.4	2	2.7	40	54.8
Sales	16	39.0	0	0	0	0	25	61.0
Marketing	6	22.2	0	0	0	0	21	77.8
Purchasing	4	15.4	0	0	0	0	22	84.6
Personnel	3	11.5	0	0	0	0	23	88.5
Finance/Accounting	5	23.8	0	0	0	0	16	76.2
Legal	1	14.3	0	0	0	0	6	85.7
Engineering	2	8.3	0	0	0	0	22	91.7
Research & Development	0	0.0	0	0	0	0	16	100.0
Quality Assurance	7	18.9	0	0	0	0	30	81.1
Maintenance	5	16.1	0	0	0	0	26	83.9
Industrial Engineering	0	0.0	0	0	0	0	18	100.0
Data Processing	2	7.7	0	0	0	0	24	92.3
Administration	4	18.2	0	0	0	0	18	81.8
Word Processing	10	55.6	0	0	0	0	8	44.4
Distribution/Warehousing	7	24.1	0	0	0	0	22	75.9
Planning	1	12.5	0	0	0	0	7	87.5
Average (%)		19.3		0.1		0.2		80.4

Table 3: Productivity Indicators in Non-Industrial Companies : A Summary(8)

FUNCTION	Partial productivity indicators		TFP Indicators		TP Indicators		Other Non-Std Indicators	
	No. of times	%	No.of times	%	No.of times	%	No.of times	%
Manufacturin (Operation)	9	36.0	1	4.0	0	0	15	60.0
Sales	12	42.9	1	3.6	0	0	15	53.5
Marketing	1	9.1	1	9.1	0	0	9	81.8
Purchasing	0	00.0	0	0	0	0	11	100.0
Personnel	1	8.3	0	0	0	0	11	91.7
Finance/Accounting	5	31.3	0	0	0	0	11	68.7
Legal	0	0	0	0	0	0	4	100.0
engineering	3	30.0	0	0	0	0	7	70.0
Research/Dev.	0	0	0	0	0	0	4	100.0
Quality assurance	0	0	0	0	0	0	5	100.0
Maintenance	2	18.2	0	0	0	0	9	81.8
Industrial Engg.	1	10.0	0	.0	0	0	9	90.0
Data Processing	1	6.7	0	0	0	0	14	93.3
Administration	2	20.0	0	0	0	0	8	80.0
Word Processing	8	53.3	0	0	0	0	7	46.7
Distribution/Warehousing	7	53.8	0	0	0	0	6	46.2
Planning	1	12.5	0	0	0	0	7	87.5
		19.5		1.0	0	0		79.5

vi) Indirect labour in manufacturing - the productivity of indirect labour such as material handlers or maintenance man is often measured by

$$\text{Productivity Index} = \frac{\text{No. of indirect labour hours to serve direct labour}}{\text{No. of direct labour hours}}$$

Aggarwal(9) has also attempted to group some important factors and their elements identified in the course of nearly 27 case studies reported on productivity. The case studies were drawn from manufacturing, utilities, local government, hospitals, educational systems, and from other fields. The groupings are primarily on the lines of functional departmentalisation. All factor elements which belong to a specific management function are put in one group. The frequency with which the factor elements of each group are mentioned in the case studies is counted. Table 4 lists the groupings, factor elements and their frequencies mentioned in the case studies. It will be obvious from the table that in most organizations, the managements' efforts to increase productivity are concentrated on the use of cost control or related techniques. Improvement of labour output and scientific application of management planning and control practices, behaviour modification attempts, efficient utilisation of equipment, technology and capital follow in that order. On the negative side, the effect of group titled government regulations happens to be the most often quoted group of factors followed by public pressures.

Thus, while it seems obvious that the adoption of total productivity concept at the organization level leaves much to be desired and indeed appears extremely limited at the present moment there is all the same a wide spread recognition of the need to evolve appropriate measure of total productivity which could render itself easily amenable and benefitial for implementation at the organizational level. The criteria which such a measure should satisfy have already been spelt out in some detail earlier.

In what follows attempt is made to study certain major advances which have taken place in respect of productivity measurement, both with regard to model formulation as well as applications to real world situations. While the coverage is by no means sought to be exhaustive, main emphasis will be on taking a historical perspective as well as remain abreast of the current state of art in productivity measurement.

7. Models of Productivity Measurement

Several authors have over a period of time presented models of total productivity measurement. In this study, important amongst these will be discussed in some detail. These are:

i) Kendrick and Creamer model of Total Productivity (6)
ii) Craig and Harris model of total productivity (10)
iii) Taylor and Davis formulation of Total factor productivity (11)
iv) W.T. Stewart approach of multiattribute utility function (4)
v) Aggarwal's composite measure of productivity (9)
vi) W.T. Stewart's multiple inputproductivity measure of production system (12).
vii) Bela Gold's integrated framework for analysis of productivity networks, cost structures and managerial ratios (13).
ix) Risk simulation and Sensitivity analysis of the Gold framework by Eilon (14, 15).

Table 4 Factor Elements Frequency (9)

Name of Group	Factor elements of the group	frequency of mention in case studies
Labour	Wages and salaries, utilizing, cost training and education, pensions and health plans, rewards and punishments, contract negotiations attitude to supervision, attendance, turnover, hours of work, participation or codetermination, job security, alienation, job classification, trade union bidding, drudgery reduction.	26
Behaviour modification & motivation	Co-operation, minimisation of conflicts, incentive plans, attitude to work, motivation to implement, organizational development, human elements, resistance to change, improved communications, suggestion systems, career ladders.	15
Management Planning & Control	Capability of management organizational design, personnel policies, job design, operations planning and control, personal help to employees, purchasing policies, maintenance policies.	21
Capital	capital cost, budgeting, working capital, fixed equipment or facilities, investor contribution, sources of capital, security.	8
Equipment	Utilisation, age, modernization, cost investments, internally produced equipment, capacity maintenance or expansion	11
Materials	Shortages, energy, cost, development of sources of supply, rejection rate	7
Government regulations	inefficient government policies, labour legislation, pollution control, health, safety, citizen welfare, commodity price support, patent monopoly privilege, required reports from companies, tariffs and import quotas, taxes or tax advantages, affirmative action, government grants and subsidies, employee service regulations, restraints on competition, antitrust enforcement, laws on incentive payments, free or subsidized facilities or utilities.	21

Technology	Obsolescence, modernisation, process design, research and development efforts, innovations, training of scientists and engineers.	9
Use of techniques for cost control	Optimization, industrial engineering, engineering economics, scheduling, value analysis, suggestion systems, zero defects, quality control, zero base budgeting, materials handling analysis, statistical work sampling, waste control, performance standards, layout design, variance analysis, inventory control, down time or idle time control, information reporting and feedback procedures.	41
Public Pressures	Market competition, contributions to public programmes and projects, quality of life programmes, community help in reducing unemployment, community support.	7

Quite apart from providing useful insights into various aspects of productivity measurement as well as clarify certain misconceptions about the same, these contributions have been of immense value in bringing closer to realization, the task of developing a meaningful model of productivity measurement which fulfilled the criteria enunciated earlier, as well as helped to overcome the problems of measurement. Undoubtedly, each one of these approaches has its own strengths and weakness. Nevertheless, cumulatively they represent an extremely valuable repository on which to rely for productivity measurement in most of the widely encountered situations. Our aim therefore will be to study both the theoretical features and demonstrated applications of the models mentioned above.

8 Total productivity measurement

We shall discuss herewith two models of total productivity measures namely: (i) the method of Kendrick and Creamer (ii) the method of Craig and Harris.

The method proposed by Kendrick and Creamer can best be described by considering an illustrative case study from amongst the 6 compiled by the authors (6). Incidentally, this appears to be the first serious attempt at a comprehensive analysis of total productivity at firm level. The case study discussed herepertains to a medium-sized manufacturer of machinery and equipment. A pilot study of productivity measurement was started with 'Machine Motor' division, which was relatively new, had good record since its inception and manufactured only three product lines, which were not subject to frequent specification change. The year 1952 was selected as the base year, as it was the first more or less 'normal' year. Calculations were made largely within the framework of profit and loss statement. Output was estimated in terms of sales value of production. This was deflated by a price index to remove the effect of price changes from the base year. Price indices were based on catalogue prices by product code. As regards labour input, manhours actually worked (including overtime) were obtained from plant records in case of daily rated employees. For salaried employees, the estimates were made by multiplying the average numbers employed during the year by a constant which represented the average annual number of hours spent on the job excluding OT, vacation and holidays. The man-hours worked in each category were weighted by the average hourly pay, in the base year. Estimation of investoi input required two steps. The first was to revalue gross assets in terms of constant (1952) prices. The second was to compute the rate of return. In case of fixed assets, these were traced back to the year of purchase and then converted to a 52 base by use of a price index. Cash and marketable securities were carried at current value in all years. Notes and accounts receivables were deflated by an index of the average billing prices of division's products. Raw materials and suppliers inventories were deflated by an index of prices paid for major types purchased. Work in process, finished parts and shipping stocks were deflated by selling price index. The same was used to deflate relatively small 'miscellaneous other assets'. To calculate the base year rate of return, income before taxes was adjusted for estimated margin on inventory change during the period and the effect of revaluing depreciation charges on the basis of 1952 replacement costs. This was divided by revalued gross assets. As for intermediate inputs, a five year period average estimated cost of each major type of raw materials provided the weights to be applied to appropriate group price indices taken from Bureau of Labour Statistics wholesale price index. 'Outside Services' supplied by HQ and other divisions of the company were valued in base year terms. In case of labour input again, due to differing labour skills, wage rates, etc. aggregation is in terms of value of input. Manhours worked in each job classification are multiplied by the base year wage rate and/or salary scale for that job classification and added. Difficulties of aggregation include: introduction of new jobs with no base year rates, etc. Adjustment of raw materials and purchased parts (adjusted for inventory changes) to base year prices is accomplished by using base year material prices. An appropriate commodity price index may also be used to adjust the current year prices. Miscellaneous other goods and services typically include utilities (heat, light, power, etc) government services (taxes), advertising, non-productive materials (office supplies, etc). Each of these are adjusted to base year terms using appropriate price deflator. To estimate capital input,

Table 5: Details of Productivity Calculations (6)

(Year 1957; base 1952)

Measurement of output	1952	1957 Current prices	1957 1952 prices
Gross sales billed	$24500	$26240	$24983
Price Index	100	105	
Less Purchase resale	1800	0	0
Plus sales value of inventory change	2262	2395	2281
Equal sales value of production	20438	23845	22523
Index	100	116.7	110.2

Class of employee	LABOUR INPUT Manhours worked (000) 1952	1957	Average hourly pay (1952)	Weighted Man hours (000) dollars 1952	1957
Manufacturing hourly	1778	1808	$1.92	$3414	$3471
Mfg. Salaried	352	308	2.56	901	788
Salaries & Administration	269	331	2.23	600	738
Engineering	114	163	2.92	333	476
Total	2513	2610		$5248	$5473
Index	100	103.9		100	104.3

