THE UNIVERSITY OF MANITOBA

PRODUCTIVITY MEASUREMENT AND PLANNING MODELS FOR MANUFACTURING INDUSTRIES

by

ABULGHASSEM MASOOD MOHAMED

A Thesis Submitted to the
Faculty of Graduate Studies in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

DEPARTMENT OF MECHANICAL ENGINEERING

INDUSTRIAL ENGINEERING GROUP

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ABSTRACT

Total productivity measurement and planning are becoming increasingly important concepts due to the inability of single measures of performance to fully explain the growth of productivity. Technological advancements are recognized as significant contributors to productivity improvement at the corporate level in manufacturing industries. Yet, their contributions have not previously been identified, highlighted nor quantified appropriately.

To answer these questions, a new Total Operational Productivity (TOP) measure, specifically established to highlight the actual resource consumptions in a manner that would help management to implement advanced technology systems in manufacturing industries and to identify their contributions to corporate productivity is introduced.

A mathematical procedure to cluster quantitative and qualitative variables in production systems, in order to determine a new Technology Factor Index (TFI), is also presented. This is done in three steps : (1) identification of technological variables that influence productivity measurement constraints, and classification of all variables, (2) determination of the degree of linear relationship between these variables by means of a correlation matrix, and (3) formulation of the TFI and development of its solution procedure. The relationship between TOP and TFI is also investigated.

The TOP measure is formulated for long-term Total Operational Productivity Planning (TOPP). The TOPP is derived as a nonlinear (fractional) objective function with linear technological constraints.

The results of the case studies done in this thesis indicate that : (1) The TOP measure shows higher trends in comparison to other total productivity measures, (2) The TFI shows a significant relationship with our TOP measure, and (3) The TOPP provides a method to ensure desired TOP growth during the planning period if allocations of outputs and inputs are made according to the solution of the model.

In summary, this research presents new contributions to prooductivity measurement and planning, with emphasis on presenting techniques that are useful to decision makers.

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TABLE OF CONTENTS

CHAPTER Page

LIST OF TABLES

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correct page numbering

LIST OF FIGURES

NOMENCLATURE

i	Type of industry or group of industries
t	Planning horizon in years
K	Output elements
j	Major input elements (Human resourses, capital, materials, energy, and other costs)
l	Elements of major input factors
Y	Output value in constant dollars
X	Input value in constant dollars
TOP_{it}	Total Operational Productivity measure in industry i at time t.
$TOPI_{it}$	Total Operational Productivity index in industry i at time t.
$SFOP_{it}$	Single Factor Operational Productivity in industry i at time t
$MFOP_{it}$	Multifactor Operational Productivity in industry in i at time t
Y_{i1t}	Selling value of shipment of goods produced in industry i at time t.
Y_{i2t}	Revenue from repairs in industry i at time t.
Y_{i3t}	Work done on material owned by others in industry i at time t.
Y_{i4t}	Other income in industry i at time t.
X_{i11t}	Total cost of employee in manufacturing operations in industry i at time t.

X_{i12t}	Cost of other production workers in industry i at time t.
X_{i13t}	Cost of executive staff in industry i at time t.
X_{i14t}	Cost of sales staff in industry i at time t.
X_{i15t}	Cost of administration in industry i at time t.
X_{i21t}	Consumption cost of machinery and equipment in industry i at time t.
X_{i22t}	Consumption cost of building construction in industry i at time t.
X_{i23t}	Consumption cost of engineering construction in industry i at time t.
X_{i24t}	Consumption cost of capital items charged to operating expenses in industry i at time t.
X_{i31t}	Cost of raw materials in industry i at time t.
X_{i32t}	Cost of purchased materials used in industry i at time t.
X_{i33t}	Total cost of maintenance and repair supplies in industry at time t.
X_{i41t}	Cost of coal and coke in industry i at time t.
X_{i42t}	Cost of electricity purchased in industry i at time t.
X_{i43t}	Cost of gasoline in industry i at time t.
X_{i44t}	Cost of diesel oil in industry i at time t.
X_{i45t}	Cost of light fuel oil in industry i at time t.
X_{i46t}	Cost of heavy fuel oil in industry i at time t.
X_{i47t}	Cost of natural gas in industry i at time t.

X_{i48t}	Cost of other fuel including steam purchased in industry i at time t.
X_{i51t}	Cost of travel expenses in industry i at time t.
X_{i52t}	Cost of research and development in industry i at time t.
X_{i53t}	Cost of taxes in industry i at time t.
X_{i54t}	Cost of marketing and advertising in industry i at time t.
d_{it}	Depreciation factor
L	Economic life of the capital asset
I	Investment expenditures during each year
OP_{it}	Dollars of operating expense
r_{jk}	Correlation factor
TFI_{it}	Technology Factor Index of industry i at time t
D_{is}	Quantitative decision variables
D_{ik}	Qualitative decision variables
QN_{ijt}	The index value of quantitative variable j
QL_{ikt}	The index value of qualitative variable k
η_{ij}	Weights corresponding to quantitative variables
η_{ik}	Weights corresponding to qualitative variables
a_{ij}	The loads of quantitative variables
a_{ik}	The loads of qualitative variables
C_{it}	The capacity of industry i at time t.
$t-1$	The previous period .
δ	Percentage of change in employment rate

CHAPTER I

INTRODUCTION

During the past decade, there has been a great deal of concern about the measurement of performance of a nation's economy. This is summarized by Drucker (1980) and shown in Figure (1.1). The term "productivity" has taken on such an importance, that it has now been accepted by all major disciplines and professions in their attempts to further influence economic growth.

Much effort has been put into simplifying the complexity of productivity concepts into a linearized, simple statement, that can be expressed through a standard formula. In practice, productivity is often interpreted as " Production per Man- hour" [Concise Oxford Dictionary] and the general approach to it can be summarized as follows:

"Productivity in economics is the ratio of what is produced to what is required to produce it. Usually this ratio is in the form of an average, expressing the total of some category of goods divided by the total input of, say, labor or raw materials. In principle, any input can be used in the the denominator of the productivity ratio. Thus, one can speak of factors of production ... labor is by far commonest of the factors used "[Encyclopaedia Britannica, 1974]. That is

$$\text{Productivity} = \frac{\text{OUTPUT}}{\text{INPUT}}$$

* CUSTOMER SATISFACTION
* INNOVATION
* INTERNAL PRODUCTIVITY
* OPERATING BUDGET
* EMPLOYEE ATTITUDE & DEVELOPMENT
* MANAGEMENT DEVELOPMENT & PERFORMANCE
* SOCIAL RESPONSIBILITY

Figure 1.1 Major area of application of performance measurement (Drucker, 1980)

1.1 Productivity Key Issues :

Several answers are needed to the question of productivity measurement in regard to its value as a measure of the economic performance and of the quality of life. These are linked to issues which are functions of the availability of natural resources, of appropriately skilled people, and appropriate technology.

Improvements in productivity are known to affect greatly social and economic parameters, such as real economic growth, gross national product (GNP), inflation control, employment, decrease in unit cost, technological innovation and customer satisfaction. Also planning techniques are needed to support measures and improvement both in short and long term. Until now these factors have been adressed in literature mainly by means of productivity measures based on a single factor, usually labor input.

(a) Gross National Product(GNP)

GNP is defined as the market value of the total output of goods and services produced by a nation's economy. There is a strong relationship between the GNP and labour productivity growth rates. Figure (1.2) shows the output/man-hr in six manufacturing countries for the period of 1960-1981. In that time period Japan has increased its labour productivity

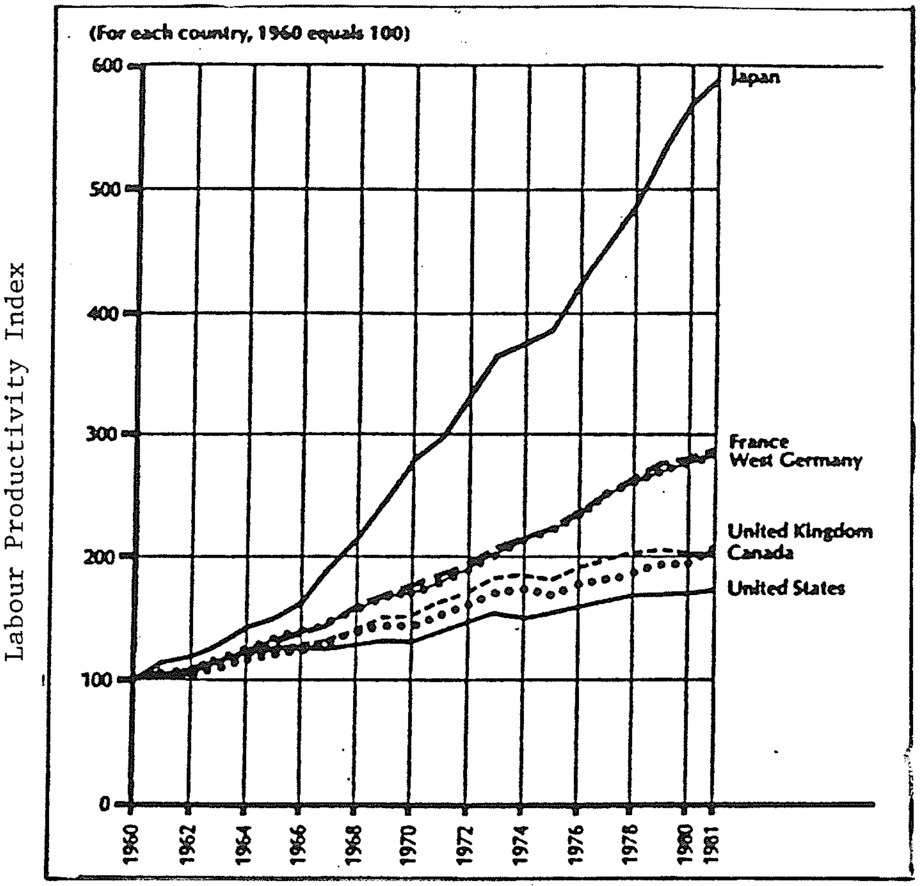


Figure 1.2 Manufacturing productivity growth, U.S. and major competitors, 1960-1981. (BLS, 1983)

480 % , West Germany and France 180% , U.K. 110 %, Canada 100 % , and U.S. only 70 % . The percentage of growth in the GNP was approximately 82 % for the first five countries, whereas U.S. had a low value of 63 % , for the same period of time (BLS, 1983). Figure (1.3) shows the significant changes of Canadian manufacturing industries' GNP (output)

relative to labour productivity.

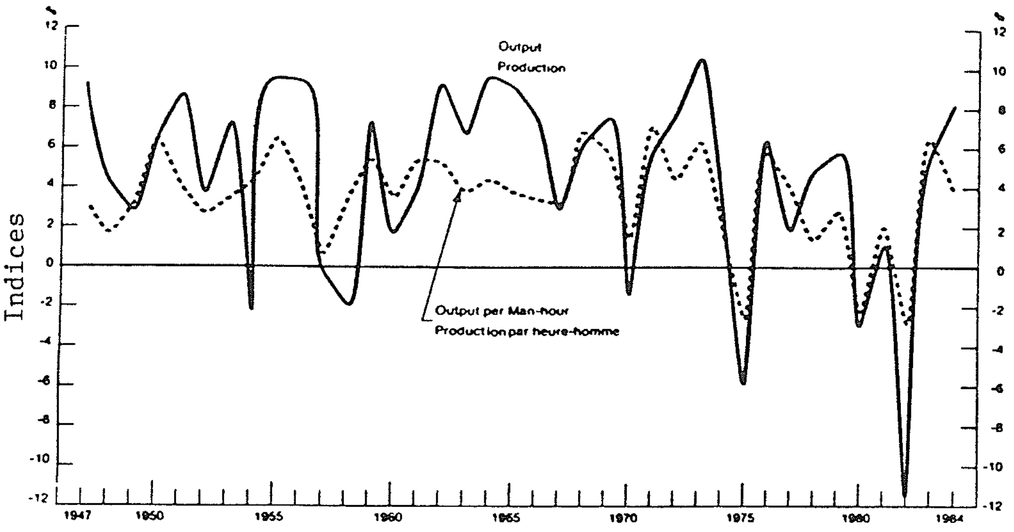


Figure 1.3 The change of Canadian manufacturing output relative to labour productivity (Statistics Canada, 1986)

Although the U.S. productivity growth rate is low, it still remains the most productive nation in the world economy, due to its very high initial productive base. The rest of the industrial world is working very hard at closing the gap. For example, in 1950 the real gross domestic product per employee in Japan was only 16 % of that of the U.S. and Germany's was 40 % . In 1973 an average Japanese worker was producing 55 % as much as a U.S. worker, while in Germany the ratio moved up to 74 %. By 1978 these ratios increased to 66 % for Japan and 88 % for Germany (Business Week, June 30, 1980).

(b) Inflation Control :

The inflation rate (annual percent change in price) can be influenced by many factors. Economists generally agree that a lack of productivity growth contributes to an increase in inflation rate. As expected, we see that the percent increase in price and labor productivity are inversely correlated as shown in Figures (1.4) and (1.5) for selected U.S industries.

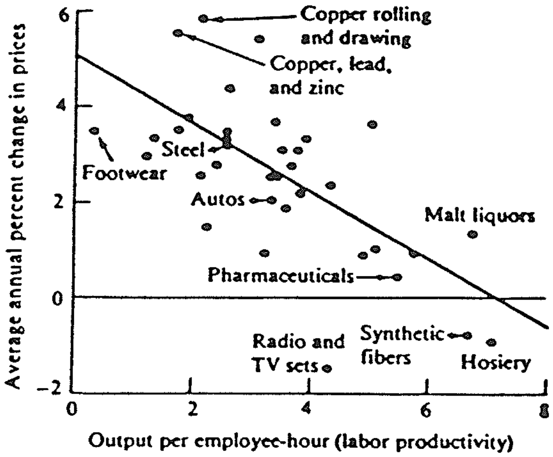


Figure 1.4 Relation Between price increases and labour productivity in selected U.S. Industries, 1960 -1978. (Productivity Perspective, 1984).

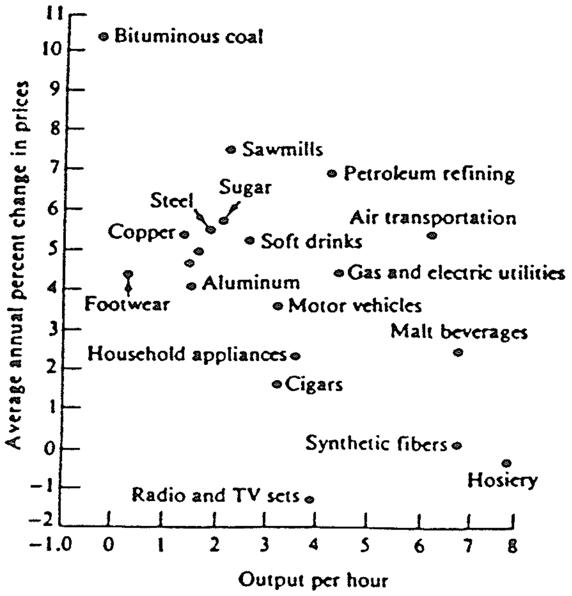


Figure 1.5 Relation between price increase and labour productivity in selected U.S. industries, 1960-1978. (BLS, 1982)

(The study by Cocks (1981) for El-Lilly company for the 1963-1974 period, using a multifactor productivity measurement approach, indicated that an average rate of growth of productivity of 10.1 % would decrease the price index by about 0.4 %).

(c) Unit Cost :

The concept of unit cost as the sum of the total input per unit of total output during the same time period, is often called consumptivity. The increasing importance of indirect inputs, such as those due to planning, control, product development, and training have further complicated the concept of unit costs because of their different levels of influences in product mix ,production and time periods.

A decrease in one class of unit cost such as labor has positively correlated with labor productivity as shown in Figure (1.6) for Canadian industries.

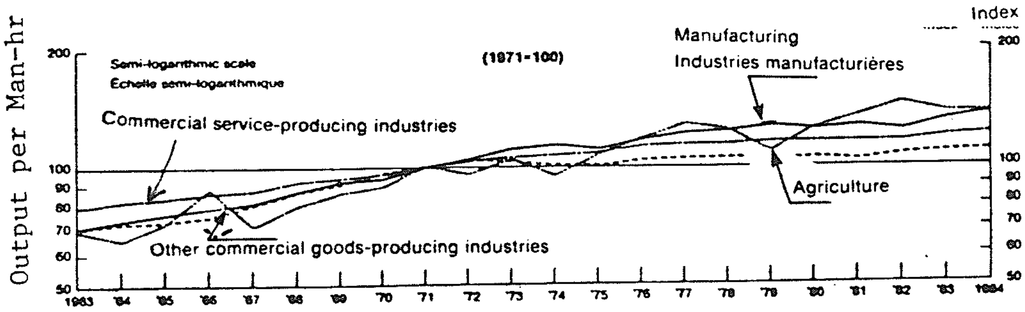


Figure 1.6.a Labor productivity in Canadian manufacturing industries, 1963-1983, (Statistics Canada, 1985).

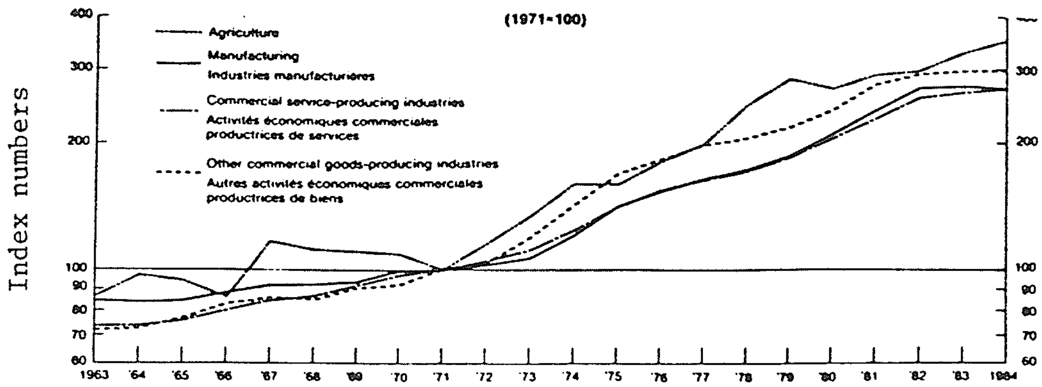


Figure 1.6.b Unit labour cost in Canadian Industries, 1963-1983, (Statistics Canada, 1985).