	CAPITAL INPUT 1952 Book Value	1952 Cur. Value	1957 Book Value	1957 1952 prices	Price Index (1952 = 100)
Cash and Securities	$2172	2172	2033	2033	100
Notes & accounts receivables	1322	1322	1588	1512	105
Inventories total	4634	4634	5357	5096	
Raw Matls. & supplies	622	622	672	633	106.1
Others	4012	4012	4685	4463	105
Fixed assets, total gross	4852	5347	5502	5761	
Misc. other assets	1156	1156	939	894	105
Total gross assets	14136	14631	15419	15296	
Memo income before tax as reported	4056		5496		
adjusted	4350	4266	5753	4466	
Rate of return (investor input) (per cent)	30.8	29.2	37.3	29.2	

PRODUCTIVITY CALCULATION

	1952 (A)	1957 Curr. Prices (B)	1957 1952 prices (C)
Output			
1. Sales value of production	$20438	$23845	$22523
Input			
a. Labour	5248	5878	5473
b. Investor input	4266	5753	4466
c. Raw materials & supplies	6308	7279	6158
d. Outside services	3056	2986	2172
e. Capital eqpt. depreciation	358	361	417
f. Other	1202	1588	1378
	20438	23845	20064
Productivity Index	100		112.3

concept of service value of capital is used - more specifically the base value. The model assumes that the firm has a leasing subsidiary to buy the land, buildings and equipment as also supply the current assets. The capital input is the payment made to leasing subsidiary and the lessors are the stockholders and debtors. A typical lease is in the form of annuity which depends upon: (i) the cost of the asset (ii) productive life of the asset (iii) desired rate of return to the lessor. The cost of the asset is the asset's original price and any capitalised costs necessary to prepare the asset for use. Appropriate capital equipment and building indices are used to adjust these to base year. Productive life is the length of time an asset is expected to be useful prior to either complete physical deterioration or economic obsolescence. This must be estimated. The rate of return for the lessors is derived from the cost of capital theory. The required rate of return is the cost plus a nominal profit. The price indices of the respective divisions were used to deflate the dollar amounts. The 'Other' cost category comprised largely of miscellaneous services purchased from other firms. This was deflated by the price index of division's own products, in the absence of more accurate indices. The smallest cost category was capital equipment depreciation. The conversion of depreciation charges to constant dollars was accomplished by using base year prices. Table 5 gives details of the productivity calculations using Kendrick and Creamer method.

9. Total productivity measurement (Craig & Harris, 10).

This model appears to be the next major development after Kendrick and Creamer's work. Here, the total productivity of the firm is measured as follows:

$$P_t = \frac{O_t}{L + C + R + Q}$$

where P_t = total productivity

L = labour input factor

C = capital input factor

R = raw material and purchased part input factor

Q = other miscellaneous goods and services input factor

O_t = total output.

Since productivity indices are calculated in base year terms, base year selling prices are used for aggregation of outputs. The outputs include dividends from securities, interest from banks and other such sources, adjusted to base year values. An appropriate cost of living index is used for the purpose. A shortcut method for deriving value of output involves deflating (or inflating) the value of output by a suitable index to calculate capital in the base year and is calculated by the weighted average method. Thus, the capital input is defined as the sum of annuity values calculated for each asset on the basis of its base year cost, productive life and the firm's cost of capital. Cash, accounts receivables, securities, inventory and other liquid assets are also part of the capital input. These are assumed to have infinite productive life. For these assets, perpetuity rather than annuity is the basis of calculation. The formula used is KC, where K is the value of the asset and C is the base year cost of capital. For instance, assume that an equipment is purchased for Rs.100000. Expected productive life = 5 years. Salvage value = 0. Weighted average cost of capital = 10%. The firm in the base year maintains a cash balance of 1 million rupees. Here the firm must turn over the capital invested and earn a 10% return, in 5 years. Using annuity tables, the annual charge is Rs.26380. Similarly, the cash input factor = 0.10 x 1000000 = Rs.1,00,000. Thus, the total capital input reduced to base year = Rs. 126380.

In the Craig-Harris model, a total productivity (TP) of 1 or 100% indicates that the firm produces exactly the correct output necessary to return proper amounts to labour, material, suppliers, outside services and capital. Capital is interpreted as a measure of firm's contribution to production input. TP of 1 means the firm breaks even. TP $<$ 1 implies the return on capital is less than cost of capital and the firm goes into red. If TP $>$ 1, the firm makes a profit and the return on capital is greater than the cost of capital.

9.1 Mathematical formulation

A mathematical formulation of the Craig-Harris model is provided by Hines (16). The formulation is developed in the following manner:

Output $Q_i = \sum_j P_j U_{ij}$

Labour Input $L_i = \sum_k n_{ik} w_k$

Capital input $C_i = \sum_p C_{ip}$

Material Input $R_i = \sum_q V_{iq} m_q$

Miscellaneous input $M_i = \sum_l X_{il} h_l$

$\therefore$ Total productivity $TP_i = \dfrac{\sum_j P_j U_{ij}}{\sum_k n_{ik} w_k + \sum_p C_{ip} + \sum_q V_{iq} m_q + \sum_l X_{ij} h_j}$

Here P_j = price/unit of item j in base period

U_{ij} = number of production units of item type j produced in period i

L_i = Labour input measure in period i

n_{ik} = number of employees in category k in period i

w_k = base period wage for category k. (includes fringe benefits also)

C_i = Capital input measure in period i

c_{ip} = uniform annual cost for item p in period i

R_i = material input for period i

V_{iq} = volume of material q consumed in period i

m_q = unit base period cost for material q

M_i = miscellaneous input in period i

X_{il} = volume of input 1 consumed in period i

h_l = unit base period cost of input l

The complete productivity calculations are shown in Table 6 below:

Table 6 Total Productivity Calculations

Cost of Capital Calculation

Capital Structure

	% of Capital structure (1)	Cost (2)	Weighted cost (1) x (2)
Current liabilities	25	0.04	0.01
Long term debt	4	0.06	0.002
Preferred stock	2	0.08	0.002
Common stock	4	0.12	0.005
Retained earnings	65	0.12	0.078
			0.097

	1968	1969	1970	1971
OUTPUT				
Total Sales revenue	384	394	299	496
Minus price change		− 1	− 4	−13
Adjusted Sales revenue	384	393	295	473
± Inventory change	− 7	+22	− 5	+ 5
Output in 1968 terms	377	415	290	478
Labour Input				
Hourly paid	76	76	56	76
Salaried	23	25	25	26
Total	99	101	81	102
Capital Input				
Buildings, land, equipment	27	30	32	34
Inventory	3	4	4	4
Accounts receivable	4	4	4	3
Cash	2	2	1	2
Total capital input	36	40	41	44
Material Input				
Material expenses	139	147	110	184
Minus price increases	−	− 4	− 7	−12
Base year dollar matl. expenses	139	143	103	172
± inventory adjustment	− 1	− 2		
Total Material Input	138	141	103	172
Miscellaneous Goods & Expenses				
Miscellaneous expenses	56	66	60	82
Federal income tax	43	37	19	48
Total	99	103	79	130
TOTAL INPUT	372	385	304	448
TOTAL PRODUCTIVITY	101.3	107.8	95.3	106.7
TOTAL PRODUCTIVITY IN RELATION TO BASE YEAR	100	106.4	94.1	105.3

Items not produced entirely within one period are partially credited to two or more periods. As regards labour input, suppose in an executive category, there is say just one executive i.e., $n_{ik} = 1$.
In this category, w_k · base period salary + base year fringest (current period bonus/IF)

where $$IF = \prod_{j=0}^{b} (1 + I_j) \text{ is the inflation factor.}$$

and I_j = inflation rate for period j periods back from the present period

b = number of periods that the current period is removed from the base period.

9.2 Application of the model

In a case application of the model, Craig and Harris consider a relatively large multiplant manufacturing company. The primary products of the company are automobile and truck components, although the company does produce some products for other markets, such as mechanical devices for aircraft. All plants and product lines are grouped and productivity calculations are made for the company as a whole. The base year chosen was 1968, and the productivity indices were calculated each year for the period 1968 through 1971. In calculating outputs, magnitudes of price changes caused by increased factor costs were subtracted from the sales revenue. No adjustments were made for configuration changes and quality improvements. An inventory adjustment was made to convert sales to production output. Total inventory value was subdivided into: finished, inprocess and raw material categories. The latter were converted into sales value.

The labour input was calculated according to the procedure described earlier. The calculation for cost of capital was based on weighted average method, using after tax consideration. The common stock and retained earnings costs were based on the management goals for these inputs. Appropriate price indices were used to deflate the costs to the base year. The base year materials costs were adjusted by material inventory changes to reflect material consumption. Other inputs were also deflated to base year value. Table 6 gives the complete productivity calculations.

10 Total factor productivity measurement

Total factor productivity (TFP) measure differs from total productivity (TP) measures, in that the TFP measure is based on value added outputs and associated inputs. The Tailor-Davis model (11) of TFP can be stated as follows.

$$TFP = \frac{(S + C + MP) - E}{(W+B) + (k_w + k_f)\ F_b\ d_f}$$

Here
- S = Sales
- C = inventory change
- MP = manufacturing plant
- E = exclusions

} Output

- W = Wages and salaries
- B = Benefits

} Labour input

- k_w = working capital
- k_f = fixed capital
- F_b = investor contribution adjustment

} Adjusted investor input

- d_f = Price deflator factor

The characteristics of the model will be briefly discussed below:

10.1 Value added output - it is the output which the firm contributes to the market value of the product. Purchased materials, rentals and services which represent output from other firms are excluded from consideration. An internal company price index is used to deflate the sales figures to the base year value. Inventory is assumed to comprise of three types. raw material, work-in-process and finished goods. The work-in-process is divided into two parts. one half raw materials and one half finished goods (depending upon their degree of completion). All values are deflated by appropriate price index.

The manufacturing plant (MP) items include items produced internally for maintenance and repairs, internally produced machinery and equipment, and research and development. This component is often ignored in productivity measurement and therefore can result in significant errors particularly when the scale of manufacturing plant activity is substantial. All MP factors are adjusted via appropriate price and cost indices to reflect the base year value. The Exclusions include externally purchased materials and supplies (M & S), depreciation on buildings, machinery and equipment and rentals. These are deflated to reflect base year prices. Direct materials are deflated by wholesale price index. The model assumes that raw materials reflect the progress and efficiency of an external operation. Depreciation is similar to a time payment of machinery or plant purchased in external segments of thecompany.

10.2 Labour input - includes all monetary compensation paid to hourly and salaried employees, including all benefits. These include items such as overtime, vacation, sickness, insurance, profit sharing, social security tax, retirement, bonuses, etc. These are adjusted to base year values.

10.3 Capital input: Both fixed and working capital components are considered. The fixed assets include buildings, machinery, equipment, deferred changes. The working capital assets include cash, notes, inventories, accounts receivables, prepaid expenses. For annualising the capital inputs, 'investor contribution' approach is used, which is the real net capital (i.e., capital after depreciation) for each year weighted by the rate of return in the base year. The rate of return is the profit before tax as percentage of total capital assets for the base year. The investor contribution is adjusted to base year prices via a GNP price deflator.

Table 7 gives details of productivity calculations for a case application reported by Taylor and Davis (11). It will be noted from the table that TFP dropped severely in 1969 and this was mainly attributed to severe price pressure in the industry. But 1970 saw a jump in production and productivity. Thereafter the firm experienced a steady growth in TFP.

Table 7 : Application of Tailor-Davis Model (11)

	1967	1968	1969	1970	1971	1972	1973
NET ADJUSTED SALES							
Sales ($) for year	91.11	92.64	60.12	78.55	77.24	84.10	92.56
Price deflator	100.00	86.4	78.8	70.3	62.7	57.3	51.4
Adjusted 1967 sales	91.11	107.22	76.3	111.74	123.19	146.77	180.88
CHANGE IN INVENTORY							
Raw materials	3.41	(0.42)	(0.36)	1.73	1.22	2.40	4.78
Finished Goods	2.01	(0.05)	0.40	0.96	0.33	0.71	1.02
½ Work-in-process (raw material)	0.96	0.51	0.21	1.01	2.76	3.11	3.53
½ Work-in-process (finished goods)	0.58	0.30	0.32	0.69	(0.53)	(0.01)	0.76
Total inventory change	6.96	0.34	0.57	4.39	3.78	6.21	9.33
TOTAL VALUE ADDED OUTPUT							
Gross Output	103.46	112.34	81.4	121.89	133.68	157.36	194.72
Sales	91.11	107.22	76.3	111.74	123.19	146.77	180.08
Manufacturing Plant	5.39	4.78	4.53	5.76	6.71	4.38	5.31
Inventory Change	6.96	0.34	0.57	4.39	3.78	6.21	9.33
Total Exclusions	63.33	65.16	47.26	72.31	80.87	97.12	123.59
M & S	59.65	61.05	43.5	66.3	72.22	85.74	107.21
Depreciation	3.12	3.53	3.59	4.78	6.21	7.83	10.17
Rentals	0.56	0.48	0.17	1.23	2.44	3.55	6.01
Total Value Added Output	40.13	47.18	34.24	49.58	52.81	60.24	71.33
TOTAL LABOUR INPUT							
Total Labour Comp.	34.17	35.63	31.49	36.85	38.94	41.14	46.78
Wages & Salaries	25.63	24.94	24.25	25.43	28.04	28.39	33.21
Benefits	8.54	10.69	7.24	11.42	10.90	17.75	13.57
Consumer Index	100.00	101.80	103.5	105.20	107.00	108.90	110.90
Total labour (1967)	34.17	35.00	30.42	35.03	36.39	37.78	42.18

TOTAL CAPITAL ASSETS

Working Capital	26.14	34.78	36.01	50.24	56.60	62.13	71.08
Fixed Capital	41.13	44.38	45.61	48.22	48.22	57.91	63.07
Total Capital Assets	67.27	79.16	81.62	99.06	109.30	120.04	134.15

INVESTOR CONTRIBUTION

Total Capital Assets	67.27	79.16	81.62	99.06	109.30	120.04	134.15
Profit before tax*	11.86						
Profit as % of Assets	17.6	17.6	17.6	17.60	17.60	17.60	17.60
Investor Contribution	11.86	13.93	14.37	17.43	19.24	21.13	23.61
Price Adjustor	100.0	101.60	103.5	106.10	108.00	109.80	112.80
Investor Contribution (1967)	11.86	13.71	13.89	16.43	17.81	19.24	20.93

(* An adjustment for depreciation charges was made in this value)

TOTAL INPUTS

Total capital input	11.86	13.71	13.89	16.43	17.81	19.20	20.93
Total labour input	34.17	35.00	30.42	35.03	36.39	37.78	42.18
Total input	46.03	48.71	44.31	51.46	54.20	57.02	63.11

PRODUCTIVITY INDEX-
TFP(value added) model

Total Output	40.13	47.18	34.24	49.58	52.81	60.24	71.33
Total input	46.03	48.71	44.31	51.46	54.20	57.02	63.11
TPF index	0.871	0.969	0.772	0.963	0.974	1.056	1.130
Adj. TFP index	100.00	111.25	88.63	110.56	111.82	121.23	129.73
% change from previous year	-	+11.25	-20.33	+24.74	+ 1.14	+ 8.42	+ 7.01

PRODUCTIVITY INDEX-ALL
INCLUSIVE MODEL

Total output	103.46	112.34	81.40	121.89	133.68	157.36	194.72
Total input	109.36	113.87	91.57	123.77	134.57	154.14	186.50
TFP Index	0.946	0.986	0.889	0.985	0.993	1.021	1.044
Adj. TFP index	100.00	104.23	93.97	104.12	104.97	107.93	110.36
% Change from previous year	-	+ 4.23	- 9.84	+10.80	+ 0.82	+ 2.82	+ 2.25

The first two of the three models discussed above aim at total productivity measurement whereas the third aims at measurement of value added productivity. The first two mainly differ from each other in measurement of the investors' input. In this respect, the method adopted by Craig and Harris of considering investor's input as equivalent annuity based on a rate of return derived from the cost of capital theory is much more rigorous than the method proposed by Kendrick & Creamer. To that extent, Craig-Harris formulation could be considered as an improvement on the formulation by Kendrick and Creamer.

11. Composite measures of productivity

Composite measures of productivity are those that are based on two or more organizational variables, identified as being crucial determinants of productivity. Thus, these models depart from the traditional consideration of productivity as being a ratio of outputs to inputs. Two composite measures of productivity are now available, viz. (1) Stewart's 'Yardstick' (4) and (2) Aggarwal's composite index (9). We shall consider each one of these in the following discussions.

Stewart (4) proposes a utility based yardstick for the measurement of productivity. Stewart believes that in most manufacturing organizations, the concept of productivity measurement and improvement is too complex for a single individual to generate an effective system which truly captures organizational productivity. On the other hand, participative approach creates group involvement by key people within the company in developing a measurement system and thus eases the problem of implementation. Thus, a nominal group technique (NGT) is used for generating key measures of productivity . The NGT comprises of the following steps. silent generation, round robin presentation, clarification, voting and ranking, discussion of results. To aggregate the vector of productivity measures into a single measure reflecting the net effect of all measures on total productivity the Keeney model (17) of multiplicative multiattribute utility function is adopted. This composite utility represents the net effect of all the surrogate measures on the perceived performance towards the organization's objectives. This composite utility thus reflects overall productivity within the definition of total organizational productivity.

11.1 Application of the Utility based model

An application of the utility based model is reported by Stewart. This involved a manufacturer of mining equipment who desired to develop a system for measuring the productivity of production operation. The operation was large/shop with substantial machinery, welding and /job assembly operations. The production force (about 700) was unionised and an incentive pay system based on time standards was im effect. The group who participated in development of productivity measures includeds six division managers in charge of production and inventory control, quality control, manufacturing services, materials control, the works manager, and the director of purchases. Each department head also brought another representative from his department to make a total of 12 participants. The following final set of nine productivity measures were evolved by the group.

i) Inventory turnover - ratio of cost of goods sold to the average inventory for a given period.

ii) Percent of direct labour covered by time standards - actual percent of direct labour hours worked which were covered by an established time standard.

iii) Key machine effiency - a percentage which relates to actual utilisation time of the high investment key machines to the available time during the period.

iv) Direct labour hour generation per direct labour hour employee - percentage of attendance hours charged as direct labour hours generated by a direct labour hour employee, indicating productive time.

v) Material identification and location accuracy - a percentage which comes from a random audit of location and identification of material on the production floor.

vi) Total operations quality cost per net sales dollar - relates the total cost of insuring quality, i.e., prevention, appraisal, internal failure, and external failure to net sales. This figure is a percentage.

vii) Internal Schedule Reliability - relates the average number of weeks an order is late in completion. This refers to parts and sub-assembling which would be added to inventory when completed.

viii) Initial shipment service level - The percentage of spare part orders from the field which is filled from inventory, thus requiring no production time prior to shipment to the customer.

ix) The percent of total direct labour attendance hours charged as direct labour hours; in three key divisions.

To use the multiattribute utility function model, a range was defined for each measure and the manufacturing vice-president was required to relate the various levels of each attribute to his concept of the perceived performance towards organizational objectives. Thus, siugle attribute utility curves were developed. Typical examples of such curves are given in Figure 1. Following the single attribute utility curve development, the relative weightings to be given the various attributes were addressed. Given the weightings, the final multiattribute utility function for the vector of productivity measures was generated, properly scaled between 0.0 and 1.0. The mathematical model used is stated below:

$$k\, U_t\, X + 1 = (k\, k_1\, u_1\, x_1 + 1)\,(k\, k_2 u_2 x_2 + 1) \cdots (k\, k_9 u_9 x_9 + 1)$$

where k = scaling constant = 0.09685516

k_1 = 0.15 Inventory turnover

k_2 = 0.12 percent of direct hours covered by time standard

k_3 = 0.05 percent utilisation of key machines

k_4 = 0.15 percent of attendance hours charged as direct labour hours

k_5 = 0.12 Material identification and location accuracy

k_6 = 0.12 Quality control costs

k_7 = 0.05 Internal factor schedule reliability

k_8 = 0.10 Shipment reliability of supply orders.

k_9 = 0.10 percent of direct labour attendance hours in three key divisions charged as direct labour hours

$U_t\, X$ = composite utility measure of manufacturing productivity

The factor $u_i\ x_i$ was selected from the single attribute utility curves developed during the study. A series of calculations enable the company to determine its composite utility measure, as follows:

$$K\ U_t X + 1 = (k\ k_1 u_1\ x_1 + 1)\ (k\ k_2\ u_2\ x_2 + 1)\ \ldots\ (k\ k_9\ u_9\ x_9 + 1)$$

$$(0.0968516)\ (0.15)\ u_1\ x_1 + 1 = a$$

$$0.011623\ u_2\ x_2 + 1 = b$$

$$0.004843\ u_3\ x_3 + 1 = c$$

$$0.014528\ u_4\ x_4 + 1 = d$$

$$0.011623\ u_5\ x_5 + 1 = e$$

$$0.011623\ u_6\ x_6 + 1 = f$$

$$0.004843\ u_7\ x_7 + 1 = g$$

$$0.009686\ u_8\ x_8 + 1 = h$$

$$0.009686\ u_9\ x_9 + 1 = i$$

$$a\ b\ c\ d\ e\ f\ g\ h\ i = P$$

$$k\ U_t\ x + 1 = P$$

$$\therefore\quad k\ U_t\ x = P - 1 = Q$$

$$U_t\ x = \frac{Q}{k}$$

where $U_t\ x$ = Composite productivity utility measure

$$0 \leq U_t\ x \leq 1.0$$

The model is unique in that it develops a single 'yardstick' from a total of 9 measures identified by decision makers, via multi-attribute utility function. Its major drawback is that it could quite be cumbersome to implement, on a regular basis. At any rate how is one to ensure that higher productivity implies higher ROI?