(d) Unemployment:

Unemployment refers to all persons of working age who, in a specified period ,are without work, are available for work, and are actively seeking work for pay or profit.

There exists a mistaken belief that unemployment will lead to increased productivity. Such a belief clearly results in increasing layoff of workers. It may however be shown that many companies actually increase their employment level because of high product demand resulting from lower production costs that come from higher productivity. In many industries high percentages of productivity growth rates are often accompanied by increases in output that require even higher labour inputs as shown in Figure (1.7). This fact has been confirmed internationally.

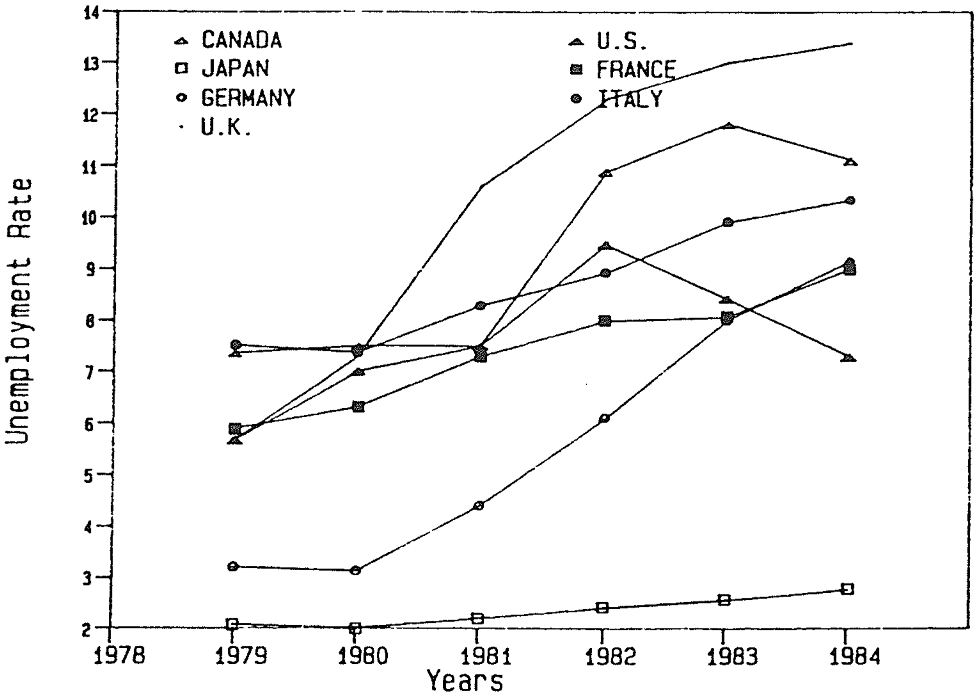


Figure 1.7 International Comparison of average annual rate of unemployment in most industrial countries for the period of 1978-1984. (Sink, 1985)

It might be interesting to consider Japan (with the highest growth rate and lowest unemployment rate) and Canada (with the least average labor productivity growth and second highest unemploment rate). Wright (1985) has attempted to isolate the causes of declining Canadian productivity compared to that of Japan. He states that the following Canadian features are the major ones underlying the differences in the respective productivity/unemployment relations:

1. Culture, mainly concerned with individualism and specialization in production.
2. Less precise job descriptions, procedures, time and motion studies, and definitive methods manuals that define elements of work functions and their relation to other.
3. Management decisions are not taken on the basis of long-term return on investment planning, but concentrate on short-term "bottom-line" profit.
4. Fewer trained employees in the area of computer applications.
5. Problem solving approaches at the operating level are very different from Japanese approaches (e.g. more dictatorial management edicts, in contrast with Japanese "concensus" methods as exemplified by their use of "Quality Circles").
6. Different market requirements.

(e) Technological Innovations and R & D :

Technological innovation and R & D are typefied by new machinery that perform similar functions as older equipment but more efficiently or more of them, usually increase overall productivity (Zohar, 1983).

Although Technological innovations are generally claimed to have positive, long-term effects on productivity and economic growth, it is very difficult to quantify their exact influences. Several studies have concluded that the return on investment from R & D is at least as high or higher than from other types of investment. Researchers have examined the relationship between R & D input effects and productivity measures . A positive correlation was found for manufacturing industries, by Griliches (1979), Nadiri (1979) and many others. A glance at the experience of some U.S. industries during the 1970's reported by Sahal (1983) shows the relationship between R & D and productivity growth shown in Table (1.1). These results indicate a generally positive correlation between innovation and productivity measurement at the industrial level.

Table 1.1 R & D Expenditure and productivity growth by industry, 1969-1979, (Sahal,1983).

Industry	Growth Rate	R & D
Chemical	1.9 %	$ 2024
Communication	3.96	5038
Electrical machinery	2.44	905
Machinary exluding electrical	0.88	3572
Fabricated metals	0.37	1157
Primary metals	-0.90	327
Rubber	0.49	378
Stone,clay and glass	1.01	191

Zohar (1982) tested various aspects of performance measurement in Canadian manufacturing industries using four production functions known as: Cobb-Douglas (C-D), Constant Elasticity of Substitution (CES), Variable Elasticity of Substitution (VES), and Translog Production Function. Their behavior was analyzed at both average and marginal performance levels in terms of capacity utilization, capital intensity and labor share in value-added output. Zohar's strategic aim was to achieve promotion of employment, efficient utilization of resources, relative price stability, equitable distribution of economic activity across regions, expansion of secondary manufacturing and technological innovation. He concluded that labour productivity is highly responsive to technology, that is, capital is highly complementary to increased labor productivity. Table 1.2 shows the average performance level in selected Canadian industries studied by him.

1.2 Discussions:

In conclusion, in order to improve productivity, some measurement mechanism must be identified and defined before the task can be proceeded with. Although the traditional productivity definition of output divided by input is straightforward and uncomplicated, its evaluation remains elusive because of the lack of definitive theoretical work, mainly at the industrial level. Gold (1983) emphasized the seriousness of continued wide-spread misunderstanding of the nature and effects of productivity measurement.

	Capacity Utilization		Labour Productivity		Real Wages		Economies of Scale		Capital Intensity		Productivity of Capital		Technological Change (g)	
	1970-77	1973-77	1970-77	1973-77	1970-77	1973-77	1970-77	1973-77	1970-77	1973-77	1970-77	1973-77	1946-77	1970-77
Total manu.	(−)	(−)	(+)	(+)	(+)	(+)	(+)	(−)	(+)	(+)	(−)	(−)	(+)	(+)
Food and bev.	(−)H	(−)L	H	H	H	H	H	(−)L	H	H	(−)H	(−)L	L	L
Tobacco	(+)H	(+)H	H	H	H	H	H	(+)H	L	L	(+)H	(+)H	(−)H	(−)H
Rub. and plas.	(+)H	(+)H	H	H	L	H	H	(+)H	A	L	(+)H	(+)H	L	(−)L
Leather	(−)H	(−)L	H	H	H	H	H	(+)H	H	H	(−)H	(−)L	(−)L	L
Textile	(+)H	(−)L	H	H	H	H	H	(−)L	L	H	(+)H	(−)H	H	L
Knitting	(+)H	(−)L	H	H	H	H	H	(+)H	H	H	(+)H	(O)	n.a.	(−)H
Clothing	(+)H	(+)H	H	H	H	H	H	(+)H	H	H	(O)	(−)H	L	(−)H
Wood	(+)H	(−)L	H	H	H	H	H	(+)H	H	H	(−)H	(−)L	(−)H	(−)H
Furn. and fix.	(−)H	(−)H	H	H	H	H	H	(+)L	H	H	(−)H	(−)H	n.a.	L
Print. and pub.	(+)H	(−)L	H	H	H	H	H	(+)H	L	L	(+)H	(−)L	L	L
Trans. equip.	(+)H	(−)L	H	H	A	H	H	(+)L	L	L	(+)H	(−)L	L	H
Electric. and electro.	(−)H	(−)H	H	H	L	L	H	H	H	H	(−)H	(O)	H	H
Non-met. min.	(+)H	(−)L	H	H	H	H	H	(+)L	L	H	(+)H	(−)L	(−)L	(−)L
Chemical	(−)H	(−)H	H	A	L	H	H	(+)L	H	H	(−)H	(−)H	(−)H	(−)H
Paper	(−)H	(−)L	L	L	H	H	H	(O)	L	L	(−)H	(−)L	L	L
Prim. metals	(−)H	(−)H	L	L	H	A	(−)H	(−)H	H	L	(−)H	(−)H	n.a.	(−)H
Metal fab.	(−)H	(−)H	L	L	L	H	A	(−)L	L	L	(−)H	(−)L	n.a.	(−)L
Machinery	(−)H	(−)H	H	L	L	L	H	(−)A	H	L	(O)	(−)H	n.a.	(−)H
Petrol. and coal	(−)H	(−)H	A	L	H	H	H	(+)H	H	L	(−)H	(−)H	(−)H	L

H - Higher than Manufacturing Sector's Average
L - Lower than Manufacturing Sector's Average
A - Same as Manufacturing Sector's Average

(+) - Compounded Annual Rate of Increase
(−) - Compounded Annual Rate of Decrease
(O) - "No Change"

n.a. - "Not Available"

Table 1.2 Annual rate of change in labour productivity , technological changes and other economic variables in Canadian manufacturing industries.(Zohar, 1982).

This research effort has been directed towards the development of productivity measures and productivity planning models applicable to manufacturing industries. First, a new TOTAL OPERATIONAL PRODUCTIVITY MEASURE INDEX is derived; this index can be used as a diagnostic measure in terms of capital and other input consumption at the operating level in production as well as service industries. In addition, a corresponding quantitative TECHNOLOGY FACTOR INDEX is proposed using factor analysis statistical techniques as a clustering approach. Finally, a TOTAL OPERATIONAL PRODUCTIVITY PLANNING method is introduced as a nonlinear (fractional) programmming problem. It allocates the output and the input components to ensure a percentage of growth of the productivity target based on the formulation of a fractional programming problem. This provides management with a new productivity measurement decision tool for short-term and long-term planning.

CHAPTER II

PART I : REVIEW OF LITERATURE ON PRODUCTIVITY MEASUREMENT

An extensive study of productivity-related literature for manufacturing industries has been carried out with special emphasis on productivity measurement models. This research indicates that most measurement indices are based on the use of different parameters in their modeling. We classify these measures according to the parameters used as follows:

1) Output,input components;
2) Application of the productivity measure (product, plant, company, industry or nation wide);
3) Purpose of measurement (maximizing profit, minimizing cost, comparison) and
4) Identification of cost source(s).

According to these four points, indices can be classified into five available measurement approaches used for measuring productivity. They are :

1) Single Factor Productivity (SFP), (usually referring to labor productivity).
2) Multi-Factor Productivity (MFP), (address more than one factor).
3) Total Productivity (TP), (attempt to address all factors).
4) Managerial Control Ratio (MCR), (financial ratios).

5) Productivity Costing Approach (PCA), (highlighting costs).

The first three approaches can be considered as "macro" productivity measures, while the last two fall into the category of "micro" level approaches . The merits of each approach are described and discussed in the following sections.

2.1 Single Factor Productivity (SFP) :

The most generally accepted measure of productivity, SFP, relates output to one input only, such as labor time. The output side usually refers to units of the finished product or the amount of real value added to the product in the enterprise. SFP may also refer to output/capital. The major contributions to this approach are :

(a) The Bureau of Labor Statistics (BLS) Index defined as:

$$\text{SFP} = \frac{\text{constant dollar value of goods and service provided}}{\text{Man-hrs of employed persons}}$$

Here, the man-hours are based on hours paid, including sick leave, other leave, holidays, and other time off in addition to actual time worked.

(b) Kendrick (1961) has published indices of labor productivity which he defined as follows:

$$\text{labor productivity} = \frac{\text{Output}}{\text{Weighted man-hr}}$$

Kendrick's index is adjusted for the composition (quality) of labor by weighting man-hours at the industrial level by average hourly earnings.

(c) Statistics Canada Index is expressed as:

$$\text{Productivity Index} = \frac{\text{Real output index}}{\text{Labor input index}}$$

Where the output is the gross domestic product by industry and the labor input is the annual average number of persons employed, i.e. output / person

(d) Eilon (1975) developed a micro SFP as follows:

$$SFP = \frac{V}{[(T_o + T_b)N]}$$

Where V = level of production demand measured in physical terms at time t;
T_o = total hours of normal work at time t ;
T_b = total hours of overtime work at time t;
N = average number of employees on the payroll.

Eilon (1984) emphasized the effect of average wages, holiday rates, overtime, benefits to employees, unit cost of labor and profit sharing.

(e) Freeman and Juker (1981) proposed several SFPs such as: (Capacity / Fixed investment) and (Direct labor / Material-utilized). Other possibilities suggested by them are shown in their Table (7.3).

(f) Roll and Sachish (1981) developed an industrial engineering index measure of SFP defined as follows:

$$P_{hj}^{B} = V_{hj}^{\overset{*}{B}} / V_{hj}^{B}$$

Where, P_{hj}^{B} SFP of input h in producing product j in period B.

V_{hj}^{B} the actual SFP of product j in period B;

$*$ corresponding standard.

The major disadvantage in the use of this index is the difficulty in constant standards updating.

(g) Turner and Tompkins (1984) proposed three single factor energy productivity measures, defined as :

1. $$\frac{\text{Britsh Thermal Units (BTU's)}}{\text{Sales}}$$

2. $$\frac{\text{\$ Energy}}{\text{\$ Sales}}$$

3. $$\frac{\text{Britsh Thermal Units (BTU's)}}{\text{Direct power used}}$$

It is clear that there are many possible variations of single factor productivity ratios. An extensive list of these, collected by Mail (1979), is shown in Appendix A.

2.2 Multi-Factor Productivity (MFP):

Since labor and capital are used most often as SFP inputs, one can define a MFP based on the ratio of output or value-added to the sum of labor and capital inputs. MFP has undergone various stages of development and applications in many econometric studies including those by Solow (1957), Denison (1962), Kendrick (1965), Griliches and Jorgenson (1966), Chistenson (1969), Nadri (1970), Cocks (1973,1981), Taylor and Davis (1977), Denny and May (1978), BLS (1983) and others. The major empirical studies are by the following:

(a) Solow (1957) introduced the MFP growth rate and called it the "Geometric Index" of the total factor productivity growth rate, Where,

$$\text{Rate of growth} = (dQ/Q) - (W_L . dL/L + W_K . dK/K)$$

where

Q = output quantity;
L = labor quantity;
K = capital quantity;

and dQ, dL, and dk denote the rate of change in quantities of output, labor input, and capital input with respect to time.

(b) Kendrick (1961) defined multi-factor productivity as follows:

$$MFP = \frac{Q}{(W_l . L + W_k . K)}$$

where a homogeneous production function is assumed.

(c) Denison (1962) used labour input weighted by labour compensation and capital input weighted by non-labour payments less depreciation and indirect business taxes. This method is consistent with his definition of output as net national income.

(d) Ahmed (1966) used weightings changing over time and an aggregate production function consistent with the Kendrick Index as:

$$\mathrm{MFP} = \frac{t.K.L}{(cL^{\rho}+dK^{\rho})^{1/\rho}}$$

Which is a linear homogeneous production function with constant elasticity of substitution σ i.e.

$$\sigma = 1 / (1-\rho)$$

where,

c and d are the efficiency parameters;
ρ is the elasticity parameter;
t is the natural (disembodied) technical change .

Kendrick and Sato (1963) report $\sigma = 0.6$ and the production function as:

$$y = A_{o}^{0.2\ t} \frac{K.L}{(CL^{2/3}+ dK^{2/3})^{3/2}}$$

for the U.S. economy over the period 1919-1960.

(e) Christenson and Jorgenson (1970) expressed the MFP index by taking the natural logarithm of the rate of growth as derived by Solow (1957).

(f) The Cobb-Douglas Function is given by the following expression (1928):

$$Q = a L^{d} K^{f} e^{u}$$

Where u is the random measurement error component; a, d and f are constants to be estimated and e is the base of the natural logarithm.

(g) The Constant Elasticity of Substitution (CES) production function was proposed by Arrow (1961) and is given as:

$$Q = a(bL^{-r} + (1-b)K^{-r})^{-v/r} .e^{u}$$

Where,

Q = Value-added output;
K = Gross book value of capital adjusted by the capacity utilization coefficient;
a = arbitrary constant of proportionality
b = distribution parameter;
r = substitution parameter;
v = degree of return on scale;
u = random measurement error with mean zero and variance $._{u}$

The CES function is more powerful than the C-D production function because the elasticity of substitution is also obtained.

(h) The Variable Elasticity of Substitution (VES) production function : Klotze (1970) is given as:

$$Q = [ck^{-r} +dK^{-mr} L^{-r(1-m)}]^{-1/r}$$

If m = 0.0, this reduces to the CES production function.

(i) Intertemporal Production Function and cost of adjustment was proposed by Domer (1961) as a measure of MFP by maximizing the Intertemporal profit function as follows:

$$R = [F(X(t)) - C(X(t)) - B(dX(t))]e^{-rt} dt$$

Where,

R = value of net receipts;
X = the vector of inputs;
$F(X(t))$ = the production Function;
$B(dX(t))$ = adjustment cost function;
r = discount rate.
t = time.