12 Aggarwal's Composite measure of productivity

Like Stewart (4), this measure also departs from the conventional formulation of productivity as ratio of outputs to inputs. The model assumes that when companies sell similar line/lines of products or services the productivity can best be measured in four areas: (i) investor's satisfaction, (ii) employee satisfaction, (iii) customers' satisfaction, and (iv) suppliers' satisfaction. The investor's satisfaction is the ratio of net profit/total investment. The ratio total value added/total number of weighted manhours is a good index of employee satisfaction. A well accepted measure of customer satisfaction, according to Aggarwal (9) is total revenue/total number of customers. Finally the suppliers' satisfaction is measured by the ratio, total value of purchases/total number of suppliers dealt with. Furthermore for any specific company, the productivity goal is to maximise the rate of return on a short term and improvement on a long term basis. Based on the above premises, the composite productivity model is stated as follows:

$$\text{Composite Productivity Index} = a\left(\frac{\text{Net Profit}}{\text{Total Investment}}\right) + b\left(\frac{\text{Value Added}}{\text{Number of weighted manhours}}\right) + c\left(\frac{\text{Total sales revenue}}{\text{Number of customers}}\right) + d\left(\frac{\text{Total value of purchases}}{\text{Number of suppliers}}\right)$$

The index is meant to be a long term overall productivity measure for the company. The four coefficients a, b, c and d can be determined using past company data, and running a linear regression. The value of coefficients can be updated as more data becomes available. However, no application of the proposed model is reported by Aggarwal. The model raises several questions. First productivity may rise while ROI actually falls. Sales value as well as number of customers may actually decline, the latter much faster. Yet productivity might be shown to have increased! And so forth, the model therefore needs much further work, before it is foolproof and becomes a candidate for implementation.

13 Multiple input productivity measurement

The model discussed below is specifically developed for determining manufacturing system productivity. In propo-sing the present model, Stewart (12) recognizes the somewhat cumbersome and inappropriate nature of his earlier 'yardstick' based on utility functions, particularly when productivity is to be measured in the manufacturing environment. In a manufacturing system, variety of products are produced as a result of blending various flow resources with particular resident resources. The flow resources typically are: materials and energy. Resident resources are: direct labour, manufacturing support, production equipment, raw material and work in process inventory. Stewart emphasizes the need to utilise quantitative production standards for particular resource, more hecause of turbulence existing within the organization's task environment with reference to product mix, proces, costs, etc. Thus, the output of the firm is viewed as the sum of various standard input requirements for producing a specific product in a base period of performance. A base period cost weighting system is used to aggregate various input standards into a composite constant value of output. The input resources are taken at the actual quantity utilization level and are base period cost weighted in the aggregate. Thus, a ratio is formed which relates the output at standard to the specific standards established im the base period. The model formulation is given below:

System Output: Q_{ij} = Number of units of product i produced in period j.

Direct labour resource: The output and input components of this resource are given as follows:

$$\text{Output} = \sum_{i} Q_{ij} \; LS_i \; LC_i$$

$$\text{Input} = \sum_{n} Q \, L_{nj} \; LW_n$$

Manufacturing Support input:

$$\text{Output} = \sum_i Q_{ij}\ MS_i \quad \text{for period } j$$

$$\text{Input} = A\ MS_j\ IF_{1j}$$

Energy Input :

$$\text{Output} = \sum_i Q_{ij}\ SE_i$$

$$\text{Input} = \sum AE_j\ IF_{2j}$$

Material Input :

$$\text{Output} = \sum_i Q_{ij}\ \left(\sum_k MQ_{ik}\ MC_{k1}\right) \quad \text{for period } j$$

$$\text{Input} = \sum_k QM_{kj}\ MC_{kj}$$

Inventory input :

$$\text{Output} = (IV_i)\ \frac{\sum_i (Q_{ij}\ SV_i)}{\sum_i (Q_{i1}\ SV_i)}\ IH \quad \text{for period } j$$

$$\text{Input} = IV_j\ IH\ IF_{3j}$$

Production Equipment

$$\text{Output} = \sum_i Q_{ij}\ \left(\sum_l ES_{il}\ BER_l\right)$$

$$\text{Input} = \sum_l EQV_l\ (DR_l + RR_l)$$

∴ Total manufacturing productivity in period j will be

$$P_j = \frac{\left[\sum_i Q_{ij}\ LS_i\ LC_i + \sum_i Q_{ij}\ MS_i + \sum_i Q_{ij}\ SE_i + \sum_i Q_{ij}\left(\sum_k MQ_{ik}\ MC_{kl}\right) + (IV)_1 \frac{\sum_i (Q_{ij}\ SV_i)}{\sum_i (Q_{i1}\ SV_i)} IH + \sum_i \left(\sum_l ES_{il}\ BER_l\right)\right]}{\left[\sum_n Q\ L_{nj}\ LW_n + AMS_j\ IF_{1j} + \sum AE_j\ IF_{2j} + \sum_k QM_{kj}\ MC_{kj} + IV_j\ IH\ IF_{3j} + \sum_l EQV_l\ (DR_l + RR_l)\right]}$$

Here, the notations have the following significance

LS_i = direct labour standard (hours/unit) for product i

LC_i = average hourly cost of direct labour for product i (base period cost)

QL_{nj} = actual quantity of category n direct labour consumed in period j

LW_n = direct labour wage during base period for labour category n.

MS_i = manufacturing support cost allocated to unit of product i (base period)

AMS_j = actual manufacturing support expense in period j (in current period value)

IF_{1j} = Inflation factor for current period compared to base period

SE_i = energy expense allocated per unit of product i (base period)

AE_j = total energy expense experienced in period j (current period value)

MQ_{ik} = standard material quantity of material type k used in product i

MC_{k1} = cost of a unit of material k in period 1

QM_{kj} = Actual quantity of material k consumed in period j

IV_j = Total inventory value (RM +WIP in period j; current period value)

SV_i = Std. (inventory) value of a unit of product i (base period)

IH = Inventory holding cost per unit of imventory value (base period)

IF_{3j} = inflation factor of inventory gvalue in period j

ES_{i1} = Std. time (hrs) per unit of product i on equipment type 1

EQV_1 = replacement value of equipment type 1.

DR_1 = depreciation rate for equipment type 1 (eqvt. to 1/economic life)

RR_1 = fair rate of return on capital for equipment type 1

BER_1 = eqpt. cost/hr. for equipment type 1 = EQV_1 $(DR_1 + RR_1)$ adjusted for a base year utilisation factor.

The manufacturing support refers to all supervisory, material and equipment resources which are not directly chargeable to a particular product. This is allocated according to the need of various products during a base period review. In the model, in material input only major materials are considered. The Inventory investment of RMs and WIP is considered but not of finished goods as this is not assumed to be a controllable variable. However, this could easily be included. The approach allows for increase in standard inventory, according to increased value of the particular products being manufactured or increase in the volume of output. In case of Equipment input, it should be recognized that equipment is unlikely to be utilised 100% time. Thus, the base year level of utilization must be reflected and the cost/hr allocated according to the base year level of capacity utilisation. The replacement value and economic life have to be consistent with each other. If machine's replacement value is established with reference to present operating condition, the economic life would be the expected remaining functional life. If the same is set on the basis of a new machine, the economic life will be = (time since machine utilisation) + expected time remaining for operation).

This model has been applied in a metal working discrete part manufacturing facility. Stewart concludes from the pilot implementation that certain factors may be excluded if not significant enough. Data base required to implement the model is normally easily available, and the model is amenable to computerisation. The frequency of productivity review could vary from 1-3 months. Finally, as in all models, managerial judgement must be exercised to determine the most cost beneficial level of detail - particularly in case of materials and equipment. The model will be specially suitable in situations where standard data as required is in existence.

14 An Integrated framework for analysis of productivity, cost structures and managerial control ratios

In a unique framework, Gold (13) attempts to examine the interrelationships which exist between physical productivities, cost structures and managerial control ratios. To that extent, this is by far the most comprehensive framework as yet developed for analysis of total productivity and provides a direct connection between physical and financial performance. It is by now obvious that in order to meet the requirements of practical decision making by management, productivity analysis should be such that covers: i) changes in levels of each type of input requirement per unit of output, ii) changes in the proportions in which inputs are combined in order to take account of substitutions (e.g. buying components instead of making them) and also in order to differentiate between changes in the productivity of major as against minor inputs (iii) differences between productivity of inputs when they are fully utilised and when their contributions are reduced by idleness (e.g. underutilised equipment). (iv) changes in all components of this 'network' of productivity relationships, as viewed simultaneously by managers capable of adjusting relationships among them, in order to improve aggregate performance.

In the Gold Framework, it is assumed that management's primary measure of aggregate performance is the rate of profit on investment. The model is developed as follows:

$$\frac{\text{Profit}}{\text{Total Investment}} = \frac{\text{Profit}}{\text{Output}} \times \frac{\text{Output}}{\text{Investment}}$$

$$\begin{aligned}\text{Profit/output} &= \text{average price} - \text{average unit cost}\\ &= \text{Value of products/output} - \text{Total costs/output}\end{aligned}$$

Part of the total investment is allocated to facilities and equipment which determine productive capacity and it is the latter which determines output potentials. Hence, we can write

$$\begin{aligned}\text{Output/Total Investment} = &(\text{Output/Capacity})\ (\text{Capacity/fixed investment})\\ &(\text{fixed investment/Total investment}).\end{aligned}$$

= Utilization rate x productivity of fixed investment x internal allocation of capital.

Thus, the productivity measurement model may be stated as

$$\text{Profit/Total Investment} = \left\{ (\text{Av. price} - \text{Av. cost}) \times \text{Utilisation rate} \times \text{productivity of fixed iuvestment} \times \text{internal allocation of capital} \right\}$$

If Equity investment is of interest, then we can write

$$\text{Profit/Equity Investment} = (\text{Profit/Total investment}) \div \left\{ \frac{\text{Equity Investment}}{\text{Total Investment}} \right\}$$

This network of managerial control ratios can be used to determine which of the strategic areas of decision making contribute most or least to the rate of return. In order to meet the four requirements of productivity analysis stated earlier, it is useful to consider the network of productivity relationships shown in Figure 1 below :

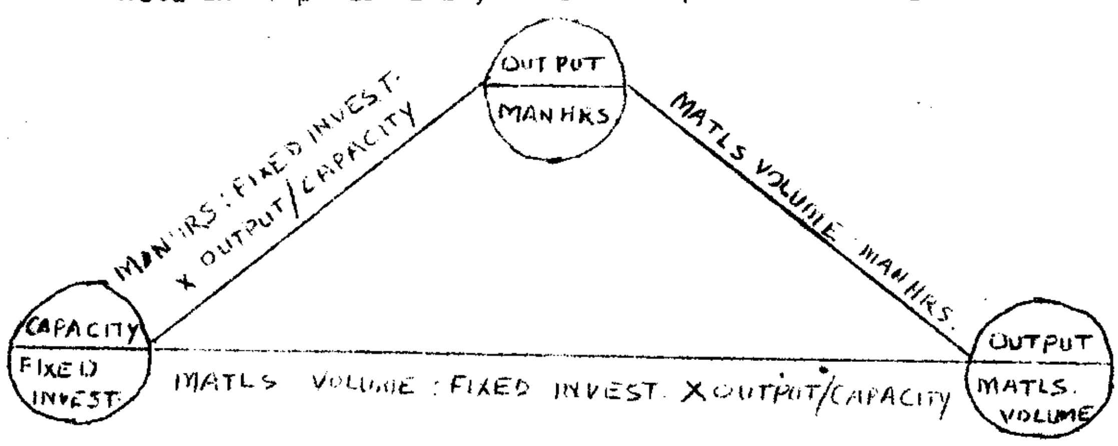

Figure 1: Network of productivity relationships (13)

The network identifies 6 components. Three cover the input requirements per unit of output including labour, materials and fixed capital. In the latter case, net fixed investment is compared with productive capacity rather than with output, in order to differentiate between what capital goods can produce and the extent to which they are underutilised. The remaining three links cover the proportions in which inputs are combined. These factor proportions relate labour and materials inputs to 'actively utilised' net fixed investment. The approach makes it clear that change in any component (say output/manhr) may be the resultant of changes elsewhere in the network and not due to changes in efforts of labour (such as new innovations, more subcontracting, etc). This can be well illustrated by the example of US Iron and Steel Industry (13). The data is presented in Table 8. It shows four subperiods with markedly different relationships: two in which the increase in output per manhour is primarily due to increases in the ratio of utilised net investment to manhours and two in which the increase is mainly due to iucrease in the ratio of capacity to net fixed iuvestment.