In this model there is no sharp distinction between fixed and variable input costs. The inputs differ only in their cost adjustment, and hence in their speed of adjustment. The parameter of underlying production functions can be obtained indirectly by estimating a set of interrelated demand functions for the inputs.

(j) Nadiri (1970) observed that an arithmetic index of the MFP growth rate can be proposed to be consistent with a production function similar to that proposed by Ahmed (1966). Nadiri emphasized the technological characteristic of the production process and movement of the relative factor prices. The salient features include:

(i) Reduction of the unit cost of all factors of production equally by applying better techniques.
(ii) The nature of technological change (bias), which creates savings in one input rather than in others.
(iii) Elasticity of Substitution, which measures the ease with which factors of production may be interchanged

in the production process.

(iv) The scale of operations in continuous or discontinuous production processes reflect changes in the scale of operation of the economy.

(v) The homogeneity of production function, i.e., whether the scale is evenly distributed amongst all factors of production.

(k) Cocks (1974, 1981) outlined a methodology for the measurement of MFPI for individual firms that allow a direct comparison for manufacturing corporations:

$$\text{MFPI} = \frac{\text{Index of output at time t}}{\text{Index of (Labor + Capital) at time t}}$$

where,

Output = net sales - real or normalized depreciation at time t - real or normalized indirect business taxes in time t - [purchased goods and services in time t]/[index of purchased goods and services in time t].

Labor input = Total man-hrs worked and paid less those lost due to vacation, sickness, or accident.

Capital input = [Gross investment of equipment or structures in time t - Retirement of equipment or structures in time t] /(Price deflator)+[Gross stock of equipment & structures - Depreciation of equipment and structures in time t] /(Price deflator).

(l) Sudit (1976) reviewed the merits of MFP measures. He concluded that common approaches to MFP design are based on standard Lasperyes, Paache, and Divisa Indices.

(m) Taylor and Davis (1977) formulated MFP for large manufacturing firms as follows:

$$MFP = \frac{(S + C + MP) - E}{(W + B) + (K_w + K_f).f_b.d_f}$$

where,

S = Sales;
C = Inventory changes;
MP = Manufacturing plant including internally produced tools and equipment, maintenance, other supporting services;
E = Exclusions ($), these items are not generated by the company and include raw materials;
W = Wages and Salaries;
B = Benefits;
K_w = Working capital;
K_f = Fixed capital;
f_b = Investor contribution;
d_f = Price deflator factor.

The fundamental difference in this model is the exclusion of raw materials as input, on the premise that some firms consider raw material purchases "fruits of someone else's labor and, as such, an obfuscation of one's own productivity effort." However, Taylor and Davis (1977) recognize the importance of "materials and others". So they add them to both output and input, to obtain what they call an "all-inclusive" model, which is close to a total productivity concept.

(n) Denny and May (1978) enhanced the scope of MFP by including the material input with capital and labor. They also specified the function of technological changes as follows:

$$MFP_t = \frac{Q_t}{I_t}$$

Where,

$$Q_t = a(t).f(K_t, L_t, M_t);$$

$$I_t = f(K_t, L_t, M_t);$$

Q_t = Limits of output level;
M_t = Quantities of material;
K_t = Quantities of capital;
L_t = Quantities of labor;
$Q(t)$ = Function of measure of technological changes;
$I(t)$ = Total input function.

Denny and May (1978) investigated the relationship between productivity measures and technical progress based on the economic theory of production function. They estimated all the parameters of the production function using some selected U.S. manufacturing industries for the period of 1949-1970. Their results showed that the rate of Hicks Neutral Technical Change is constant and slightly larger than the average annual growth in MFP. The biased factor augmenting model of technical change has a significant effect on the MFP index.

(o) Mansfield (1980) developed a model to measure MFP including the effect of research and development as follows:

$$Q_t = A\,e^{\lambda t}\,R_{tb}^{\alpha_1}\,R_{ta}^{\alpha_2}\,L_t^{\nu}\,K_t^{1-\nu}$$

Where,

Q_t = Industry's value added in year;
R_{tb} = The industry's stock of basic research and capital;

R_{ta} = The industry's stock of applied research and development capital;
L_t = The industry's labor input in year t;
K_t = The industry's stock of physical capital in year t.

This model was applied to the data of 119 firms concerning past and prospective changes in the composition of R and D expenditure. The results indicate that there is a statistically significant and direct relationship between the amount of basic research carried out by an industry and its rate of increase of MFP when its expenditures applied on R and D are held constant.

(p) BLS U.S. (1983) defines MFP as [value added-output per unit of combined labour and capital inputs]. Output is measured net of its intermediate inputs; or as the aggregate value-added. Labour input is measured as total hours, and capital input is measured as the value of service rendered by the stock of capital.

2.3 Total Productivity (TP) :

Basically, total productivity is defined as the ratio of total output in physical or monetary value to the total inputs such as labor, capital, material, energy, and other costs. Both outputs and inputs are deflated to a base period.

Total productivity analysis seeks to determine the physical output relative to the combined effects of changes in labor, capital, material, energy, and other costs. The major contributors to total productivity research are reviewed below :

(a) Kendrick and Creamer (1965) introduced the concept of productivity measures and indices in manufacturing companies in their book entitled "Measuring Company Productivity,". Their indices are basically of three types: Total Productivity, Multi-Factor Productivity, Single Factor Productivity.

The Total Productivity Index for a given period

$$= \frac{\text{measured-period output in base-period prices}}{\text{measured-period inputs in base-period prices}}$$

Where,

output = value of goods and services provided;
input = man-hrs + capital + material and other costs.

They analyzed TP as well as with SFP in six companies. They found that TP was a more appropriate measure in four companies. Kendrick (1974) pointed out that TFP measures are not appropriate to the study of cost-price relationships at company and industry levels because of the importance of material and other cost inputs; the economics achieved in their usage per unit of output, affect the total cost/unit of output as well as prices.

(b) Craig-Harris (1973) defined the TP function in more detail by introducing the "other" costs involved in producing physical output. They emphasized that "if a company's labor productivity is increased by improving the raw material quality, where extra cost does not offset the savings due to reduced man-hrs of labor, then it could be disastrous for management to award a wage hike to its labor based on improved SFP of labor, when in fact, there may be no net gain at all." Therefore they defined a productivity measure as:

$$TP_t = \frac{O_t}{L_t + K_t + M_t + X_t}$$

where,

TP_t = Total productivity;
O_t = Total output ;
L_t = Labour factor input;
M_t = Material factor input;
K_t = Capital factor input;
X_t = Other costs input factor.

In the Carig-Harris (1973) model the output includes revenue, dividends from securities, and interest from bonds and other financial sources in base period values. Additional input factors X represents heat, light, power, insurance, taxes, advertising and non-productive material. All inputs are deflated to base period prices. Hines (1976) expressed the Craig-Harris model in a more symbolic form and showed that the production system is dynamic in its relation to various elements involving delay and nonlinear effects.

(c) Mundel (1976) presented two indices for measuring total productivity :

$$\text{TPI} = \frac{\left[\frac{O}{I}\right]}{\left[\frac{O}{I}\right]} \text{ X } 100 = \frac{\text{current period index}}{\text{base period index}} \text{ X } 100$$

$$\text{TPI} = \frac{\left[\frac{O}{O}\right]}{\left[\frac{I}{I}\right]} \text{ X } 100 = \frac{\text{Output index}}{\text{Input index}} \text{ X } 100$$

Mundel (1976) did not specify exactly how the outputs and inputs are broken down and measured. In most of his paper, Mundel discussed the errors caused by using productivity indices: suboptimization of overly simplistic measures of output, and counting outputs that are not related to goals, to inputs or to the final product.

(d) Sumanth (1979) defined total productivity as the "ratio of total tangible output (in physical or value terms) to the sum of all tangible inputs (in cost terms)."

We summarize the Sumanth model, by the following equations:

Total Productivity for product i in period t

$$TP_{it} = \frac{O_{it}}{I_{it}}$$

where,

O_{it} = the total output,
I_{it} = the total input.

Total Productivity for the firm in period t is given by

$$TPF_t = \sum^{N} W_{it} \cdot TP_{it}$$

where W_{it} is the ratio of total input of one product with respect to the total of all such inputs combined for N products manufactured in the firm. Finally, the total productivity index for the firm is given by

$$TPIF_t = \frac{\sum_i TP_{it} \cdot W_{it}}{\sum_i TP_{i0} \cdot W_{i0}} \qquad \text{for all } i$$

This approach is appropriate where several product lines constitute a large portion of the firm's output, but could be cumbersome for a more even distribution of products and

for a facility with no clear product line.
Militzer (1980) and The American Productivity Center (APC)(1980) proposed TP models generally similar to the Sumanth model.

(e) Roll and Sachish (1981) developed productivity indices at the plant level by measuring the actual value of each input factor and relating these to the standard input per unit of output. This was an extension of the work of Kendrick and Creamer (1965). The overall economic productivity index is defined as follows:

$$P = \frac{\sum_i \sum_j V_{ij}^{A} Q_{jc}^{A}}{\sum_i \sum_j V_{ij}^{B} Q_{jc}^{B}}$$

Where,

V_{ij}^{A} = the actual input factor i per unit of j in plant A;

Q_{jc} = product mix j;
c = the respective input factor unit price;
A = the plant under measurement;

B = the standard plant.

The Roll and Sachish (1981) model is applicable only to plants having a small number of products and using standard engineering practices over long periods of time. Setting standards for the entire company operations is very difficult if not impossible. The output and input ingredients are not broken down in this model. Finally, this approach measures efficiency or effectiveness rather than productivity.

(f) Stewart (1983) defined the total productivity for a manufacturing company as " the relationship between the output at standard values to specific inputs at actual levels of consumption during the current period review." Then, if the actual consumption of various specific resources exactly matches the specific standard in the base period, a productivity ratio of 1.0 would be observed. If various actions taken by management or other members of the organization result in actual reduction of the consumption of inputs with respect to the standard established in the base period, a productivity ratio greater than 1.0 will be obtained. Other features of the model are similar to the traditional total productivity model.

(g) Harl and Bresser (1984) developed a corporate productivity measure, which is defined as the ratio of value added to labor, material purchased for the production process, and the capital input factor. They tested the relationship between nine productivity measures and six earning measures where the productivity measures were: (sales /labour), (sales/capital), (sales)/(labor + capital + material),... , (value-added) / (capital+ labor + material). The earning measures were: (earing/share, return to investment,......,return on total inputs). A multiple linear regression analysis was used. The results show that the corporative productivity measure is the one most correlated with earning measures.

From the point view of our study, some "fringe" measures of total productivity are not considered in this analysis.

(h) Sink (1984) developed a total productivity model where the basic equation is :

$$TP = \frac{\sum_{1}^{s}\sum_{1}^{sc}\sum_{1}^{st} Q^{O}_{ctlk} \cdot P^{O}_{ctlk}}{\sum_{1}^{4}\sum_{1}^{Sc}\sum_{1}^{St} Q^{I}_{ctlk} \cdot P^{I}_{ctlk}}$$

Where,

I = input data;
O = output data;
Q = Quantities of input (Q) or quantities of output (Q);
P = unit cost (P) or unit price(P);
C = Class of input and output. For inputs there are four basic classes (energy, labour, capital, materials). For outputs there can be as many classes designated by the user (i.e. models, product, line,etc.)
t = type of input or output. This designation is for type of input or output within a class. (i.e. direct labor, gas,robotics).
l = level of input or output. This designation is for level within a type i.e. direct labour classification welders, quality of materials,etc.
j = base period or standard data or last period, etc.
k = current period.

Sink's (1984) model defines performance as the growth in real output over the growth of real inputs between two periods. This model is based on the decomposition of the increase in nominal revenues between growth in quality and changes in prices. Price recovery is defined as the ability of the firm to raise its product prices in the face of raising input prices. Finally, taking the ratio of total revenue to total cost is a measure of "performance". This profitability performance ratio measures how revenues grew relative to costs. A Profitability index is computed as : Profitability ratio = Productivity ratio X Price recovery ratio. This approach ties in productivity with the major concern of most firms: profitability, and price recovery.

(i) Edosomwan (1985) has developed a total productivity model as a task oriented approach. His model is based on a task as unit of work accomplished primarily at a single location, by a single agent, during a single time period, producing useful output from some resources available. Edosomwan (1985) considers a new technological version of variables input and output expenses. A new method of allocating overhead expenses at the task level is also proposed.

This model is mainly built to provide a total productivity measurement in a printed circuit board production environment. It can be considered as a specific case of the total productivity measure.

2.4 Managerial Control ratio:

Managers often resort to financial ratios as a measure of productivity. Some of these approaches include those by Gold (1964, 1973, 1979, 1982, 1983), Aggrawal (1980) and Risk (1965).

(a) Gold (1983) emphasized that advances in productivity analysis can assist management in planning, by pointing out the associated changes in the "structure of costs" and their resulting interactions with input factor prices as well as with the relative importance of the input cost categories affected :

$$\begin{aligned}\frac{\text{Total profit}}{\text{Total investment}} = {} & (\text{Average price} - \text{Average unit cost}) \\ & X(\text{ capacity utilization rate}) \\ & X(\text{ productivity of fixed investment}) \\ & X(\text{ internal allocation of capital}).\end{aligned}$$

Where,

Average price = value of product/ output;

Average unit cost = Total cost/ total output;

Capacity utilization rate = output/capacity;

Productivity of fixed capital = capacity / fixed investment;

Internal allocation of capital = fixed investment/ total investment.

From this "network" he link the total cost/output is linked to the wage/output, fixed cost/output, as well as material cost/output ratios. Gold (1985) made contributions of his model analysis as follows:

1) changes in the level of each category of input requirement per unit of output, including material, facilities, investment and salaried personnel as well

as direct labor;

2) changes in the proportions in which inputs are combined in order to consider substitutions;
3) differences between the productivity of inputs when they are fully utilized and when their effects are reduced by idleness;
4) variations in all components of this "network of productivity relationships ".

(b) Risk (1965) provided a model similar to that of Gold (1964). He has chosen the return on investment as a starting point and divided assets within departments into ratios which can be used to measure performance of individual departments or cost centers. Risk (1965) broke down these ratios as shown in Figure (2.1), where the framework includes unit costs of capital, production workers, and material input. In this model productivity measurement starts with the ratio of operating profit/operation assets, which is not productivity as Risk has pointed out. A conclusion which can be drawn from his work, is that further minimization of costs will not ensure maximum productivity.

(c) Aggarwal (1980) proposed a composite productivity index based on four financial ratios, which is =

$$a \frac{\text{Net Profit}}{\text{total investment}} + b \frac{\text{Value added}}{\text{number of weighted (man-hr)}}$$
$$+ c \frac{\text{total sales revenue}}{\text{number of customer}} + d \frac{\text{total dollars purchased}}{\text{number of suppliers}}$$

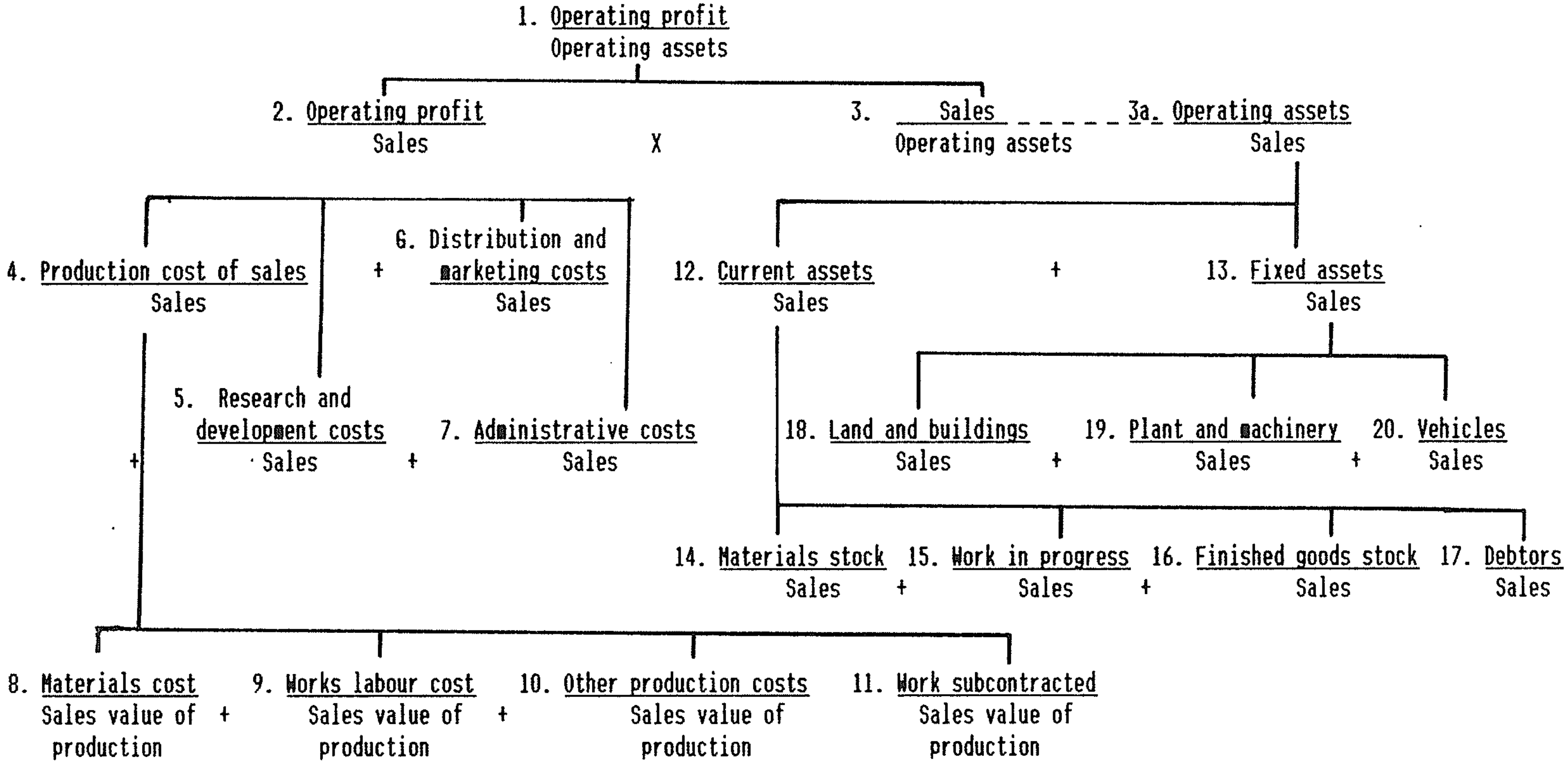


Figure 2.1 A breakdown of Ratios (as Advocated by the Centre for Interfirm Comparison, Risk (1965)).

where a, b, c and d are regression coefficients.

Aggarwal explained that every ratio can be used individually to measure the specific productivity element that is most appropriate for its respective group of users. For example the first is useful to investors, the second to employees, and so on.

2.5 Productivity Costing Approach (PCA):

Productivity costing is a system approach to integrate productivity measurement and absorption costing, based on the capacity of production. It is common to both direct and managerial costing.

(a) Bahiri and Martin (1970) set the principal objectives of this method as follows:

(1) Minimal and stable costing rates for each facility, related to the maximum feasible facility capacity;
(2) Realistic product costs and related profits;
(3) The development of unit product, group of products, and total system productivity indices;
(4) A system operating profit derived by deducting total idle facilities from the total of product profit generated.

The breakdown of costs used by Bahiri and Martin is given in Figure (2.2). A full list of all productivity indices constructed is given in (Bahiri and Martin, 1970, P.611). Among them are:

a) Total Earning Productivity Index $= \dfrac{\text{total earning}}{\text{conversion input cost}}$

b) Profit Productivity Index $= \dfrac{\text{Profit}}{\text{Conversion input cost}}$

c) Total System Profit Index $= \dfrac{\text{System profit}}{\text{Total system operating cost}}$

The objective here is maximize the ratios a, b and c. This approach mainly analyzes the cost of individual products within the firm and is more related to profit rather than productivity .

(b) Husband and Ghobadian (1981) developed a "predictive model for unit cost" for batch manufacturing firms as follows :

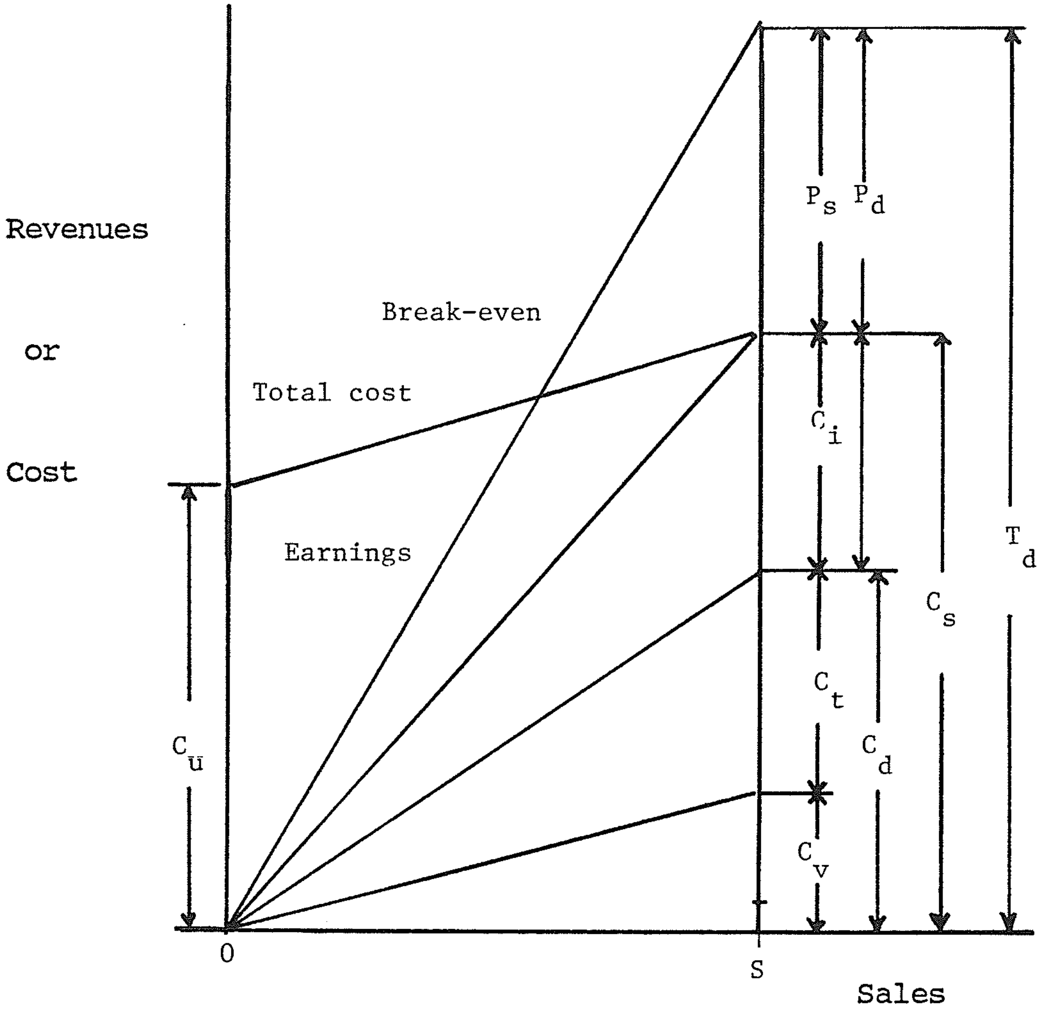
$$TUC = \frac{L}{O} + \frac{C}{O} + \frac{R}{O} + \frac{Q}{O}$$

or $$TUC = LUC + CUC + MUC + QUC$$

Where

TUC = total unit cost;
LUC = labour unit cost;
CUC = capital unit cost;
MUC = material unit cost;
QUC = other costs unit cost.

This model deals with the evaluation of batch production unit costs at manufacturing industries.



Where,

S = Sales Revenue
M = Material costs
Td = Total earning (S-M)
Cu = Fixed processing costs
Cd = Product processing costs
Pd = Product profit
Cs = Total system (facilities)
Ci = Idle facilities costs (Cs - Cd)
Ps = System profit (Pd - Ci)
C_v = variable processing costs.
Ct = Product processing (facilities) cost

Figure 2.2 Productivity costing breakdown (Bahiri and Martin, 1970)

2.6 State- of-the-Art in Productivity Measurement :

The theoretical work described in Section 1 covers productivity measures particularly relevant to managers of manufacturing companies. Some of these measures have been dealt with in more detail than others. The points considered include : output or outputs, input or inputs, capacity, ratio of inputs to outputs, cost breakdown, ratio of actual value to standard value, etc.,. Based on this review a chronological flow chart of productivity measurement indices is shown in Table (2.1). The flow chart illustrates the development of productivity measurement indices in the last three decades from 1950's to 1986.

2.7 Productivity Indices Parameter Surveys:

Productivity indices parameter indicators reported by five types of productivity measurement classified in Section 1. are shown in Table (2.2). The cross mark corresponding to each measure represents the utilization of that parameter in the productivity measurement technique considered.

2.8 Advantages and disadvantages of Existing Productivity Measures and basis for this Reasearch:

Productivity measures presently used in manufacturing industries are summarized in Table (2.3). After examining Tables (2.2) and (2.3), we propose a number of criteria which can be useful for better measurement of productivity.

Table 2.1 Historical Development of Productivity Modeling Approaches and Contributors

Single Factor productivity

Kendrick (1961)
BLS in U.S.
Statistics Canada
Eilon (1975)
Mail (1979)
Roll & Sachish (1981)
Turner (1984)

Multifactor Productivity

Solow (1957)
Kendrick (1961)
Denison (1962)
C-D Production Function
CES Production Function
VES Production Function
Cocks (1974, 1981)
Taylor & Davis (1977)
Denny & May (1981)
Mansfield (1980)
BLS in U.S.A.

Total Productivity

Kendrick & Creamer (1965)
Craig & Harris (1973)
Mundel (1976)
Sumanth (1979)
Roll & Sachish (1981)
Stewart (1983)
Sink (1984)
Edosomwan (1985)

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*************************
* Mohamed & Hawaleshka  *
* (1985) based on the TP*
*************************
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Managerial Control Ratio

Gold (1955-1984)
Risk (1965)
Aggarwal (1980)

Productivity Costing

Bahiri & Martin (1970, 79)
Husband & Ghobdin (1981)

Table 2.2 Survey of parameters included in productivity measurement indices

	Productivity Measures				
Relevant Parameters	SFP	MFP	TP	MCR	PCA
Output	X	X	X	X	X
Labor input only	X				
Capital input only	X				
Material input only	X				
Energy input only	X				
Unit cost of labor				X	X
Unit cost of capital				X	X
Labor + capital		X			
All input costs			X		
All input unit cost					X
Time trend	X	X	X	X	X
Linear assumption	X	X	X	X	X
Deflated value	X	X	X	X	
Considers labor view point	X				
Macro Measure	X	X	X		
Micro Measure				X	X
Industrial Eng.method	X		X		
Tangible index	X	X	X	X	X
Direct measure	X	X	X		
Indirect measure				X	X
Most frequently used	5	4	3	na	na
Statistics available	X	X			

Table 2.3 Advantages and Disadvantages of the five basic approaches of industrial productivity measures.

ADVANTAGES	DISADVANTAGES
SINGLE FACTOR PRODUCTIVITY (SFP)	
1. Labor productivity is measured more easily than other productivity indices.	1. SFP does not measure the productive contribution of the whole production system.
2. Historically, technological innovation has been acknowledged through the displacement of labor by increasing SFP of man-hr.	2. Misinterprets the risk of including unrelated shifted output increase due to measurement of a single input only.
3. Labor input forms a relatively large part of the production system inputs.	3. Can increase rapidly as a result of mechanization and automation which are not included in this measure.
4. Statistics of employment and man-hrs are often readily available.	4. Can be misleading factor in labor negotiations involving productivity consideration.
MULTIFACTOR PRODUCTIVITY(MFP)	
1. Measure the change in output per unit of combined labour and capital.	1. Exclude some material input; may ignore some technological improvement due to its value added approach.
2. The inclusion of changes in capital input along with purchased materials and services moves the value of SFP considerably closer to an ideal measure of efficiency in the use of all resources.	2. The production function does not reveal the causes of observed, changes; it does not indicate the means by which these changes might be enhanced.
	3. Does not specify the variation in relative utilization of capital and labour.
TOTAL PRODUCTIVITY (TP)	
1. It is the most inclusive index for measuring the	1. Does not show the interaction between input

Table 2.3 (continued)

whole production function. 2.Provides the rate of growth (loss) for the whole company.	and output simultaneously 2.Is too broad to be used as a tool for improvement in specific areas of operation 3.Each input factor such as labour, capital, material, and energy is considered to be a dependent parameter which is not so.
MANAGERIAL CONTROL RATIO (MCR)	
1.Provides the interaction of technology by the profit/investment ratio. 2.Presents a blend of physical and financial aspects of resource flows for short and long term planning.	1.Does not derive the industry productivity ratio. 2.Deals with capital input input changes rather than with the whole production system inputs. 3.The percentage increase (decrease) in each individuall financial activity ratio does not necessarily indicate effects on over-all productivity. 4.The breakdown of the financial measure will reflect aspects of performance rather than producivity.
PRODUCTIVITY COSTING (PC)	
1.Deals with unit cost of a product and cost ratio investigation.	1.Deals with profit-cost-analysis rather than productivity 2.Clearly demonstrates the effect on overall system costs of production below capacity which contribute to price, but not to productivity. 4.The analysis of managerial cost of each single product is not feasible for a company producing a large number of products.

The criteria are:

1) Consider all types of input and output factors at the operating level.
2) Reflect the effect(s) of dynamic changes in manufacturing process operations by means of relationships between production and resources.
3) Permit an understanding of the effect of input factor(s) substitution and trade-off implications.
4) Determine the productivity values for the current as well as permit their estimation for the next planning periods.
5) Identify key problem areas for productivity improvement.
6) Highlight the contribution that could be made to productivity enhancement by specific factors, eg: utilization of modern advanced production methods and tooling.

Our work has been directed toward the development of appropriate productivity measures that address these criteria.

CHAPTER III

MOTIVATION AND OBJECTIVE OF THIS RESEARCH

From the review of the literature on productivity measurement presented in Chapter II, it is clear that all conceptual productivity measurement indices fall into five major classes.

There has been no consistency nor uniformity in the definitions of productivity, Eilon (1983). In fact, the number of new definitions that continue to be generated, seem to obscure and confuse the exact nature of productivity and its purpose.

Recently, more attention is being paid to the "Total Productivity Index" class than to other measures such as single, multi-factor and other accounting indices.

The absence of an adequate productivity measure to evaluate the effects of changes is reflected in a recent statement by Gold (1983, 1985):

> "It is obvious that although input, output and other data can be accumulated at innumerable levels representing progressively larger sectors of the economy, many of these statistical aggregates may represent only the passive resultant of heterogenous decisions; to influence them, it is necessary to identify

> the decision points involved as well as the objectives, incentives and penalties of the decision maker."

This statement underlines the importance of developing decision analysis tools to be applied to the productivity framework in order to facilitate appropriate guidelines and possible clear objectives to the management of an organization. The conclusion reached by Sink (1984) in his recent review of the-state-of-the-art and practice of productivity measurement techniques, that "a great deal of relative to developing productivity measurement systems needs to be accomplished."

The main purpose of the introduction of productivity measurement models is to improve the allocation of inputs and outputs efficiently and effectively within a company, an industry, or a national economy.

Productivity improvement literature outnumbers that on productivity measurement by at least three to one. Although productivity improvement is important, there exists no conceptual, logical, comprehensive framework to enable managers to systematically think of ways to improve productivity in their particular organizational system (Sink, 1985). Most of the productivity researchers believe that productivity planning is the key to achieve higher economic growth. Cotton,Jr. (1976) summarizes in the following statement:

> "Productivity doesn't just happen by trying harder, it must be planned. But how do you plan for productivity, and what factors are involved?"

Sumanth (1979) recognized the fact that productivity measurement represents only one of four stages of the process of what he terms the "productivity cycle". These include measurement, evaluation, planning and improvement.

Smith (1980) emphasized that "the need to plan for improving productivity and business performance is probably the most important area of management which needs attention and yet, at present is neglected"

This research is a response to the needs underlined by the above statements. Our objective is to address the problem of productivity measurement, the influence of technological parameters and productivity planning and how to make it more effective and useful to managers.

3.1 Objectives of this research

In view of the above perspective, the objectives of this research can be formulated in the following manner:

1. To review and extend the state-of-the-art of productivity measurement for the manufacturing sector.
2. To develop a Total Operational Productivity model (TOP),

which (i) takes into account quantitative outputs and inputs appropriate to each industry, (ii) determines real values of growth and loss through the planning time period and (iii) indicates the productivity value at the operating level of the firm.

3. To devise a procedure which can identify the correlation and weights of various productivity factors. As a result of this analysis a Technology Factor Index (TFI) is constructed as a quantitative measure of technology growth in the manufacturing industry. A factor analysis multivariate statistical technique will be utilized to accomplish this step.
4. To explore the statistical relationship between the Technology Factor Index and the Total Operational Productivity measure in the industry sector.
5. To devise a Total Operational Productivity Planning (TOPP) model which would give management advice about optimal allocation of outputs and inputs so that a higher rate of productivity growth might be attained. For this purpose the fractional programming approach will be used.
6. To use case studies from Canadian metal fabricating industries to illustrate the usefulness and applications of our proposed models.

3.2 Organization of the research report:

This thesis is divided into eight chapters. The first one presented the background and the importance of the productivity concept to economics and social interests. In Chapter II, we gave an extended review previous research into productivity measurement at various levels, giving major emphasis to works directed to the manufacturing industry. Remarks and criticisms are given and summarized. In Chapter III an analysis is made based on the survey in Chapter II, to indicate the direction of research that we will follow in subsequent chapters. Chapter IV defines and presents in detail, what we introduce as the Total Operational Productivity (TOP) measure. A case study is also presented. In Chapter V a Technology Factor Index (TFI) is derived with a case study shown as well. In Chapter VI a new Productivity Planning Model is formulated as a nonlinear programming problem, specifically as a Fractional Programming problem. In Chapter VII, the productivity planning model is applied to a case study. Chapter VIII presents a summary, our conclusion and suggestions for further research on productivity and its relation to the manufacturing industry.

CHAPTER IV

TOTAL OPERATIONAL PRODUCTIVITY MEASUREMENT MODEL

Based on the review of literature presented in Chapter (II), the most common approaches to tracking productivity in an industry or a firm through the consideration of one or more of several possible input factors. When single factor productivity is used, it usually refers to labour productivity rather than to other resources such as materials or energy. Some firms do employ measures that incorporate the effects of several resources or inputs simultaneously. These measures are called multi- or multiple-factor models. Such measures consider the importance of several factors rather than that of just one.

In the past, productivity measurement methods have tended to misrepresent real economic improvements that can be achieved from the introduction of advanced technology tools and methods. Specifically, they tended to show declining absolute values of total productivity measures resulting from such technologies. Such results can lead to serious underestimation by management, investors and technical staff of the value of economic improvement achievable from new technologies.

Therefore, we propose to develop a Total Operational Productivity Measurement Model at the industrial level which is clearly needed for appropriate scaling and highlighting production system dynamic factors in terms of technological changes. This model will be applicable at various operating levels in an organization.