Table 8

U.S. Basic Iron and Steel Industry (13)

	Output Manhrs %	Capacity Net fixed investment %	Utilised net fixed investment Manhrs. %
1904	+ 46	+ 57	- 8
1921-29	+ 69	+ 7	+ 60
1929-47	+ 73	+ 70	+ 2
1947-69	+ 45	-60	+265

In the integrated productivity analysis, cost effect of changes in any or more of the 6 components of productivity network must be analysed. This can be achieved by superimposimg "the structure of costs" onto the "network of productivity relationships". This is shown in Figure 2. This enables to relate changes in 'apparent' input productivities and factor proportions through factor prices to each of the unit costs and it also enables to relate changes in individual

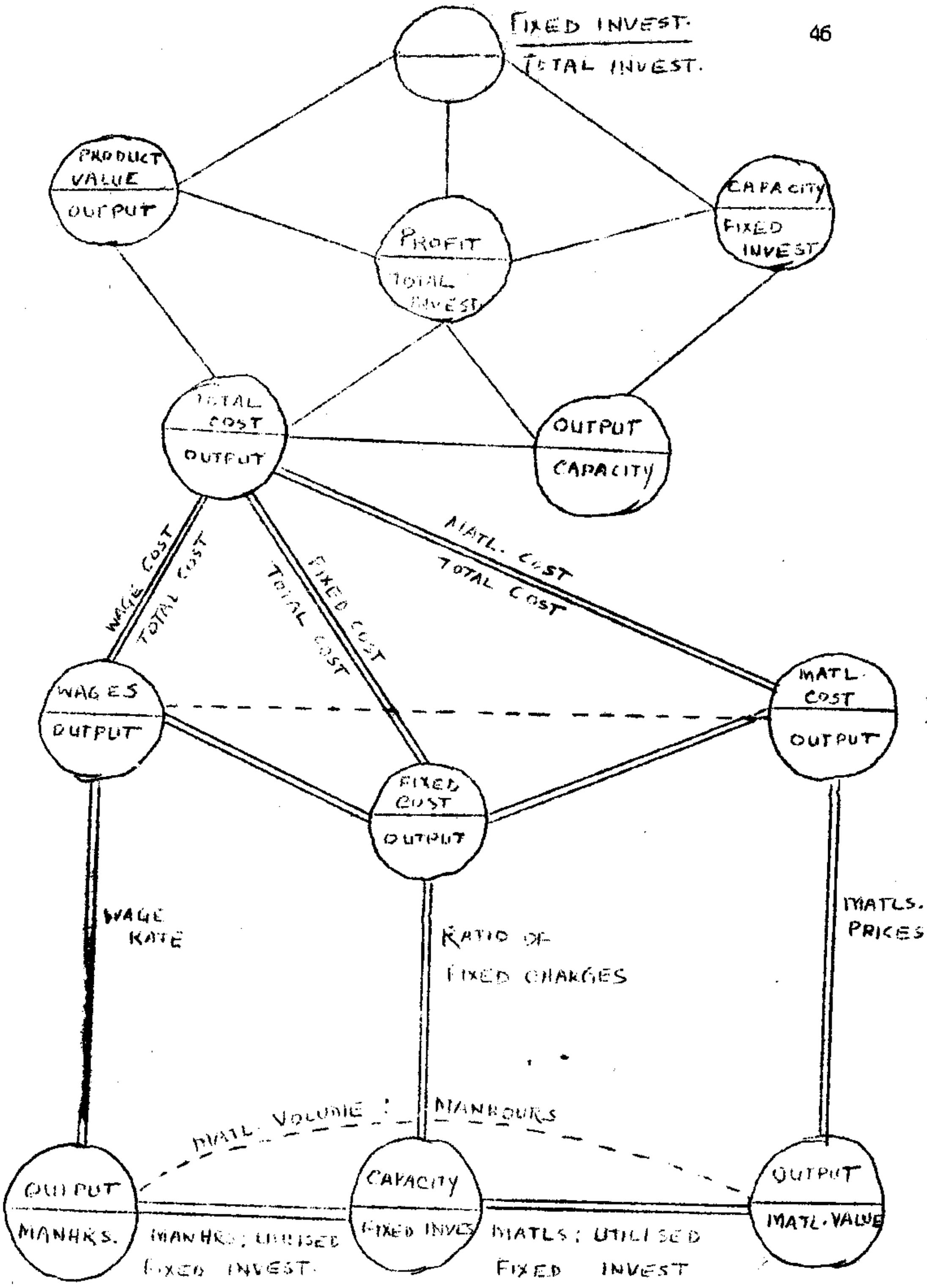

Figure 2: Productivity network, cost structure and Managerial control ratios (13)

unit costs through cost proportions to total unit costs. Finally, the integration with 'managerial control ratios' enables to relate changes in the rate of profit on investment with changes in unit costs, cost proportions, factor prices, factor proportions, apparent factor productivities as well as other determinants of changes in the ratio of profits on investment. The framework can be used in analysing past performance, in developing integrated plans for achieving specified future targets as well as in appraising alternative innovations. In the framework, the change of total unit cost from period 1 to period 2 compared with period 1 is given by

$$\Delta\left(\frac{\text{Total costs}}{\text{Output}}\right)_{2,1} = \left[\Delta\left(\frac{\text{Wage costs}}{\text{Output}}\right)_{2,1}\left(\frac{\text{Wage cost}}{\text{Total cost}}\right)_1\right] + \left[\Delta\left(\frac{\text{Material cost}}{\text{Output}}\right)_{2,1}\left(\frac{\text{Matl. cost}}{\text{Total cost}}\right)_1\right] + \left[\Delta\left(\frac{\text{Other costs}}{\text{Output}}\right)_{2,1}\left(\frac{\text{Other costs}}{\text{Total cost}}\right)_1\right]$$

14.1 Analysis ofor rates of change

The productivity model of Gold (13) can be mathematically expressed as follows (2/4).

$$r = (p - c)\,ek = aek$$

Here, r = return on total investment

p = unit price for the output

c = unit cost for the output

a = $p - c$ = unit profit for the output

e = Output/capacity = capacity utilisation of the plant

k = capacity/total investment

= (Capacity/fixed investment) (fixed investment/Total investment).

Suppose after a certain period, the rate of return becomes r+dr. This may be expressed as:

This may be expressed as

$$(r + dr) = (a + da)\ (e + de)\ (k + d_k)$$

where da, de and dk are corresponding incremental changes in a, e, and k respectively during that period. If we let $r^* = dr/r$, $a^* = da/a$, and $k^* = dk/k$ and if a^*, e^* and k^* are small, then we can write

$$r^* = a^* + e^* + k^*$$

it should be emphasized that this equation provides a decomposition of the relative change in the rate of return into its several constituent parts but does not identify the original cause/causes that subsequently lead to a series of changes in the system.

14.2 Measurement Problems associated with Gold Framework

A detailed analysis of the problems associated with measurement methodology for applying Goldframework has been reported by Eilon et al. (2, 15). The major problems which have been identified are :

i) price and the effect of the base year.

ii) Output (or input) index numbers

iii) fixed investment

iv) changes in productivity components

v) measurement of capacity

vi) transfer price

vii) analysis of past data

We shall briefly consider each of these.

14.2.1 Price and effect of the base year: Edgeworth formula (18) is used to determine the ratio of output PO in year n to the output in base year 1. This is defined as follows:

$$PO_{n,1} = \frac{Q_n(A)\ P\ (A) + Q_n\ (B)\ P\ (B) + \ldots}{Q_1\ (A)\ P\ (A) + Q_1\ (B)\ P\ (B) + \ldots}$$

A and B are different products. Q denotes physical quantity. P is the average price given by $P(i) = \frac{1}{2}(P_1(i) + P_n(i))$ (where i stands for a specific product.

In case prices are unknown for any product during a period, two approaches may be used. In one, the unknown price is equated to the base year price. In the second approach, missing prices are estimated based on trend extrapolations or prevailing market prices for similar products, etc. Both are adequate for practical purposes, although they contain an element of arbitrariness. Instead of using arithmetic average for price estimation, we may also adopt the geometric mean given by

$$P(i) = \sqrt{P_1(i)\ P_n(i)}$$

This approximation is considered to be generally superior. As regards base year, a year that is as 'normal' or 'representative' is selected as base year. However discrepancies can occur from the choice of base year and their magnitude is affected by the pattern of price and physical output changes. This is because in general

$$PQ_{b,a} \neq PQ_{b,c} \ / \ PQ_{c,a}$$

although $PQ_{b,a}\ PQ_{a,b} = 1$ is a special case.

14.2.2 Fixed investment – the conventional measure is gross fixed investment less depreciation. This depends upon the accounting procedures adopted in the firm for determining fixed assets – replacement costs, inflation accounting, gradual write off due to depreciation, etc.

14.2.3 Changes in productivity components: As described earlier, these can be analysed using the equation $r^* = a^* + e^* + k^*$

14.2.4 Measurement of capacity: This problem is particularly difficult when the plant produces a product mix. Concept of 'capacity envelope' can be used in such a case. In principle, this is a production possibilities curve for the set of all product mixes, as shown in figure 3, for a 2 product case. Thus, in figure 3, at point A, capacity utilisation $e_1 = OA/OB$ and at point C, it is equal to $e_2 = OC/OD$. The measurement of physical output without resorting to the use of price factor may be done with reference to plant utilisation. Thus, if $e_2 > e_1$, output at C is greater than at A and the increase is given by e_2/e_1.