4.1 Total Operational Productivity(TOP):

Total Operational Productivity can be defined as the ratio of the total quantified value of shipments of goods of own manufacture to the total quantified value of human, capital, material, energy, and other costs consumed in terms of constant dollars, during a specific time period.

The reason for considering shipments of goods as output at the industry level is due to the fact that current worldwide data collection bases at this level are geared towards shipment.

The definition of TOP depends on the status of the production system being operated. Several approaches have used the "cost value of capital", (Kendrick and Creamer, 1965), (Stewart, 1983) or "leasing capital concept" (Carg-Harris, 1973), (Sumanth, 1979), or "fixed assets concept", (Millis, 1980) to represent this dimension. None of these approaches have considered the actual total consumption such as the actual equipment and facilities utilization in the production process.

The TOP model considers the use of equipment and facilities in terms of wear and tear and consider the capital investment in that equipment or facility as separate engineering economy concept. This allows us to avoid the pitfalls of many other models that tend to show extreme low productivities at the initial installation of the productive systems due to giving full weight to the investment value in that system, while showing grossly inflated productivities for systems in a fully amortized condition.

4.1.1 Quantified Output Elements:

Quantified Output Elements, shown in Figure (4.1), will be described next.

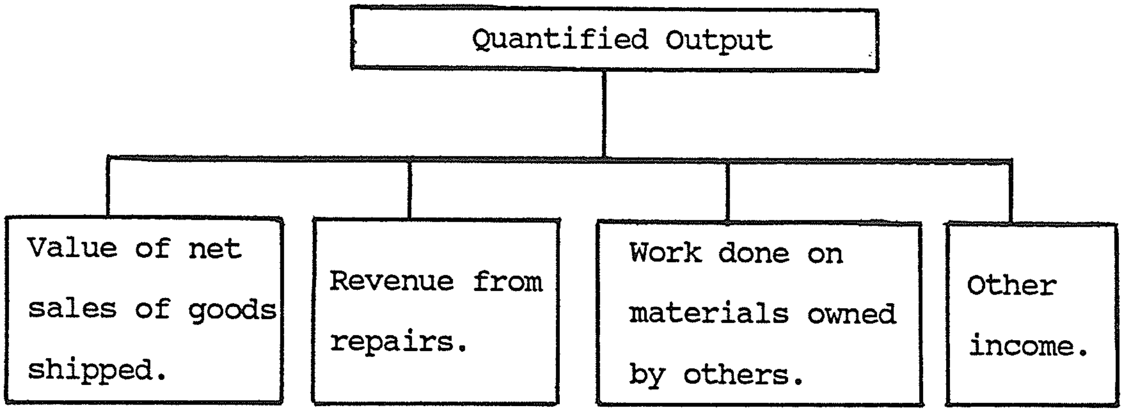

Figure 4.1 Quantified output elements for the Total Operational Productivity Model.

a) Selling value of shipments of goods can be expressed as :

$$\text{Value of net sales of goods shipped} = \frac{\text{Quantity shipped X Current selling price in dollars}}{\text{Selling price deflation index}}$$

where,

$$\text{Selling price deflator} = \frac{\text{Current Selling Price}}{\text{Base Period Price}}$$

b) Revenue from Repair: income from service and repair of own products and of those of other manufacturers, in constant dollars.

c) Work done on Materials owned by others: is the amount received in payment for contract work done on materials and products owned by other establishments, excluding repairs.

d) Other Income: such as investment income (if it can be related to the production system).

e) A negative output component equal to total expenses related to shipping costs, sales taxes and possible discounts, all of which affect the net income, must also be considered.

4.1.2 Quantified Input elements:

Quantified Input Elements, shown in Figure (4.2), will be described next. These elements are shown in detail in Figures (4.3) to (4.7).

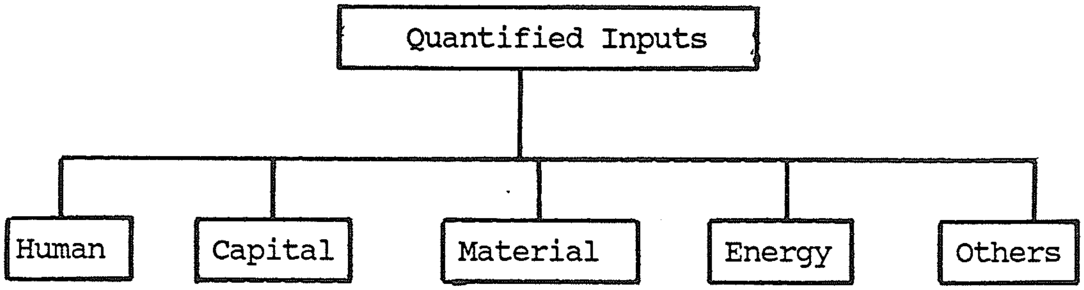

Figure 4.2 Quantified Input Elements.

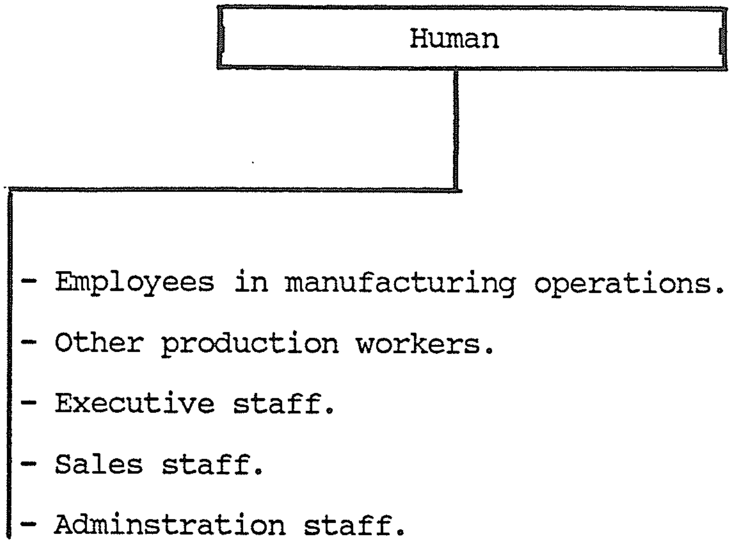

Figure 4.3 Human Input Elements.

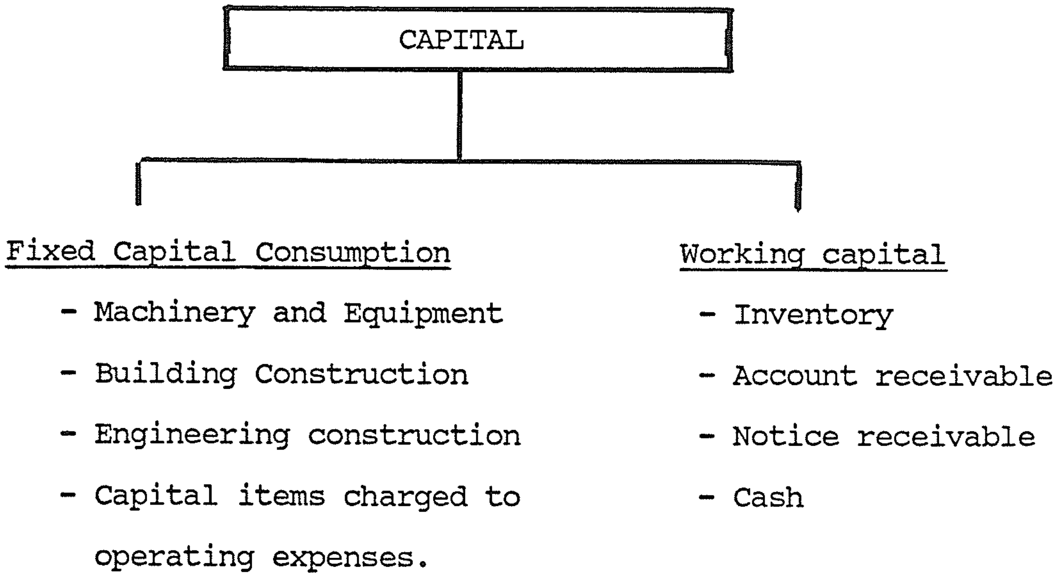

Figure 4.4 Capital Input Elements.

Materials and Supplies

- Raw Materials
- Purchased Materials used in manufacturing operations.
- Total Value of operating, maintenance repair supplies purchased excluding fuel used in manufacturing operations.

Figure 4.5 Materials and Supplies Input Elements

Energy

- Coal and Coke
- Natural Gas
- Gasoline
- Kerosene, stove oil
- Diesel oil
- Light fuel oil
- Heavy fuel oil
- Electricity purchased
- Other fuel including steam purchased

Figure 4.6 Energy Input Elements

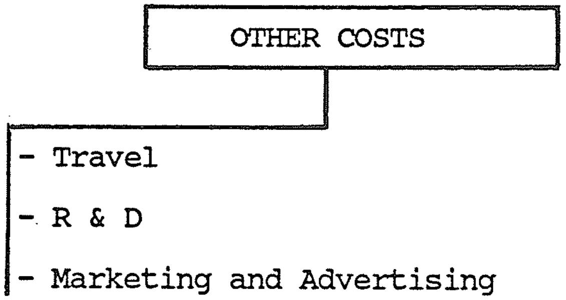

Figure 4.7 Other Costs Input Elements.

a. <u>Human resources input</u>:

The new measure of total productivity developed in this Chapter extends the scope of productivity measures by inclusion of all elements of human input contributing to the output. Other measures usually consider only one or few such elements. We propose that a method of measuring human input in manufacturing industries may be stated as follows :

$$\frac{\sum \begin{array}{l}\text{Salaries}\\ \text{in dollars}\end{array} \left[\begin{array}{l}[\text{ Executive staff}] + [\text{Administrative staff}] + \\ [\text{ Employees in manufacturing operations }] + \\ [\text{ Other production and related workers,} \\ \text{ including employees engaged in} \\ \text{ construction and production of} \\ \text{ machinery equipment for own use}]\end{array}\right]}{\text{Cost index}}$$

b. Capital input:

Investment as well as operating capital is recognized as a major component of the productivity equation. It may be useful to summarize the most common production theoretical approaches to the measurement of capital. Denison (1980) measures capital as the stock of equipment, structures, and inventories used. Gross and net stocks are weighted by 0.75 and 0.25 respectively to give an estimate of net capital stock. Although it is based on a general analysis of industrial experience, this "heuristic" approach is rather imprecise. Jorgenson (1967) measures capital as net stocks of only equipment and structures. Kendrick (1980) measures capital as gross stock used. The Bureau of Labor Statistics (BLS, 1983) measures capital as the sum of (stock + rental prices + assets). A summary of these approaches to the measurement of capital is shown in Table (4.1).

Table 4.1 Major approaches to the computation of capital input measures (BLS, 1983)

Characteristic	BLS	Denison	Jorgenson	Kendrick
Weights:				
Asset prices		x		x
Rental prices	x		x	
Aggregation of assets:				
Fixed weighted		x		x
Variable weighted	x		x	

None of these four major approaches account for the actual capital consumption within the production processes.

In total operational productivity we attempt to measure the capital in terms of its real value. This is rather difficult to obtain in accurate form. We propose to determine the actual capital consumption by :

$$\text{Total Capital Consumption} = \frac{\sum_{i=1}^{T} I_i d_{it} + OE_{it}}{L \times \text{Price index}}$$

where,

d_{it} = Depreciation factor (eg: straight line depreciation.)

i = Industry .

t = Time period.

L = Assumed economic life of the capital asset.

I = The investment expenditures ($) during each period.

OE_{it} = Operating Expense dollars during the measurement period.

It should be noted that stocks are usually evaluated at the end of each calendar year and thus some minor adjustment is required to move the estimate to the middle of each calendar year or period desired. For certain industries alternative measure of depreciation may be appropriate.

c. <u>Materials and supplies inputs</u>:

The material component of manufacturing input is commonly considered to be approximately equal to the labour input. It is thus a major factor in the productivity equation. In fact, with ever-accelerating changes in manufacturing technology that are mainly directed toward the minimization of labour, material/supplies components will assume an increasing level of importance. The Statistical report by Canadian Machinery and Metalworking (1983) showed that metalworking manufacturing is responsible for about 34 % of total manufacturing output in Canada. It is interesting to note that a similar pattern emerges in the comparison of the output value of material producing industries in Canada with that of the material using industries. This comparison is shown in Table (4.2). It indicates that material usage represents about 50 % of the value of shipments for 1981. Materials and supplies may be measured in the TOP model as:

Total cost of materials and supplies in constant dollars =

$$\frac{\left\{\begin{array}[t]{l}\text{Total cost of}\\ \text{raw materials}\\ \text{used}\end{array} + \begin{array}[t]{l}\text{Cost of components}\\ \text{purchased used}\end{array} + \begin{array}[t]{l}\text{cost of non return-}\\ \text{able containers,}\\ \text{shipping \& packaging}\end{array}\right\}}{\text{Intermediate cost index}}$$

$$+ \frac{\left\{\begin{array}{l}\text{Value of operating, maintenance and repair supplies}\\ \text{purchased and used in manufacturing excluding fuel}\end{array}\right\}}{\text{Intermediate cost index}}$$

$$+ \frac{\left\{\text{Value of work done on materials owned by other firms}\right\}}{\text{Intermediate cost index}}$$

Table 4.2 Material usage as proportion of shipments in Canadian Metalworking Industries,(Maclean Hunter Research Bureau, Nov., 1983)

Industry name	Materials used$ 10^6	Factory shipment$ 10^6	ratio m/s %
Primary metals	08139	14450	56.3
Metal fabricating	06446	12376	52.5
Machinery	04511	08690	51.9
Transportation equipment	14488	21800	66.46
Electrical products	04441	08938	49.69
Miscellaneous industries	39546	68736	57.53

d. Energy input:

Energy consumption is an important component in the Total Operational Productivity concept since energy-related cost have been increasing faster than the rate of inflation. According to all forecasts, the cost of energy will continue to grow in the future. In considering "energy productivity" (one of the typical single factor productivity measures), Turner and Parker (1984) concluded that this was very difficult to monitor. This is mainly due to lack of appropriate metering, poor energy usage and poor energy cost data maintained by typical industries. Industries differ greatly in their energy use profile due to such variables as location, weather, number of people, product manufacturing intensity, as well as many others. Energy input can be measured in Total Operational Productivity by:

$$= \frac{\text{Total energy input in current dollors}}{\text{Energy cost index}}$$

or, in an expanded fashion, by detailed listing such as:

$$\frac{\left\{\begin{array}{l}\text{coal + coke + natural gas + gasoline + kerosene +}\\ \text{diesel oil + light fuel oil + heavy fuel oil +}\\ \text{electricity purchased + other fuel including steam}\end{array}\right\}}{\text{Energy cost index}}$$

e. <u>Other costs input</u>:

Even though other costs usually represent a relatively small percentage of the total input, attention should be given to them in order to obtain an accurate measurement to productivity indicators.

4.2.1 <u>Total Operational Productivity Model Formulation</u>

The Total Operational Productivity Model (TOP) was defined earlier in this chapter. Several versions of it can be developed including "single factor operational productivity" and " multifactor operational productivity".

TOP can be given by the following expression:

$$TOP_{it} = \frac{\sum_{k=a}^{e} Y_{ikt}}{\sum_{j=1}^{J} \sum_{\ell=1}^{L} X_{ij\ell t}} \tag{4.1}$$

Where,

TOP_{it} = Total Operational Productivity measure in industry i during time t.

Y_{ikt} = Amount of output value shipped from industry i during time t for output type k, (k = a,b,c,d,e) as specified in section 4.1.1 .

$X_{ij\ell t}$ = Amount of input consumed in industry i during time t, for input J .

j = 1,2,......J ,

ℓ = 1,2,.......L , where ℓ are the elements of each j, as specified in the input elements.

TOP can be expanded as :

$$TOP_{it} = \frac{Y_{111} + Y_{121} + Y_{131} + Y_{141} +....+ Y_{ikt}}{X_{1111} +X_{1121} +X_{1131} +.......X_{ij\ell t}} \qquad (4.2)$$

for the current period, with TOP_{it-1} referring to the Total Operational Productivity at the selected base period .

Therefore, the Total Operational Productivity Index is equal to

$$TOPI^{t}_{it} = \frac{TOPi(t)}{TOP_{i(t-1)}} \qquad (4.3)$$

In the case where one input factor such as human input represents a large part of the input components, (typically greater than 50 % for service industries such as governmental departments), or where material input is responsible for the highest percentage of input costs (typical of metalworking industries) the Single Factor Operational Productivity can be defined as :

$$SFOP_{it} = \frac{\sum_{k=1}^{K} Y_{ikt}}{\sum_{\ell=1}^{L} X_{ij\ell t}} \tag{4.4}$$

Where, $j = 1$ for human inputs, $j = 2$ for capital input, $j = 3$ for materials and supplies input, $j = 4$ for energy input, $j = 5$ for other costs input.

If one or more factors are more important in the input than others, we can express a Multifactor Operational Productivity as follows:

$$MFOP_{it} = \frac{\sum_{k=1}^{K} Y_{ikt}}{\sum_{j}^{J} \sum_{\ell}^{2} X_{ij\ell t}} \tag{4.5}$$

Where the notation is similar to the single factor operational productivity.

4.2.2 Advantages of the Total Operational Productivity Measure :

As shown in the indicated chapters and case studies, our TOP measure has the following advantages:

1. TOP is the most inclusive measure available considering all output and input factors.
2. TOP encourages the introduction of new production systems by highlighting their positive contribution to corporate productivity.

3. TOP provides a better planning approach for the growth of the whole economic productivity in terms of total allocation of output and input (Chapter 6).
4. TOP can be easily related to the total profit and total cost concepts.
5. TOP is shown to have a positive relationship with the Technology Factor Index (TFI) (Chapter 5).

4.3 A Case study : Productivity Measurement in metal fabricating industries in Canada

Within the Canadian metal-working group of industries, the metal fabricating sector is the second largest employer with approximately 135,000 employees producing $ 12.5 billion of output in 1984, (Statistics Canada, 1985).

To illustrate the applicability of our TOP measurement model, we will use data collected primarily from Statistics Canada publications.

Formulation of the total operational productivity (TOP_{it}), the single factor operational productivity ($SFOP_{it}$), the multifactor operational productivity ($MFOP_{it}$) and the total operational productivity index ($TOPI_{it}$) requires the identification of the output quantity shipped and input quantity consumed, together with the associated prices and costs indices.

We try to point out the sensibility of our approach by using two different methods for evaluating human and capital inputs. Other input factors do not seem to be as affected by different evaluation methods due to the data constraints. There are several methods to measure capital, human and other types of inputs. These were reviewed in the early stage of this research. We call these Method I. The procedure proposed by us in this work is called Method II.

Method I:

1. Human input includes mainly direct labor input;
2. Capital input combines the value of capital investment and capital consumed.
3. Other input elements are not considered in great detail.
4. The output is considerd as value-added, units produced or sales only .

Method II:

1. Human input includes all contributors to the corporate production process as shown in Figure (4.3).
2. Capital input considers the amount of capital consumption, rather than accounting for the capital cost in investment terms.
3. Output elements are considered as shown in Figure (4.1).

4.3.1 Data Base for the Case Study

1. Output

The output measure used in this research was defined as the value of total sales, services, and related activities. The value of shipments are defined as net selling values at the reporting establishment, excluding discounts, returns, allowances, sales taxes and excise duties and taxes and transportation charges by common or contract carriers.

2. Inputs

Five input factors were considered in this study: (1) human input, (2) fixed capital used and working capital consumption, (3) materials and supplies consumption, (4) energy consumption, and (5) other costs. Each input cost was deflated to constant (1971) Canadian dollars.

a) Human Inputs

The annual Statistics Canada catalogues for Metal Fabricating Industries do not provide sufficient detail with which to distinguish between classes of human input, but do provide the total amount of human input components. The calculation of the total human input dollar value was done by the following method :

(i) Production and related workers are represented by the total hours at work during the year plus hours not worked but nevertheless paid for, such as paid vacations, holiday,etc. Overtime hours are included.

(ii) Administrative input is calculated as the total man-hours engaged in non- manufacturing operations.

(iii) Executive staff input is grouped through the sum of their salaries, benefits and related expenses.

(iv) Sales staff input is considered in the same manner as executive staff input.

b) Capital Consumption

The item includes fixed capital consumption as well as working capital consumption in constant dollar terms.

(i) Fixed Capital

Fixed capital is a difficult task to measure, since one could consider initial costs, book values or even "values to the organization". The measurement of fixed capital consumption can be estimated as the value of wear and tear and obsolescence undergone by production systems during their service life. In this research, we use the well known " Straight-line" depreciation method to account for this.

b) Working Capital Input

This represents the book value of accounts receivable, notice receivable, and cash spent to produce the output shipped in the given period.

3. Material and Supplies Input

This include the values in constant dollars of raw materials, containers, supplies, purchased materials, supplies and sales returned including the associated charges .

4. Energy Input

This refers to dollar amounts actually used (including fuel used in cars, trucks, etc.). Figure (4.6) shows all the items considered for this input factor.

5. Other Costs Input

Refers to all items in Figure (4.7).

4.4 Results and Discussion of the Case Study:

According to the procedure derived above, we calculated Total Operational Productivity, Multi-factor Operational Productivity and Single Factor Operational Productivity, based on the data derived from the Statistics Canada information. The raw data for output and input variables are shown in Tables (4.3) to (4.7). In order to account for the effect of inflation, the raw data has been deflated to the base year (1971). The price and cost indices are shown in Table (4.8). The resulting data ready for use in the TOP model is given in Table (4.9).

According to the results determined in Table (4.10) for the Total Operational Productivity measure , an average annual growth of 3.7 % is achieved , while if we use the traditional total productivity measures (reviewed in Chapter 2), an average annual growth of less than 1 % is found as given in Table (4.12) for the same type of industries. It is also worthwhile to look at Figure (4.8), which shows the results of the two measurement approaches plotted against differences. These are :

1. Total Operational Productivity measures the actual value of shipments of goods, revenue from repairs and all sources of other income for the whole industry, (and not by single product) as an output. Other measurement models measure output as total output-intermediate goods and service (Kendrick and Creamer, 1965). The summed value of all units produced times selling price (Craig and Harris, 1973). The value of finished, and partially finished units of a product and other interest income (Sumanth, 1979, 1984) and many others.
2. Total Operational Productivity considers the total input at the corporate level, which refers to the sum of human input salaries, wear and tear of machinery and facilities, consumption of materials and its containers, energy consumption and other cost expenses in constant dollars. Other total productivity measures consider only labour to account for human input (Craig and Harris, 1973) and (Roll and Sachish, 1981). The capital input is considered in most total productivity models as total capital investment or stock of capital. However, Craig and Harris (1973) and Sumanth (1979, 1984) used the "leasing capital concept". Few total productivity models consider energy input as a separate input factor. The supply costs are omitted from all the previous productivity measurement models, while the TOP makes

it clear with the materials input component. These differences make the TOP measure a much better method for helping managers to plan their strategic decisions regarding the future of an organization.

Single factor operational productivity values, as shown in Table (4.14) and used by Statistics Canada, have higher annual average growth rate (output/man-hr) than our measure which includes all human input. Other single factor operational productivities are determined in Table (4.14) and plotted against the time period 1971-1982 as shown in Figures (4.9) to (4.16).

Multi-factor operational productivity of human and capital consumption showed better results for the same industry when compared to the traditional measures, as shown in Table (4.10) and Table (4.11) and plotted over the same time period in Figure (4.17).

In summary, the proposed Total Operational Productivity measure is developed to resolve the problem of providing appropriate productivity measurement indicators to the economy, when intensive capital cost equipment is introduced into the production systems such as CAD/CAM systems, Robotics, Automated Storage and other technological improvement techniques. This is done by accounting for the consumption value of capital and other four inputs on one hand, and considering on the other hand value of output as the total value of shipments with other incomes in constant dollars, but not produced.

A MicroSoft computer program using DOS System Version 3.2 for the IBM PC/XT or Jr written in FORTRAN-77 has been developed to allow easy determination of total operational productivity and the associated index and single factor productivities. The program is given in Appendix B.i. The productivity measurement program consists of 6 subroutines plus a control program. These subroutines perform the following functions:

1. read in the input data file
2. determine the Single Factor Operational Productivity
3. determine the Multi-Factor Operational Productivity
4. determine the Total Operational Productivity.
5. determine Productivity Indices
6. generate results for different output devices such as CRT screens, printers as well as disk files.

Sample calculations for the output shown in Tables (4.10) to (4.14) are given in Appendix B.ii.

Table 4.3 Output (Value of shipments of goods) in Canadian Metal Fabricating Industries in current 000,000 dollars.

	SIC CODE								
Year	301	302	303	304	305	306	307	308	309
1971	208.86	450.16	61.35	948.00	478.75	208.41	124.61	478.00	228.74
1972	245.17	456.57	168.35	1187.00	560.52	333.63	113.54	557.96	219.37
1973	257.41	592.34	201.67	1256.00	691.17	417.71	127.04	675.01	212.93
1974	296.27	839.79	261.65	1380.48	960.34	499.76	157.52	858.15	268.18
1975	429.92	879.95	313.81	1461.55	875.17	522.53	164.49	927.97	269.85
1976	535.15	840.50	334.33	1718.12	910.62	579.19	195.69	994.55	313.95
1977	557.47	818.29	343.14	1947.44	1006.64	638.62	192.65	1033.12	339.92
1978	614.16	861.91	414.66	2351.63	1173.66	724.15	242.86	1221.18	432.97
1979	613.11	1066.17	526.49	3179.11	1382.34	912.77	313.56	1360.95	535.91
1980	634.48	1100.00	579.78	3776.58	1422.69	995.97	357.99	1534.56	599.64
1981	653.00	1165.00	634.37	3742.28	1516.58	1026.52	389.21	1574.64	686.20
1982	662.00	1203.00	603.66	3567.98	1326.73	962.13	401.00	1411.57	644.31

Table 4.4 Human input in Canadian Metal Fabricating Industries in current 000,000 dollars.

	SIC CODE								
Year	301	302	303	304	305	306	307	308	309
1971	49.222	114.606	30.834	156.102	87.625	79.783	20.531	74.737	103.159
1972	56.879	118.026	36.366	264.450	106.528	94.684	19.794	70.506	115.671
1973	59.925	138.941	39.628	193.046	124.416	117.860	22.193	67.006	138.044
1974	73.294	168.756	47.121	227.946	144.149	137.819	27.685	83.402	158.228
1975	105.304	182.919	59.160	244.241	140.980	143.633	30.515	96.971	178.485
1976	124.930	198.324	63.313	286.452	152.642	162.132	35.347	105.308	194.980
1977	118.190	208.061	62.579	301.858	170.585	172.644	34.446	113.643	208.441
1978	120.090	199.369	75.603	369.457	199.736	201.076	42.867	137.546	243.910
1979	133.628	244.606	91.089	396.457	232.768	246.209	54.466	167.644	252.839
1980	152.314	260.419	98.661	426.873	233.246	260.225	61.900	190.078	291.950
1981	151.847	295.675	109.736	457.613	235.518	278.589	63.056	217.878	285.638
1982	201.695	285.555	105.897	456.509	222.052	270.311	65.345	218.749	260.535

Table 4.5 Capital consumption input in Canadian Metal Fabricating Industries in constant (1971) 000,000 dollars.

Time Year	Machinery and equipment	Engineering construction	Building and construction	Operating expenses
1971	62.20	.90	18.20	15.40
1972	65.30	.90	18.60	15.50
1973	68.60	1.00	19.10	16.00
1974	72.10	1.00	19.90	16.50
1975	75.60	1.10	20.60	16.90
1976	78.70	1.10	21.60	17.20
1977	80.80	1.20	21.70	17.40
1978	82.30	1.20	21.20	17.10
1979	84.50	1.20	22.90	16.60
1980	87.60	1.20	22.80	16.60
1981	90.20	1.20	23.60	16.60
1982	92.00	1.20	25.10	16.00

Table 4.6 Materials and Supplies in Canadian Fabricating Industries in current 000,000 dollars

	SIC CODE								
Year	301	302	303	304	305	306	307	308	309
1971	97.631	189.451	84.347	499.794	253.294	97.546	69.170	77.494	245.143
1972	116.022	198.631	96.685	522.520	269.900	118.283	60.855	74.858	268.348
1973	128.273	261.233	106.454	626.126	368.434	152.443	71.364	73.782	328.872
1974	146.279	372.594	135.589	745.295	524.711	185.550	84.927	94.572	434.512
1975	208.111	391.084	160.880	784.328	504.369	190.346	82.327	100.697	459.505
1976	263.387	369.273	174.282	952.129	508.563	225.914	97.297	109.591	492.154
1977	282.699	358.183	184.663	76.769	561.127	235.131	96.534	122.339	503.491
1978	308.729	415.116	224.302	87.437	646.380	250.028	121.557	150.760	596.614
1979	328.016	547.410	276.745	109.639	767.083	329.752	159.739	188.942	701.817
1980	324.839	548.150	297.826	109.776	817.825	347.267	189.760	204.347	754.440
1981	430.783	641.043	326.907	136.736	848.399	355.267	192.602	239.738	782.025
1982	420.347	614.999	312.291	127.363	752.074	302.301	194.534	202.488	674.949

Table 4.7 Energy input in Canadian Metal Fabricating Industries in current 000,000 dollars

	SIC CODE								
Year	301	302	303	304	305	306	307	308	309
1971	1.597	4.058	1.524	9.477	5.846	2.923	.956	2.524	6.632
1972	1.658	4.085	1.747	9.889	6.734	3.299	.916	2.449	7.247
1973	1.906	4.386	2.000	11.598	7.811	3.769	.977	2.226	8.403
1974	2.298	5.782	2.390	13.598	10.064	4.497	1.347	2.802	10.624
1975	2.606	6.803	2.703	14.602	11.010	5.322	1.515	2.835	11.591
1976	3.647	7.733	3.344	19.616	13.568	6.285	2.066	3.402	14.351
1977	3.773	8.768	3.347	22.539	17.266	7.505	2.115	4.082	16.152
1978	4.524	9.624	4.161	27.695	19.460	8.040	2.386	4.495	19.773
1979	5.618	12.227	5.055	30.608	22.162	10.039	2.747	5.215	22.549
1980	6.800	12.506	6.160	34.181	25.384	11.673	3.133	6.105	26.457
1981	8.021	15.436	6.749	42.521	29.276	12.720	3.441	7.646	27.540
1982	8.664	18.948	8.451	52.538	34.801	16.514	3.634	11.749	31.139

Table 4.8 Selling Price Indices in Canadian Metal Fabricating Industries (Source: Statistics Canada).

Year	Industry selling price index	Intermediate inputs cost index	Energy index
1971	100.00	100.00	100.00
1972	104.7	104.6	100.3
1973	112.8	112.9	106.0
1974	134.1	135.9	102.6
1975	152.3	155.3	150.7
1976	162.3	164.6	185.3
1977	172.2	178.6	222.7
1978	188.2	193.8	251.6
1979	211.5	231.5	275.9
1980	232.7	265.8	312.9
1981	256.0	272.9	396.4
1982	277.8	384.4	470.5

Table 4.9 Summary of Output and Input Data in Canadian Fabricating Industries in Canada in (1971) 000,000 dollars.

OUTPUT AND INPUT VARIABLES						
Time Year	Output Values	Employee R.Worker	Capital Consumption	Material Supplies	Fuel & Elect.	Other Cost Input Valu
1971	3522.00	716.39	96.20	1613.90	35.53	35.53
1972	3650.50	748.57	100.30	1676.00	41.26	36.40
1973	4032.16	798.10	104.60	1875.02	34.00	49.50
1974	4324.20	790.82	109.50	2016.35	52.05	43.20
1975	3875.90	875.14	114.10	1855.51	39.14	45.70
1976	4197.80	852.18	118.20	1936.08	39.94	45.90
1977	4202.10	843.20	121.00	1930.85	34.03	37.40
1978	4511.20	820.14	122.80	2101.59	39.81	29.50
1979	4915.80	785.92	125.20	2305.60	42.12	38.80
1980	5117.10	737.95	129.20	2168.32	42.69	36.90
1981	4853.10	767.88	132.60	2243.92	38.09	39.85
1982	4160.90	542.59	134.30	1483.09	38.28	40.00

Table 4.10 Operational Productivity Measures in Canadian Metal Fabricating Industries

PRODUCTIVITY MEASURES			
YEAR	SFOP	MFOP	TOP
1971	4.9163	4.3343	1.4104
1972	4.8766	4.3004	1.4027
1973	5.0522	4.4668	1.4092
1974	5.4680	4.8030	1.4357
1975	4.4289	3.9181	1.3230
1976	4.9260	4.3259	1.4029
1977	4.9835	4.3581	1.4165
1978	5.5005	4.7842	1.4488
1979	6.2548	5.3953	1.4907
1980	6.9342	5.9011	1.6427
1981	6.3201	5.3895	1.5061
1982	7.6686	6.1471	1.8590

Table 4.11 Operational Productivity Indices in Canadian Metal Fabricating Industries.

	PRODUCTIVITY MEASURES		
YEAR	SFOPI	MFOPI	TOPI
1971	1.0000	1.0000	1.0000
1972	.9919	.9922	.9945
1973	1.0276	1.0306	.9992
1974	1.1122	1.1081	1.0180
1975	.9009	.9040	.9381
1976	1.0020	.9981	.9947
1977	1.0137	1.0055	1.0044
1978	1.1188	1.1038	1.0272
1979	1.2723	1.2448	1.0570
1980	1.2604	1.3615	1.1647
1981	1.2855	1.2434	1.0679
1982	1.5598	1.4182	1.3181

Table 4.12 Productivity Measures in Canadian Metal Fabricating Industries.

PRODUCTIVITY MEASURES		
YEAR	MFP	TP
1971	1.1788	.7595
1972	1.1776	.7578
1973	1.2405	.7815
1974	1.2874	.7968
1975	1.0911	.7116
1976	1.1600	.7503
1977	1.1435	.7451
1978	1.1906	.7607
1979	1.2724	.7914
1980	1.3123	.8375
1981	1.2207	.7755
1982	1.1066	.7878

Table 4.13 Productivity Indices in Canadian Metal Fabricating Industries in Canada.

PRODUCTIVITY MEASURES			
YEAR	SFPI	MFPI	TPI
1971	1.00	1.0000	1.0000
1972	1.014	.9990	.9978
1973	1.051	1.0524	1.0290
1974	1.077	1.0922	1.0491
1975	1.086	.9257	.9369
1976	1.114	.9841	.9879
1977	1.152	.9701	.9811
1978	1.244	1.0101	1.0016
1979	1.264	1.0794	1.0421
1980	1.354	1.1133	1.1027
1981	1.355	1.0356	1.0211
1982		.9388	1.0373

Table 4.14 Single Factor Operational Productivities in Canadian Metal Fabricating Industries.