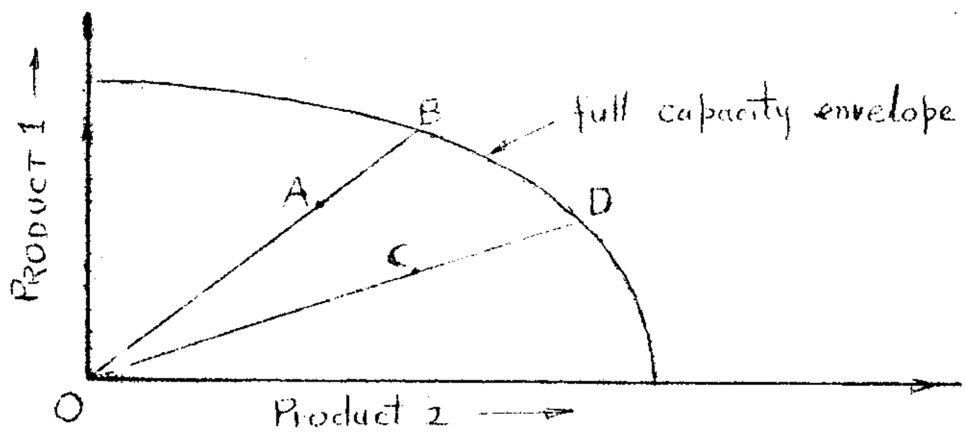

Figure 3: Capacity envelope & Plant Utilisation

14.2.5 The case of intermediate outputs: Suppose some output of an intermediate process is available for sale, as shown in Figure 4:

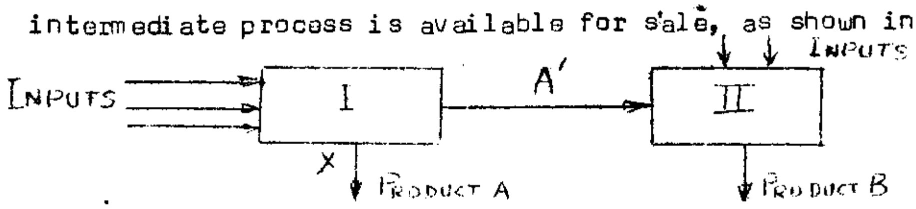

Figure 4: Outputs of the Process

A' = amount of product A transferred to dept. II

X = amount of product A sold

$A' + X \leq A_{max}$.

Let A_{min} and A_{max} be min. & max. levels of outputs of process I. Let B_{min} and B_{max} be corresponding min. & max levels of outputs of process II. Assuming a linear relationship and the two process complex to be a single entity, the capacity envelope will be as shown below in Figure 5.

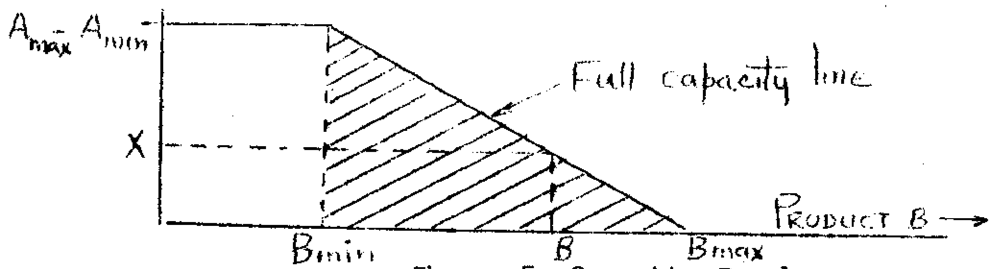

Figure 5: Capacity Envelope

Here X represents the amount available for sale of A, at a particular level of B and at full capacity level of A. The total output of the product mix X and B can be aggregated through the use of an output index.

14.2.6 <u>Effect of transfer price</u>: Assume that departments in a plant are linked in series. We know that r = ack. At full capacity operation of a dept., and constant k, r depends on <u>a</u> which depends entirely on unit price p. Thus, for the two stage process considered above, let S = unit price of X and t = unit transfer price of A'. Then, the average unit price for dept. I is

$$p = \frac{sX + tA'}{A} = S\left[1 - u\left(1 - \frac{t}{s}\right)\right]$$

where $u = A'/A$.

Transfer price affects the two departments in opposite ways but has no effect on the profitability of whole plant.

14.2.7 <u>Analysis of past data</u>: Usually three methods are adopted: i) time series analysis, ii) pattern analysis, iii) regression analysis. Time series analysis helps reveal any exceptional modes of behaviour of a given parameter. The pattern analysis help analyse whether two parameters exhibit similar trends. Value of one parameteris plotted against the corresponding value of the other parameter. The time path of the relationship charted and useful inferences drawn from the pattern that emerges. The regression analysis is widely used, particularly when enough data is available.

Balke (3) recently reported application of the Gold model to two separate operating units within the same company, namely the Standard Oil Company of Ohio (Sohio). This company is capital-intensive process industry with more than $ 100,000 in total assets per employee. While retaining profit responsibility at the business level, it organized and managed as two almost independent segments - Sales and Production. Total investment was approximately identical for sales and production. The former was more heavily weighted toward working capital, the latter towards net fixed investment. Evaluation of the business test application of the model led Balke to four important conclusions regarding the capabilities of the model, namely:

i) The model provides a single valid measure of profitability (ROI), together with an accurate explanation of the reasons for changes in its levels and trends.

ii) The model provides a single valid measure of growth (Edgeworth) index of output) for a multiproduct firm (line of business, plant, etc.) while facilitating the assessment of the impact of that growth on other economic results.

iii) The model can be applied to sales activities with the same degree of confidence with which it has previously been applied, by Gold to manufacturing activities, provided that capacity utilisation for sales groups can be defined.

iv) The model permits differentiation of the cause of results between external uncontrollable economic forces (i.e., inflation and recession) and internally controllable business decisions (i.e., pricing, investment, product mix, product quality). The studies thus confirm that the model is an important tool for management planning, control and prediction.

15 <u>Sensitivity Analysis and Risk Simulation Model</u>

Eilon and Soesan (2) present a risk simulation model, particularly suitable for sensitivity analysis of the Gold formulation. The Gold productivity model involves many variables and interrelationships. Some are likely to be more significant than others. The purpose of sensitivity analysis is to establish the extent to which various criteria as well as the system as a whole are affected by a given incremental change of each variable. The simplest way is to construct a sensitivity Table as shown in Figure 6, where major factors and ratios of interest are included. For an incremental change of 1% for each of the factors listed on the left, the effect (in %) is recorded for each of the ratios enumerated at the top of the table. The Table is strictly valid only at a given level of operations, usually identified as current plant activity. Moreover it assumes that an incremental change takes place for each of the listed factors in isolation. The manager may be interested in exploring the possible effect of several changes taking place simultaneously. For this purpose, various alternative scenarios may be explored through a series of deterministic appraisals, giving the manager a reasonably good insight into the behaviour of the system under his control.

There are however many circumstances where possible changes in factor would be specified by a range of values rather than single estimates. For instance, wage rates may increase by 5 to 10%, materials costs by 2 to 6%, demand may rise by 4 to 8% and so on. In such a situation, risk simulation analysis is very helpful, where the productivity model is simulated for different levels of factor changes. Thus, it is not a single estimate for, say, the effect on the return on investment that is found, but a distribution of values of the ROI. From such a distribution, the expected value and the range within which the resultant value would lie can be readily computed. The model is schematically shown in Figure 7.

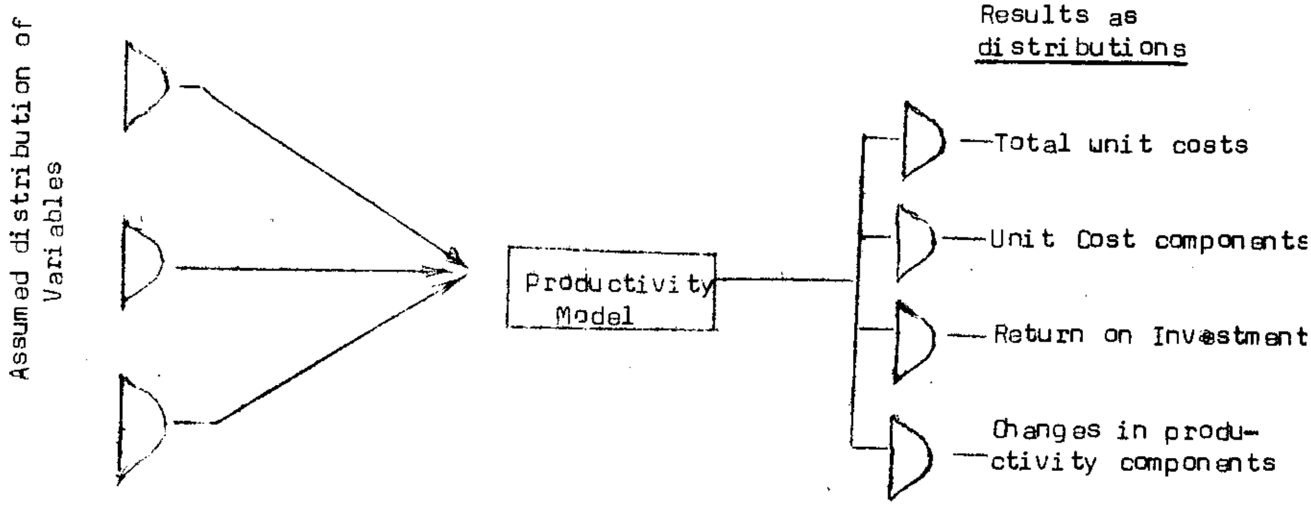

Fig. 7. Risk Simulation Model (2)

1% Change in		Effect on (In %)							
		Output Unit Cost				Unit Profit Margin a*	Output Capacity e*	Capacity Total Inv. k*	Return on Investment r*
		Labour	Material	Capital	Total				
Labour	M-hr/Output Unit								
	Wage Rates								
Material	Volume/ Output Unit								
	AV. Costs.								
	Av. Unit costs								
	Fixed Inv.								
	Capacity								
	Output								
	Sale Price								

Fig. 6. An Incremental Sensitivity Table (2)