SINGLE OPERATIONAL PRODUCTIVITY MEASURES					
YEAR	SFOPH	SFOPC	SFOPM	SFOPE	SFOPO
1971	4.9163	36.6112	2.1823	99.1275	100.0568
1972	4.8766	36.3958	2.1781	88.475	100.2885
1973	5.0522	38.5484	2.1505	118.5929	81.4578
1974	5.4680	39.4904	2.1446	83.0778	100.0972
1975	4.4289	33.9693	2.0889	99.0266	84.8118
1976	4.9260	35.5144	2.1682	105.1027	91.4553
1977	4.9835	34.7281	2.1763	123.4822	112.3556
1978	5.5005	36.7362	2.1466	113.3183	152.9220
1979	6.2548	39.2636	2.1321	116.7094	126.6959
1980	6.9342	39.6060	2.3599	119.8665	138.6748
1981	6.3201	36.5995	2.1628	127.4114	121.7842
1982	7.6686	30.9821	2.8056	108.6964	104.0225

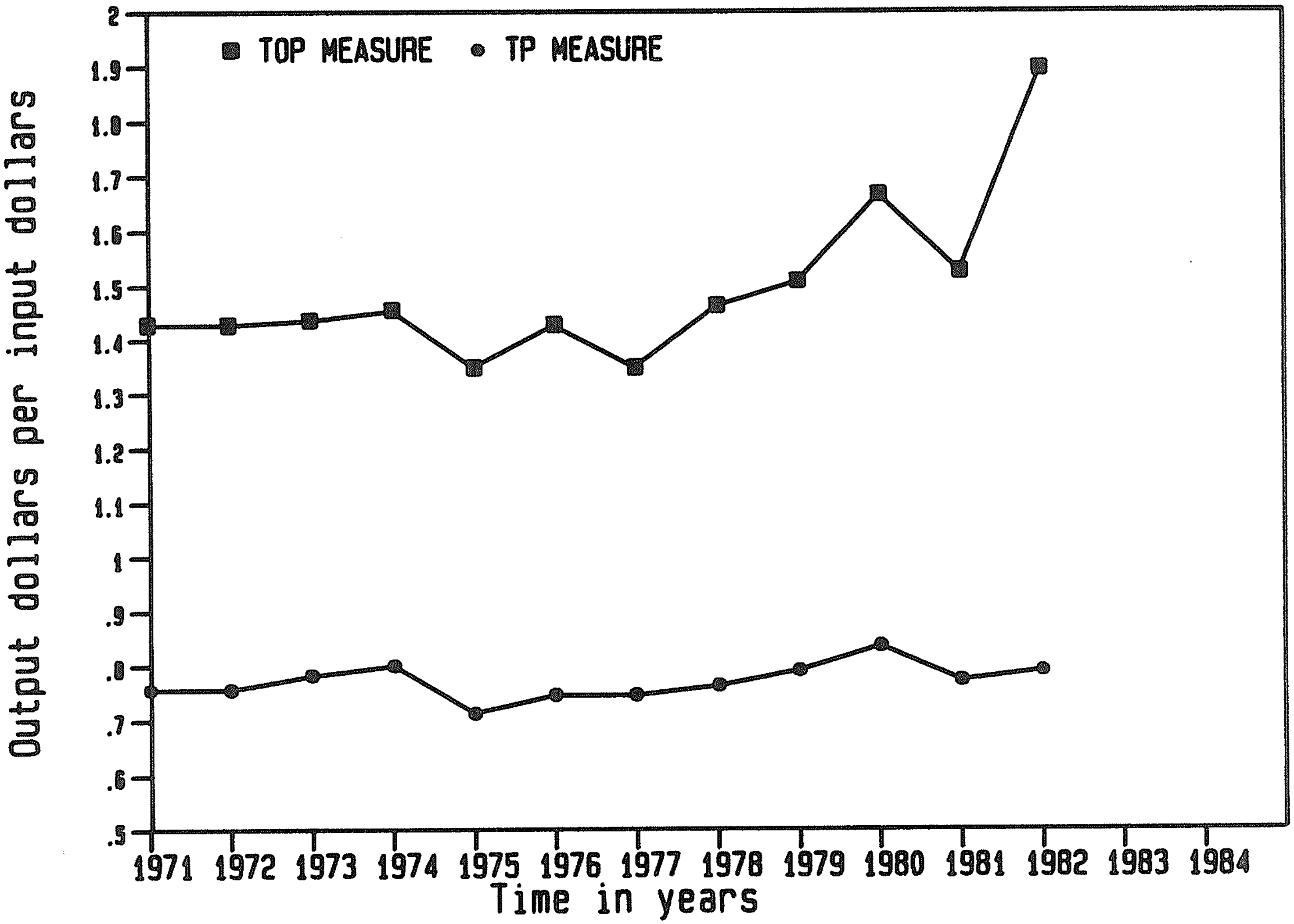

Figure 4.8 Total Operational Productivity (TOP) and Total productivity (TP) measures in Canadian metal fabricating industries.

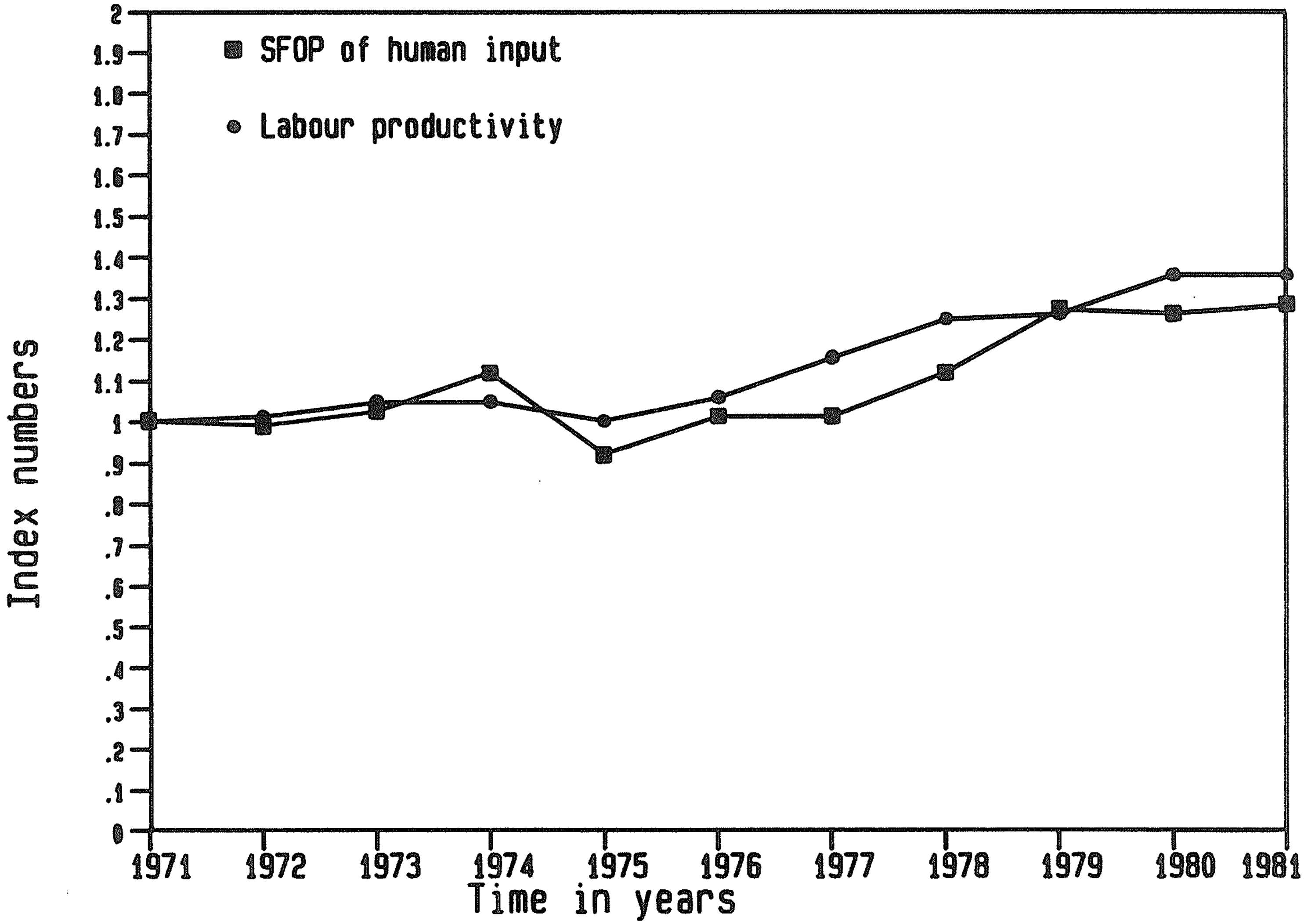

Figure 4.9 Single Factor Operational Productivity of human input (SFOPH) and single factor productivity of labour in Canadian metal fabricating industries.

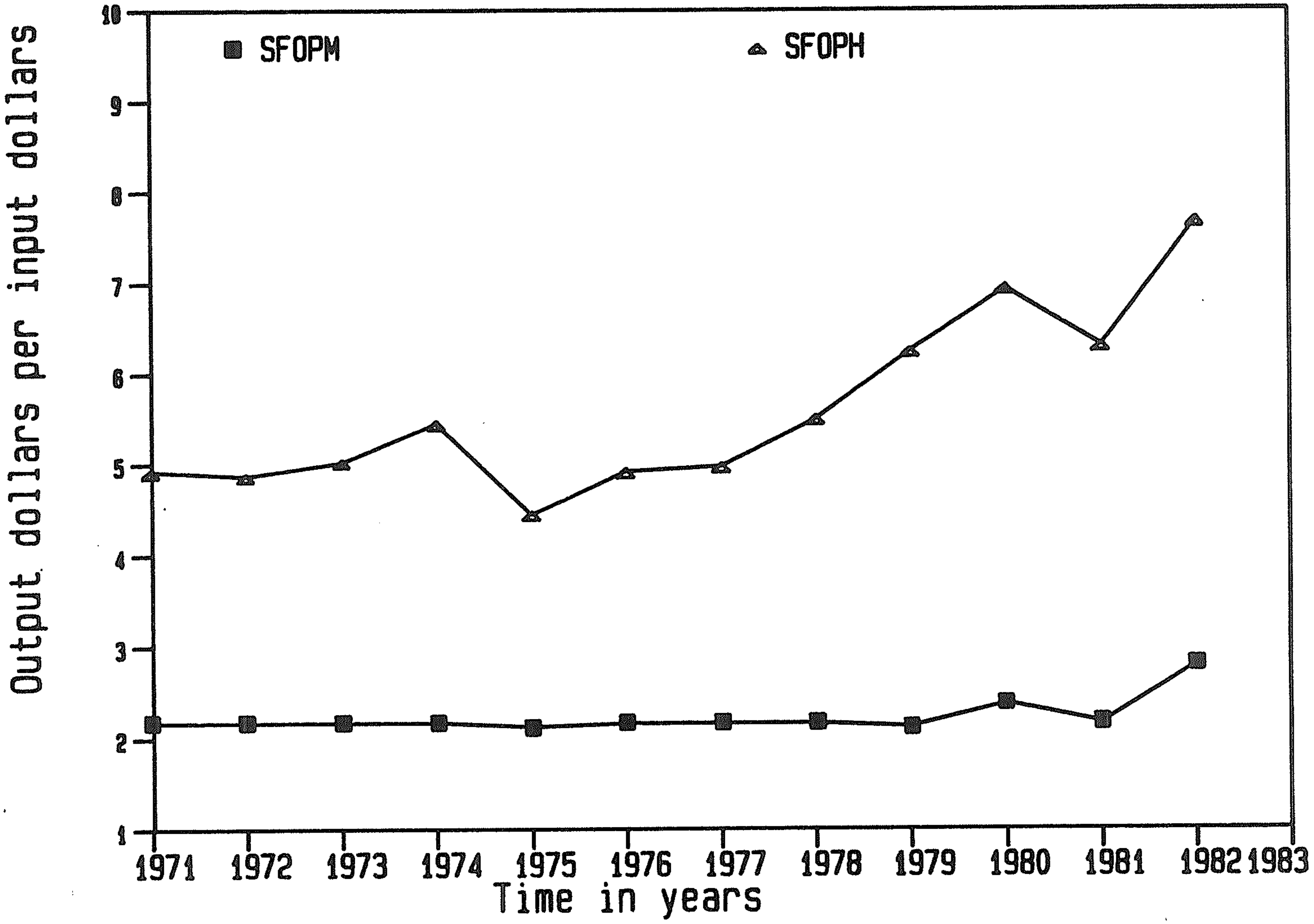

Figure 4.10 Single Factor Operational Productivity of material and supllies and Single Factor Operational Productivity of human inputs in Canadian metal fabricating industries.

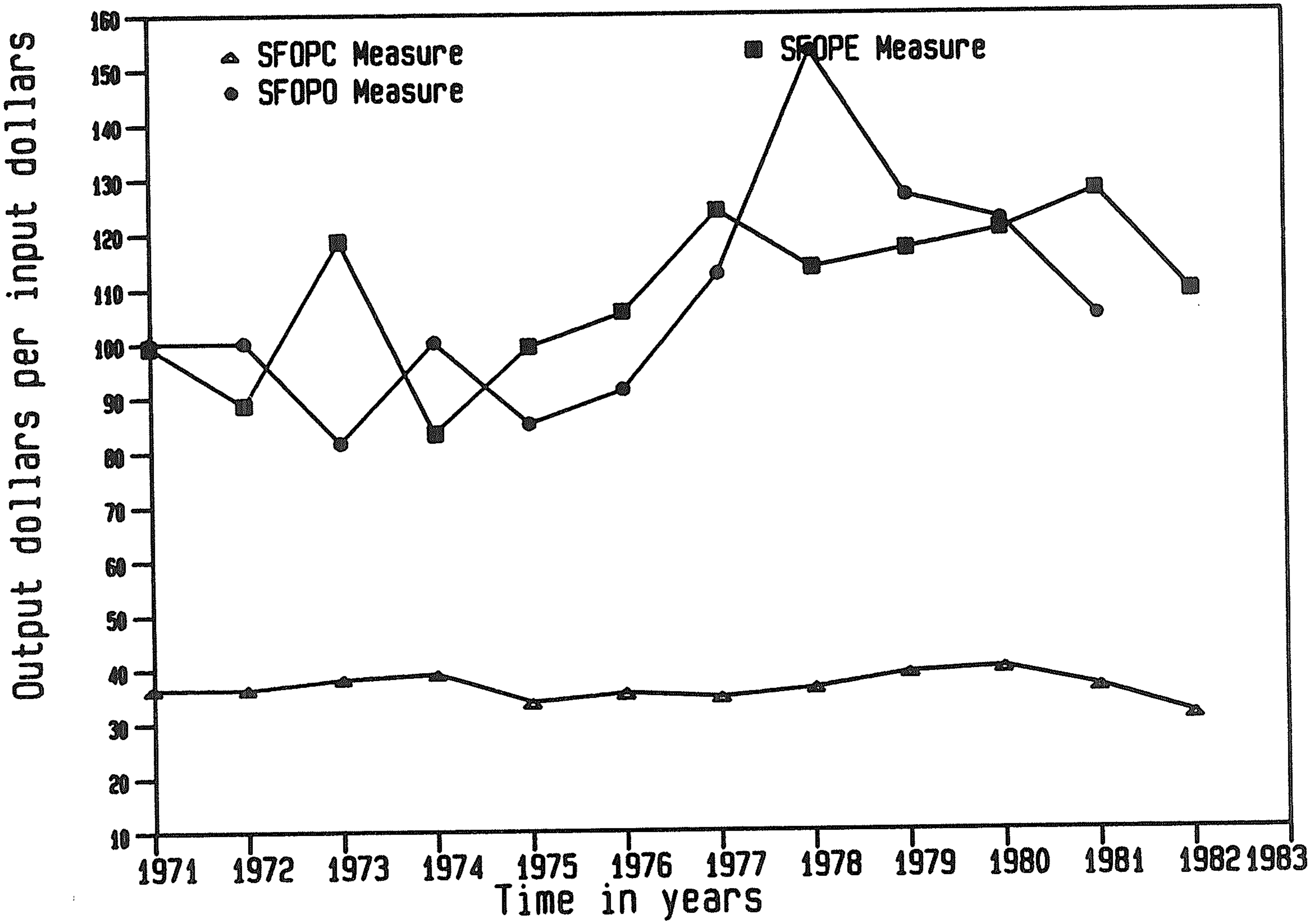

Figure 4.11 Single Factor Operational Productivities of Capital (SFOPC), energy (SFOPE) and other costs (SFOPO) in Canadian metal Fabricating industries.