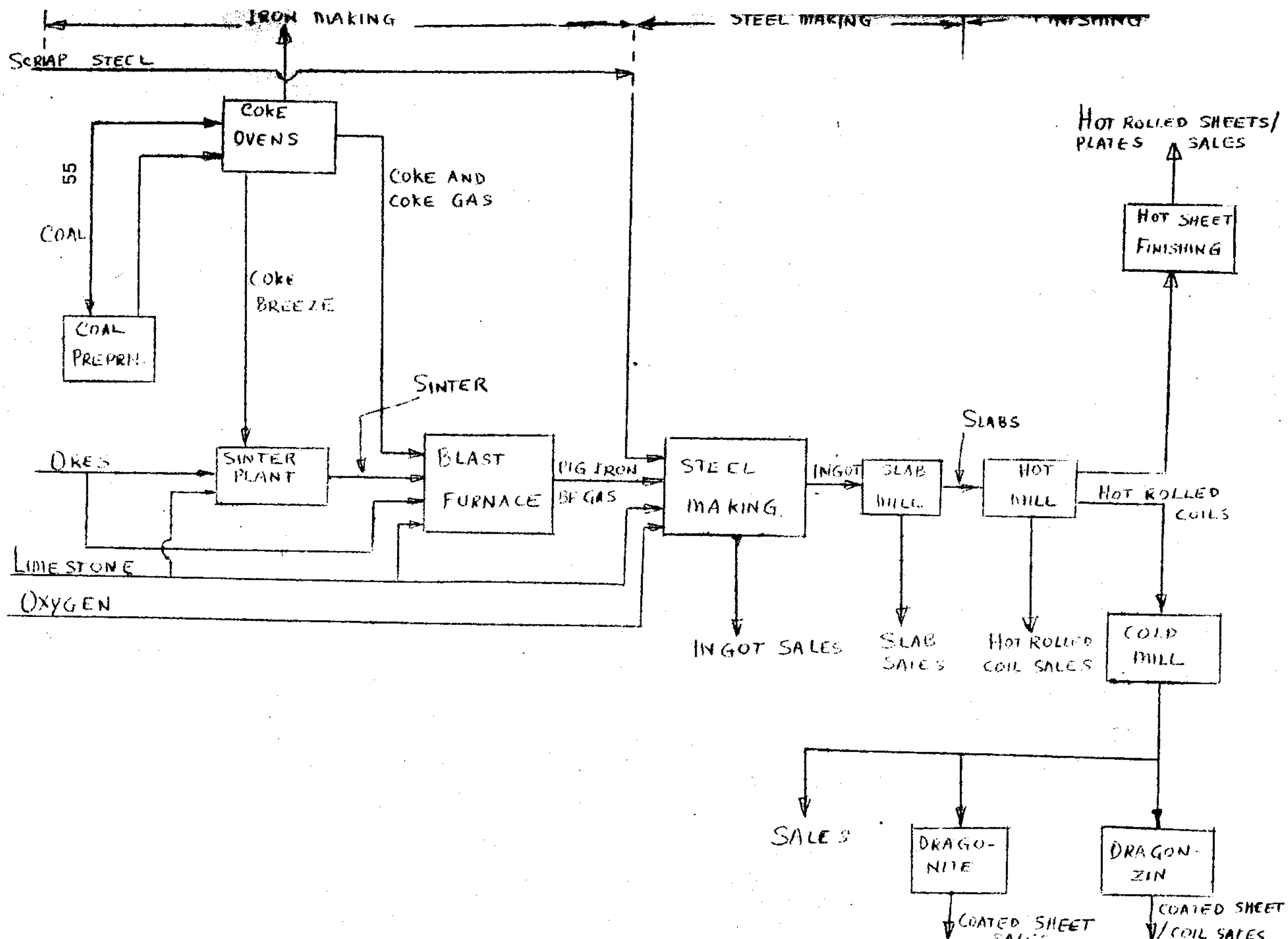

Figure 8: Simplified Flow chart of operations at Port Talbot Steel Works (2)

16. A case study to illustrate Gold and Eilon Models

We shall now consider at some length important aspects of a comprehensive application of the Gold & Eilon models reported in (2).

The case study pertains to the operations of an Integrated Steel Plant at Port Talbot Steel works. The simplified flow chart of the operations is given in Fig. 8. Coal is fed into coke ovens to produce coke, coke gas, and coke breeze. Most of the coke is charged into the blast furnaces along with ore and limestone to produce molton pig iron. All of the latter is fed into steel furnaces together with scrap steel and oxygen to yield steel ingots, most of which are rough rolled in the slab mill. Subsequent processing stages produce a variety of hot and cold rolled as well as coated steel products.

For productivity analysis, the plant is divided into three production departments and services which is regarded as a separate department as shown in Fig. 9 below:

Iron Making	Steel Making	Finishing
Services and ancillary activities		

Fig. 9. Schematic division of the plant (2)

The major inputs and outputs of the integrated steel plant considered in the analysis are given in Fig. 10. The plant is a part of British Steel Corporation and hence, the value of its turnover and its profit margins are not entirely within its own control. First the productivity relationships and cost structure are examined. The managerial control ratios are then described and discussed. Sensitivity analysis is performed next. Finally, various questions concerning the performance of the plant are examined.

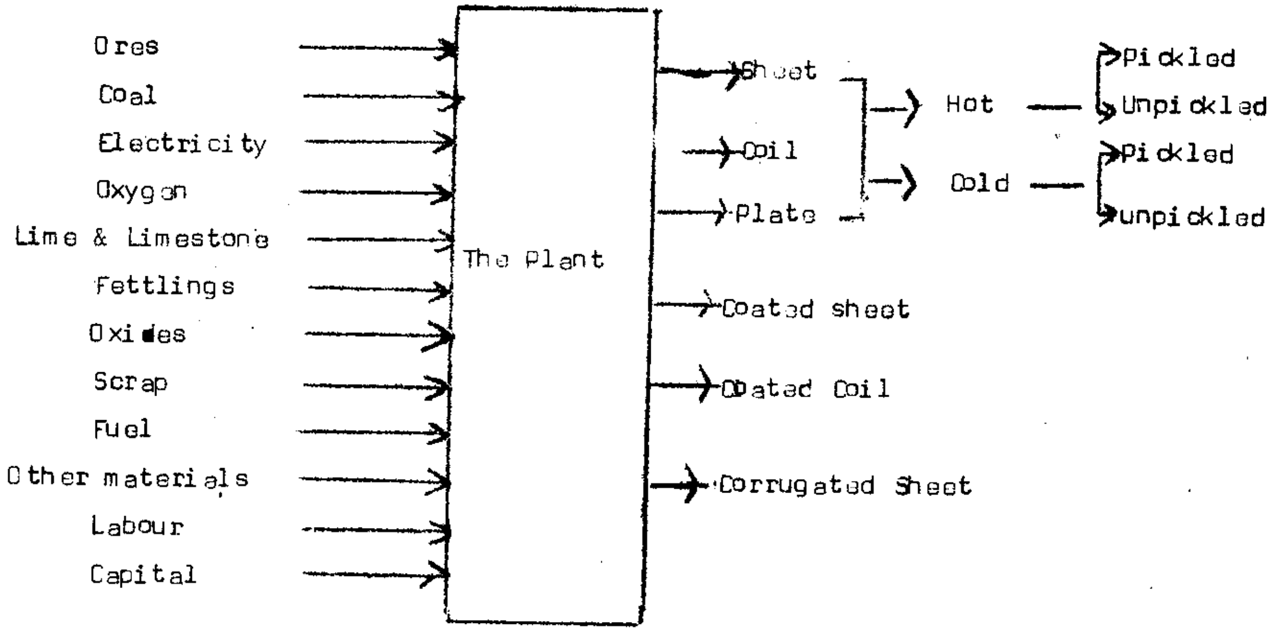

Fig. 10. The Plant-inputs and major outputs (2)

The framework for collecting data was derived from the model which requires information about:

Output and capacity

inputs of labour, materials and fixed investment

factor prices including wage rates, materials prices and capital charge rates

These data, then made possible calculation of indexes of changes in each of the following components of network of productivity relationships, cost structure and managerial control ratios:

direct input productivities:	labour, materials, net fixed investment
direct input proportions:	labour/materials, labour/utilized capital, materials/utilized capital.
Unit production costs:	wages, materials, capital charges, other costs.
Cost proportions :	Wages/total cost, material/total cost, capital charges/total cost and other costs/total costs.

Total unit production costs

Managerial control ratios.

16.1 Productivity ratios: To start with, fixed investment, capacity, materials volume, output and manhours trends are plotted for an 8-year period under study. These represent the main physical inputs and outputs. The capacity of the plant as a whole is its capacity to product ingot steel. Next, the labour productivity, capital productivity and utilised capital/labour are analysed. The relation between these is given by

$$\frac{PO}{M.Hr.} = \frac{CAP}{IF} \times \frac{IF \times PO/CAP}{M.hr.}$$

$$\text{Labour productivity} = \text{Capital productivity} \times \frac{\text{Utilized capital}}{\text{M.hr.}}$$

An 8-year analysis indicated that an upward trend in labour productivity was mainly due to increase in actively utilised fixed investment in relation to labour. Wherever decreases occurred, these were mainly due to sharp decreases in productivity of capital (years 3 & 4). Interrelationships between the materials productivity, capital productivity and utilized capital/materials was then studied. We know that

$$\frac{PO}{MV} = \frac{CAP}{IF} \times \frac{IF \times PO/CAP}{MV}$$

$$\text{i.e., Matl. productivity} = \text{Capital productivity} \times \frac{\text{Utilized capital}}{\text{material}}$$

It was found that the productivity of materials (PO/MV) showed horizontal trend till year 4, followed by a sharp decline in year 5 and by an upward trend thereafter. This resulted from off setting adjustments in productivity of capital (CAP/IF) and actively utilised capital. Thereafter increases in capital productivity and in the ratio of utilised capital to materials alternated in raising productivity of materials.

16.2 The Structure of Costs: To analyse the structure of costs, the turnover, total costs and factor costs (wages, materials, depreciation, other expenses) were studied for the 8-year period. The total turnover over the period rose by 8.2% but the increase was not steady. Total costs rose more steadily after a slight fall in year 3 while the fluctuations in the cost components of total cost were as marked as in turnover.

The factor costs as proportions of total costs and proportions of total turnover were then studied. It was found that the cost proportions and turnover proportions were not stable. The wages were found to average 17.5%, Wages and salaries 23.9%, materials 49.2% of total costs. Depreciation was surprisingly low (6.1% total cost average).

16.3 Changes in unit price and Unit costs: Average selling price per unit of output (turnover/volume of physical output) rose almost steadily after year 2 and was 21.1% higher at the end of the period than at the beginning. Similarly, the unit costs of wages, material, depreciation and other expenses (including salaries) rose by 30.8, 26.4, 33.7, and 88.5% respectively. Total unit costs rose by 40.9% over the period, the major increase occurring in the last 4 years.

16.4 Relative effect of cost adjustments on prices: Taking the whole period at Port Talbot, the average selling price rose by 21.2%. Unit costs of materials, wages, salaries, depreciation and other costs (including profits) rose by 26.4, 30.8, 63.9, 33.7 and -1.7% respectively. In year 1 materials constituted 44.9% of total value, wages 16.1%, Salaries 4.8%, depreciation 4.9%, other costs 29.3% (proportions of turnover are considered). Table 9 shows the calculation of the contribution of each cost factor to the change in selling price.

Table 9 : Relative Effects of cost adjustments (2)

Cost Factor	% change years 1-8	Weight Year 1	Total contributions	% Contribution
Materials	26.4	0.449	11.9	56.4
Wages	30.8	0.161	5.0	23.7
Salaries	63.9	0.048	3.1	14.7
Depreciation	33.7	0.049	1.6	7.6
Other	-1.7	0.293	-0.5	-2.4
Total		1.000	21.1	100.0

Overall the following conclusions could be drawn:

1) Increase in output/manhour is largely attributable to technological improvements.

2) Despite fluctuations in costs, the internal composition of manufacturing costs remained relatively stable.

3) The wages and salaries, although constitute a significant proportion of total cost, is by no means 'the greater part of the selling price'.

4) There is some evidence to support the inverse relationship between output and unit costs, although the evidence is not conclusive owing to major technological changes during the middle of the period.

16.5 Managerial Control Ratios: First unit cost, average selling price and direct profit were studied for the 8-year period. Unit costs have had a wider amplitude of fluctuations than average prices, but both increase in 5 years out of 8. Costs rose more than price in four of these 5, reducing direct profits. In the remaining years, both tended to reduce unit profits.

Secondly, the unit costs, average selling price, utilisation rate, productivity of capital, allocation of capital and return on capital were studied. It was found that in the short term, unit profit and return on capital tend to vary togethermuch more than the other determinants of the return on capital. Thus, when unit profit and return on capital were plotted together, the result strongly supported the hypotheses that return on capital is linearly correlated with unit profit.

16,6 Sensitivity analysis: The following assumptions were made for the sensitivity analysis, using sensitivity table.

1) Whilst the factor listed on the left of the sensitivity table changes, all other factors remain constant.

2) The base year cost proportions, profit to turnover margin and the ratio of fixed to total investment are constant throughout at the levels operating in the base year.

3) 1% change in fixed investment in either direction alters capital charges by 1% in the same direction.

4) 1% increase in capacity results from some change other than change in fixed investment.

It was again observed that significant effect on the return on investment was exercised by the sale price and the total unit cost. 1% increase in price led to 6.15% increase and 1% increase in total unit cost led to 5.15% decline respectively in the return on investment. There was relatively low effect of changes in capacity and the level of output. Furthermore, material costs were most significant (1% increase yielding a decline of 2.75% in ROI) while labour unit costs have a lower effect (1% increase leading to a decline of ½% in the return).

16.7 Risk simulation

A risk simulation analysis was carried out based on the range estimates shown in Table 10 below. The objectives of the analysis were two fold: (i) to forecast the effects of estimated changes on total unit costs and on return on investment (ii) to estimate the price that should be charged for slabs in order to ensure that there is a chance of about 1:5 that ROI would not decline .

Table 10: Assumed changes in Base Year Slab Mill data (2)

Variable	Range estimates for risk simulation
Labour	
Total man hours	down 0-10% mean 5%
Wage rates	up 5-15% mean 10%
Outputs	
1) Mild steel slabs	up 5-15% mean 10%
2) Silicon slabs	down 0-10% mean 5%
3) Hire rolled slabs	0 or between 25089 and 35478
Costs	
Hire rolled ingots	£ 0.9171 - £ 1.1702 mean £ 1.0436
Mild steel & Silicon Ingots	Up 0-10% mean 5%

The results of the risk simulation (consisting of 1000 runs) for the increase in unit cost and its components are shown in Table 11.

Table 11 Increases in Unit Costs & Components (2)

Increases in Unit Costs	$\Delta(\frac{TC}{PO})$ Total	$\Delta(\frac{M}{PO})$ Matls.	$\Delta(\frac{W}{PO})$ Wages	$\Delta(\frac{CC}{PO})$ Capital	$\Delta(\frac{OE}{PO})$ Other expenses
Mean	4.2	4.8	-3.1	-7.2	-7.2
Std. devn.	2.2	2.3	1.8	1.3	1.3

The formula used was:

$$\Delta\left(\frac{TC}{PO}\right)_{2,1} = \Delta\left(\frac{M}{PO}\right)_{2,1}\left(\frac{M}{TC}\right)_{1} + \Delta\left(\frac{W}{PO}\right)_{2,1}\left(\frac{W}{TC}\right)_{1} +$$

$$+ \Delta\left(\frac{CC}{PO}\right)_{2,1}\left(\frac{CC}{TC}\right)_{1} + \Delta\left(\frac{OE}{PO}\right)_{2,1}\left(\frac{OE}{TC}\right)_{1}$$

In order to estimate the effects of the predicted changes on return on capital, it is necessary to assume selling price, for the slabs produced. For illustrative purposes, only the following prices were selected for the three products: 1) Mild Steel slabs £ 35/ton, 2) Silicon slabs £ 39.34/ton, 3) Hire rolled slabs £ 3.15/ton. The results of the risk simulation analysis are summarised in Table 12.

Table 12: Index of return on capital & its determinants

	r	a	e	k
a) No price increase				
mean	74.4	68.8	107.8	100.0
Std. devn.	(19.9)	(17.8)	(1.5)	(0)
b) Price increase -5%				
mean	118.6	109.2	108.8	100.0
Std. devn.	(20.4)	(17.8)	(1.5)	(0)

It is clear that the major contributor to the reduction in ROI is the reduction in unit profit, the effect of which is only marginally offset by an expected improvement in utilisation.

The Risk Simulation (RS) model allows the distribution of ROI to be derived, so that the probability of outcomes below or above a given value may be readily obtained. Thus, from the RS analysis, it was found that a 5% increase in prices for the three products will lead to a chance of about 5:1 that the ROI will not fall below the 100 mark.

17 CONCLUSIONS

It is obvious that from the studies reported above that considerable headway has been made in the effort towards evolving a suitable measure of productivity at the plant level. A great deal of clarity now exists about the important requirements, that such a measure should fulfil. Among those that have been identified, mention could be made of the following: (i) that the measure should fulfill certain necessary criteria (ii) that it should be free of some commonly made but rather serious errors (iii) that it should overcome problems normally associated with productivity measurement over a period of time. In depth studies are now available with respect to all these three requirements.

Interestingly enough surveys carried out of the current status of adoption of productivity measures even in large U.S. industrial and non-industrial corporations suggests that it is the non-standard measures of productivity that currently enjoy wide spread adoption. These are followed by partial productivity measures. Adoption of total productivity and total factor productivity measures seems almost conspicuous by absence. Also it appears that manufacturing/operations and sales functions seem to be the two functions in the forefront of large scale use of productivity indicators. The survey thus clearly points to an imperative need for education in total productivity measurement both in industry as well as other organizations.

The major efforts towards development of productivity measures in recent times appear to have been aimed at measurement of total productivity. Nevertheless it is possible to group the proposed measures in the following three types:

i) Measures based on productivity being considered as ratio of total outputs to all the inputs.

ii) Measures based on consideration of total factor productivity i.e., value added outputs and the inputs that achieve this.

iii) Composite measures which reflect either managerial judgement or level of satisfaction of interest to different groups such as employees, customers, investor and suppliers.

iv) Measures which enable integrative analysis of interaction between productivity, cost structures and managerial control ratios.

Thus, the indices developed by Kendrick & Creamer (6), Craig & Harris (10) and Stewart (12) belong to the first category. The measure proposed by Tailor and Davis (11) belonged to the second category. Stewart's multi-attribute utility function (4) and the composite productivity index proposed by Aggarwal (9) can be said to belong to the third category. Finally, the framework proposed by Gold (13) as well as the risk simulation and sensitivity models of Eilon et al. (2,14, 15) represent the fourth category.

The main advantage of Craig Harris method over that of Kendrick and Creamer lies in the fact that in the former, the capital input is propoerly derived from the cost of capital theory, as apayout in the form of annuity, instead of considering depreciation as a component of this input, which can be quite misleading. When the interest of the firm is in assessing how the factors which are more amenable to internal control affect the internal value addition to the outputs, the total factor productivity measure (11) as proposed by Tailor and Davis will be very useful. In all the above three models, estimation of outputs and all inputs as well as their aggregation follows similar procedures. It is only with regard to estimation of capital input that they differ. None-the less, in all the three cases, the estimates cannot be said to truly reflect the actual cost of capital.

The above methods are however predominantly tools for measurement of productivity and do not possess the requisite diagnostic capability to identify areas requiring attention for improvement of productivity.

The composite measures show a refreshing departure from the conventional approach of viewing the 'concept of productivity' as one which can merely represented by the ratio of outputs to inputs. But much further progress is called for before any such measures could be recommended for meaningful adoption. Stewart's approach for example in its present form, could be far too cumbersome as well as difficult to understand and interprete by management. Therefore its acceptability for implementation on a continuing basis stands to question. Moreover, there is no guarantee that his utility based productivity index necessarily reflects changes in the ROI of the firm. Also the index could be subject to the more serious criticism of relying too heavily on judgement concerning internal variables that affect organizational productivity. Similarly, the composite index proposed by Aggarwal, at its present stage of development seems to clearly suffer from some fundamental flaws. It could, for instance , easily happen that the firm's sales revenue and customer base decline sharply and yet the composite index could show the productivity to have actually gone up! Indeed, many other non-standard measures reported by Sumanth(7,8) in his survey also suffer from such inherent drawbacks. Therefore their consideration for general applicability is seriously impaired, although the same might have demonstrated their worthwhileness under some specific circumstances. Even many of the productivity measures used in service organizations, as reported by Aggarwal (9) seem to be far from satisfactory.

This brings us finally to the integrative framework of Gold (13) which enables simultaneous analysis of interactions between productivity networks, cost structures and managerial control, ratios. Using this framework, change in ROI (which is the crucial indicator of firm's productivity) can be traced, through the analysis of interactions to changes in unit costs, cost proportions, factor prices, factor proportions, apparent factor productivities, as well as other managerial control ratios. Thus, any misleading and fallacious conclusions which could otherwise result regarding contributory factors to productivity change can be averted. The framework has been extensively field tested and its reported applications include industries like Iron and Steel (2,19) and petroleum (3).

The usefulness of this framework has been considerably enhanced by the sensitivity analysis and risk simulation model of Eilon et al (2,15). This way, impact on ROI could be predicted for a range of change (rather than single value changes) in any of the components of the Gold-framework. This development has dramatically rendered the frame work an exceptional tool for management planning and control (3). Moreover, the framework effectively dispels the notion, beyond any element of doubt that changes in 'apparent factor productivities' are due to changes in intrinsic contributions of the respective factors alone. This way the dangers inherent in blanket but erroneous adoption of partial productivity measures are convincingly exposed.

Thus it could be concluded that the current state of art is sufficiently advanced to facilitate fairly accurate measurement of productivity at the firm level. Furthermore, it is also possible to analyse changes in productivity through the network of managerial control ratios, cost structures and factor productivities, and relate them to changes in relevant components of this network. It is also possible to predict, plan and control changes in productivity arising out of likely changes in any or more of these network components. Some of the methodologies, in particular, those due to Stewart (12), Gold (13), and Eilon (2,14,15) can also be applied at specific departmental or functional levels. Consequently the effect of changes in departmental or functional levels on firm's productivity can be assessed. However, the models being primarily meant for assessment at firm level are somewhat difficult to apply readily at departmental levels, particularly when the number of departments is large and affect the total productivity through a complex of interrelationships amongst them.

It is in this context that the need for a framework which enables analysis of interactions between departmental productivities and their effect on total productivity becomes imperative. It is only when these interactions are understood thoroughly that firm level productivity goals could be translated into practical targets or goals for various departments,which is so vital for planning, control and implementation of productivity programmes. Future effort will therefore have to take cognizance of the need for evolution of such a framework.

Likewise prevailing methodologies do not explicitly allow for assessment of the effect of changes in productivities of individual product lines or production plants on the total productivity as a whole in case of multi-product multi-plant companies. In the evolving, contemporary business structures, these considerations are very significant. Suitable frameworks for productivity measurement and analysis will also have to encompass such business situations. After all, the full benefits of productivity programmes could be reaped only when productivity goals are effectively translated into group or individual goals for concerned functionaries within the organization and thus integrated with their own growth and career aspirations. Moreover, decisions on capital investment, capacity expansion, technological changes, etc., in specific product lines or plants will have to take into account not only the effect of these on the respective line/plant productivity but also the extent to which the latter influences the total organizational productivity.

It is also felt that exploration of productivity analysis framework as a predictive tool for purposes of budgeting, planning and control needs much further investigation. For instance, effect of uncertainties in likely levels of outputs or inputs, etc. on the predictive ability of the frameworks needs more indepth study than has been attempted hitherto. Like any other measure of business performance, productivity also cannot escape the effect of uncertainties.

The attainment of productivity goals under conditions of constraints on the levels at which different components like factor prices, factor proportions, etc. are likely to operate needs to be studied, in order to be able to take decisions regarding factor substitutions, introduction of innovation, etc.

Finally, it is felt that since productivity measurement has now come a long way from the early efforts towards model formulation it will of much benefit to standardise on the methods of estimation of inputs and outputs, as well as on the use of deflators to base period values.

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