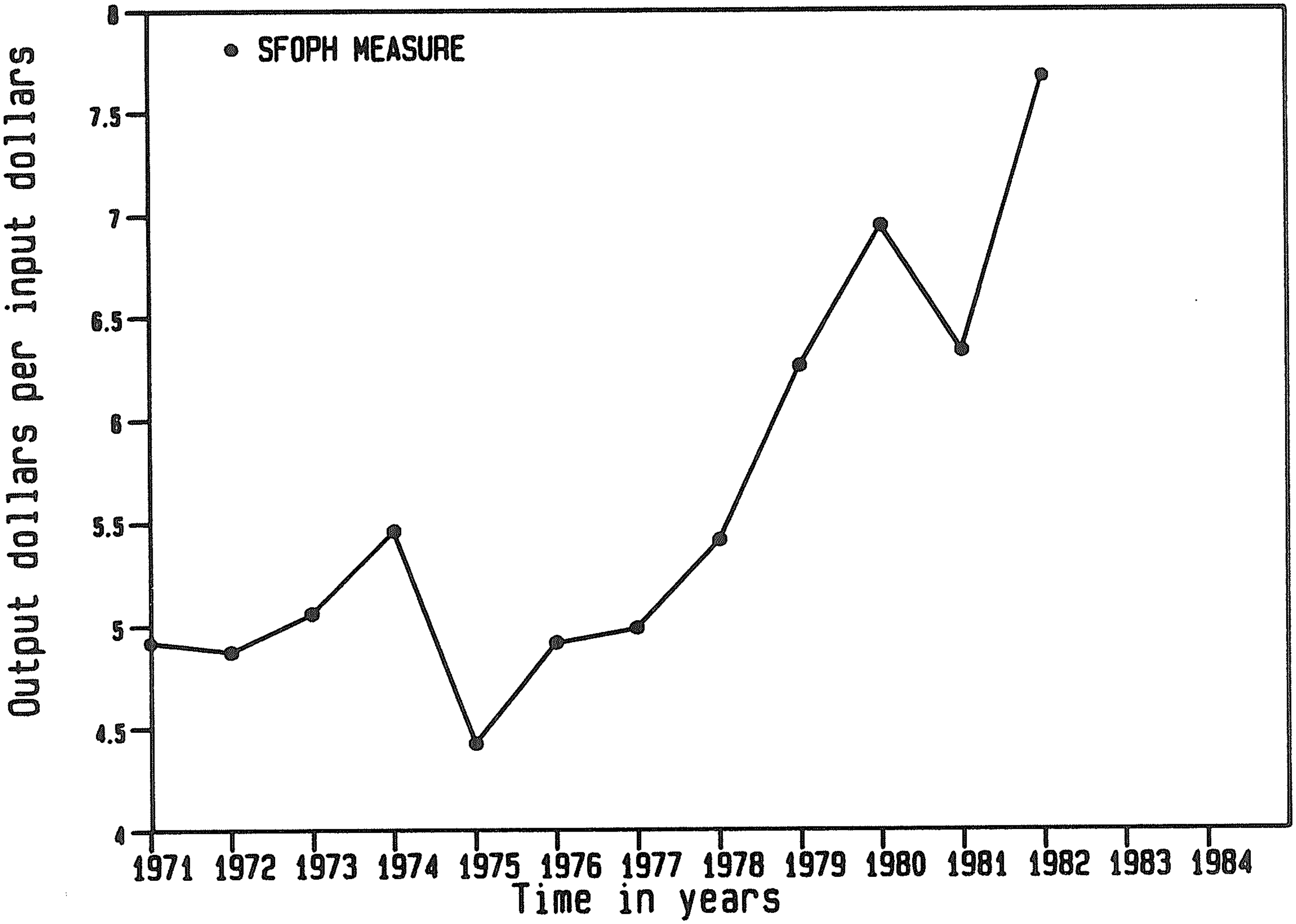

Figure 4.12 Single Factor Operational Productivity of human in Canadian metal fabricating industries.

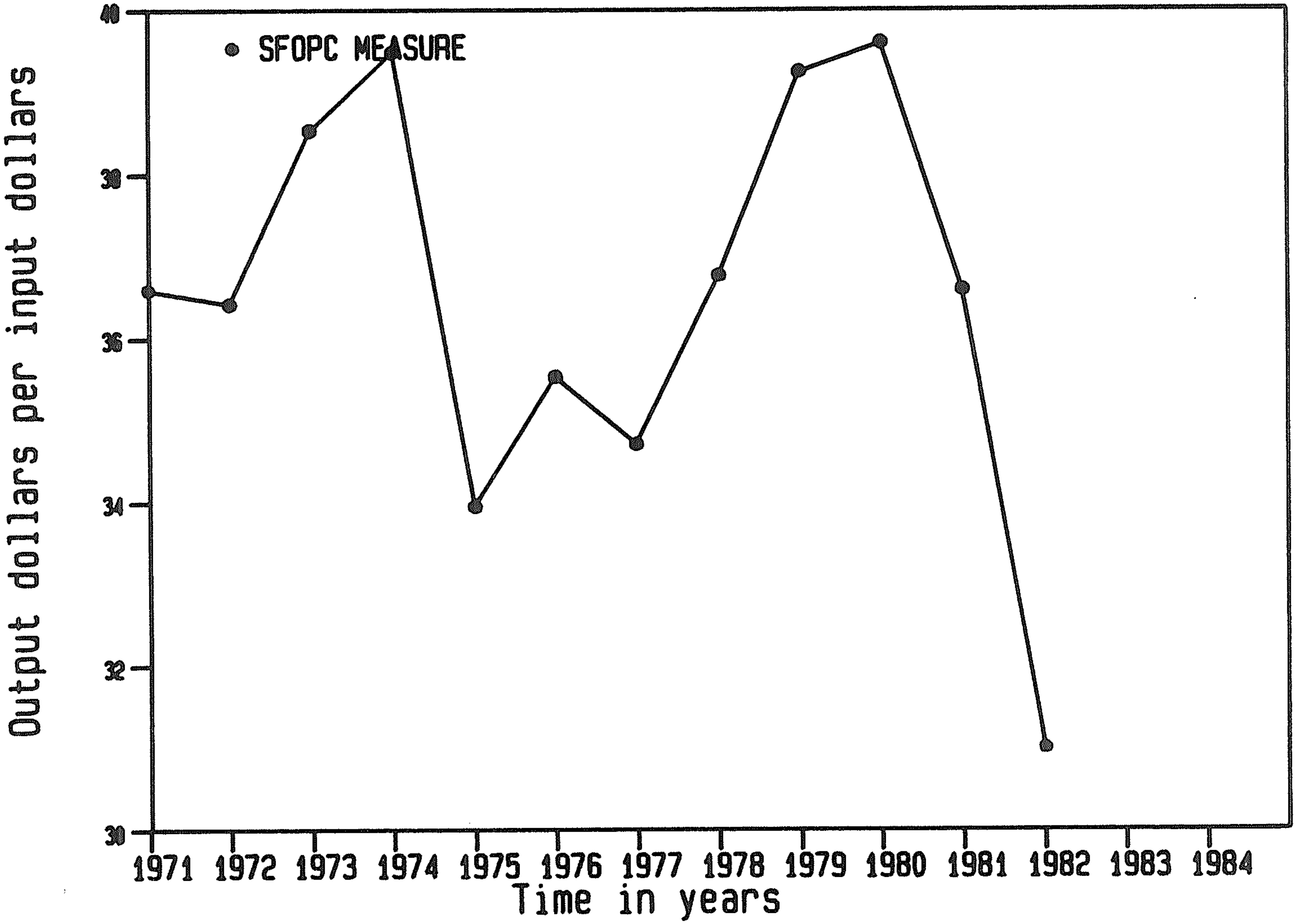

Figure 4.13 Single Factor Operational Productivity of capital inputs in Canadian metal fabricating industries.

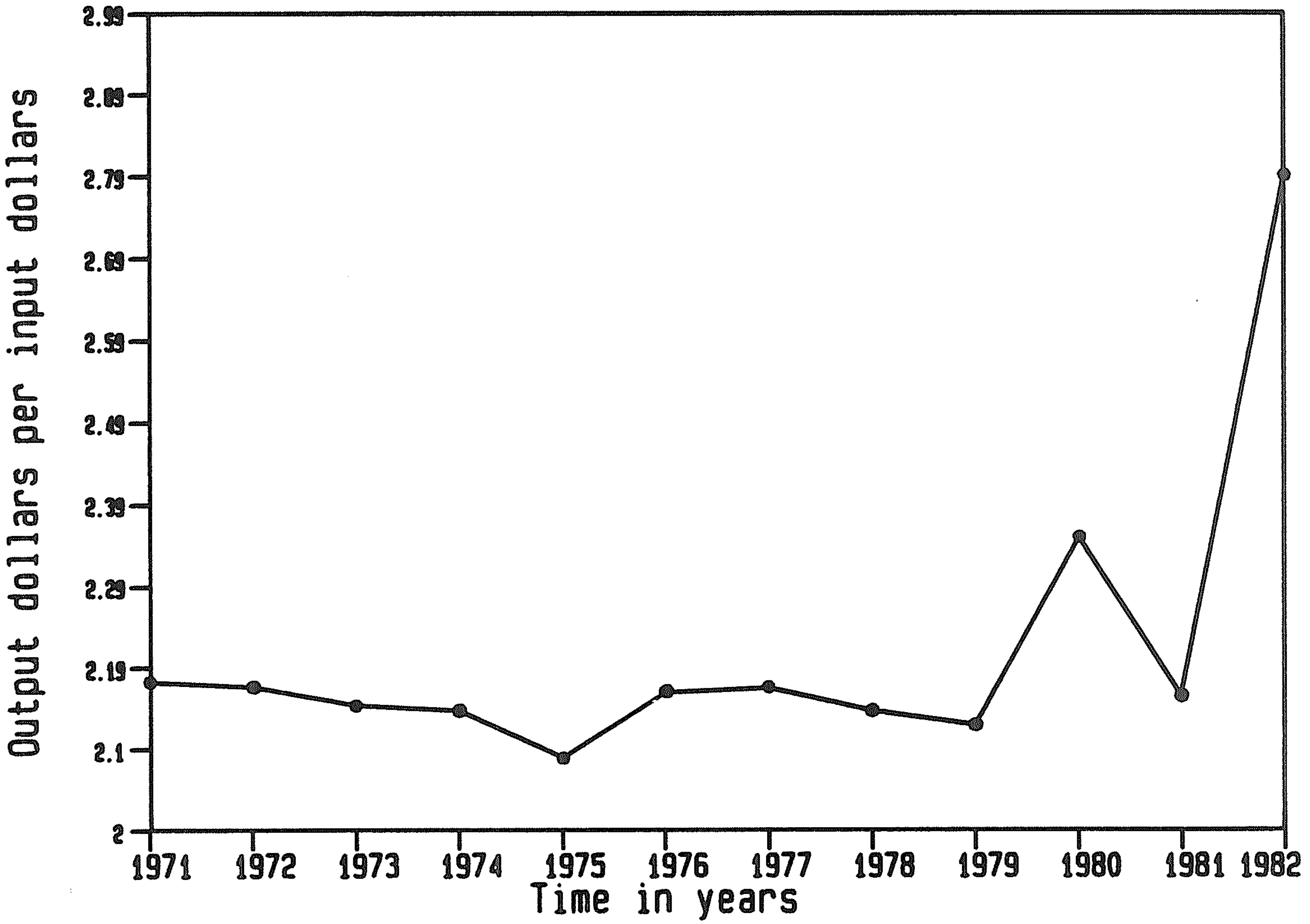

Figure 4.14 Single Factor Operational Productivity of materials and supplies inputs in Canadian metal Fabricating industries

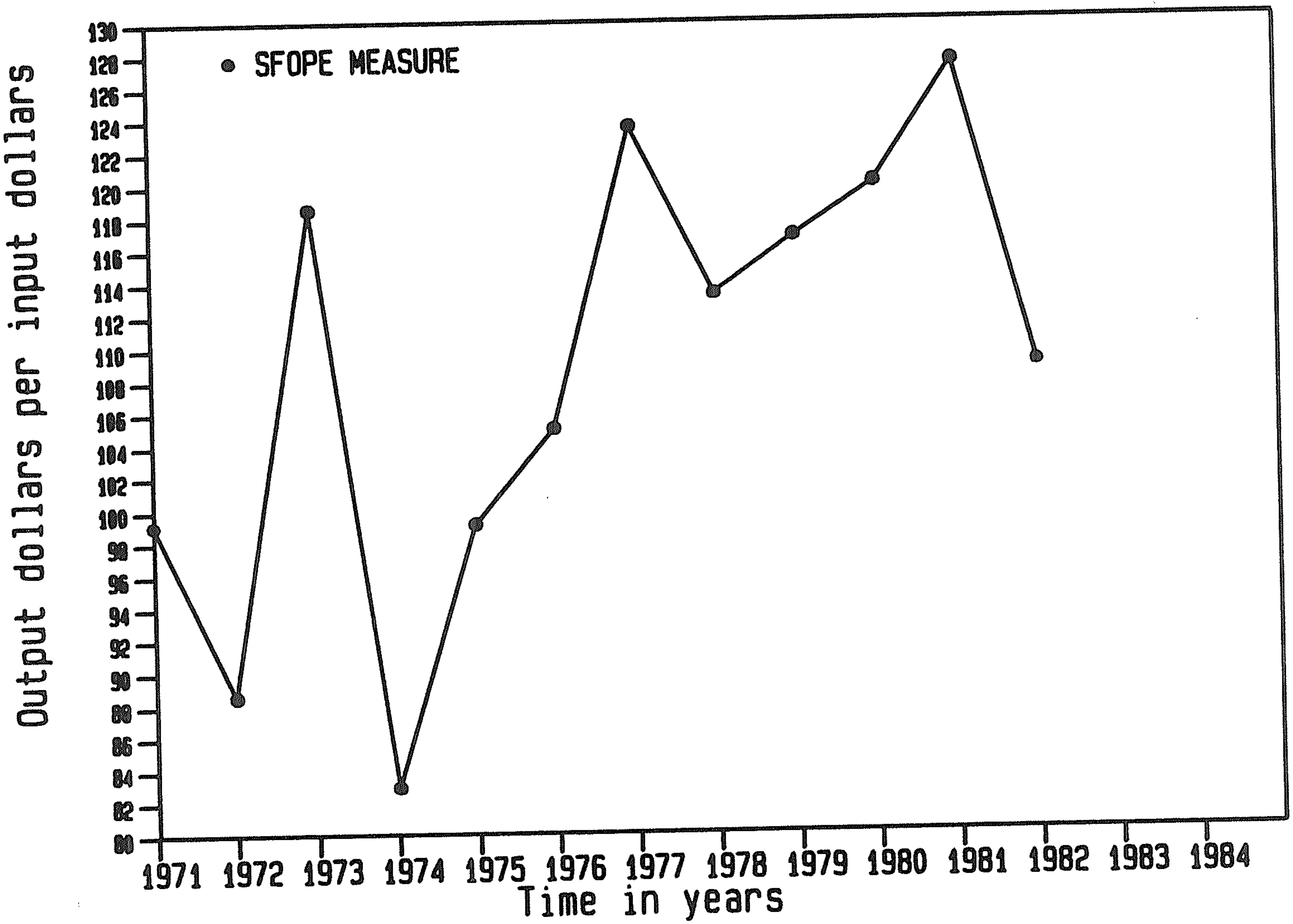

Figure 4.15 Single Factor Operational Productivity of energy inputs in Canadian metal fabricating industries.

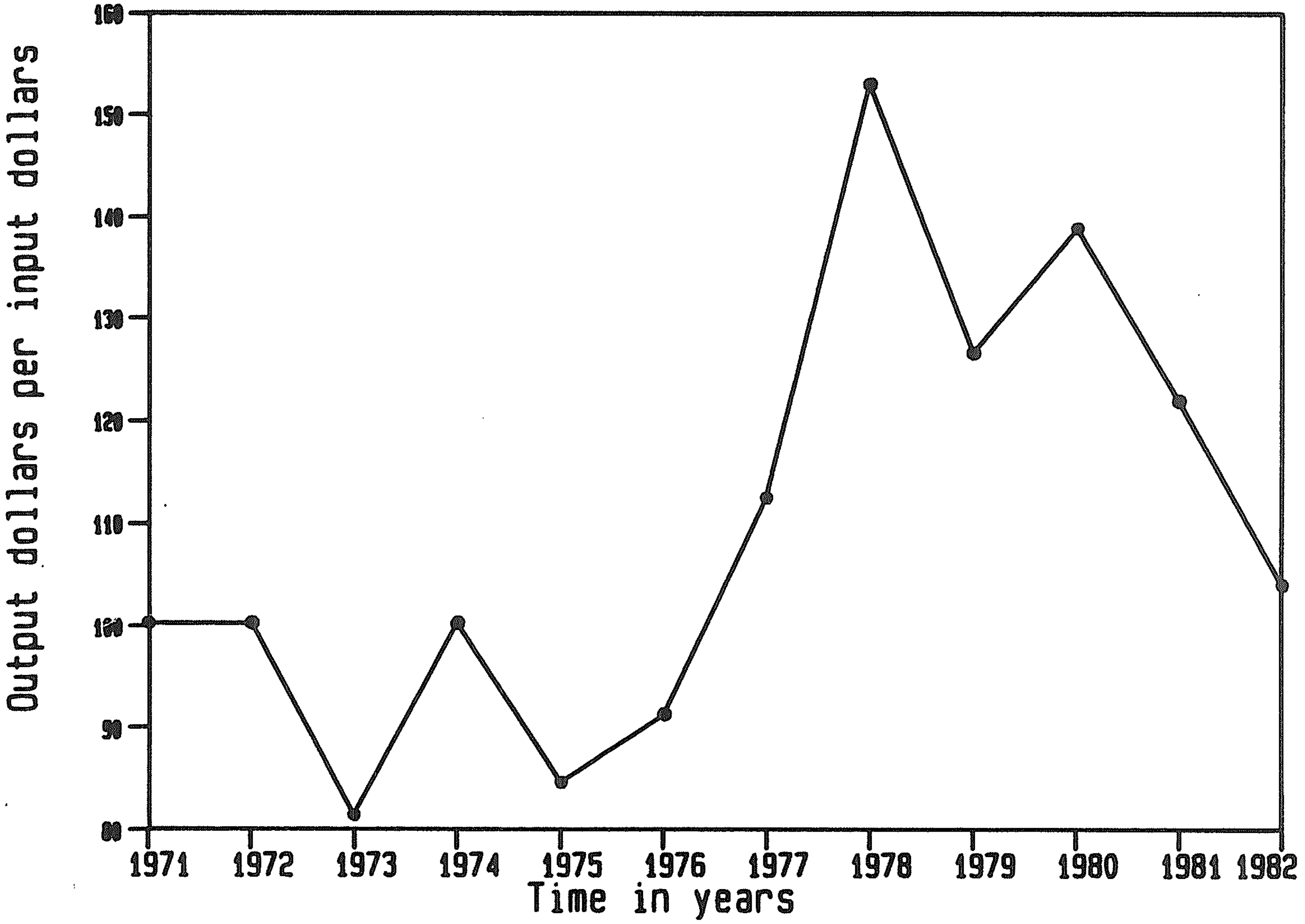

Figure 4.16 Single Factor Operational Productivity of other cost inputs in Canadian metal fabricating industries

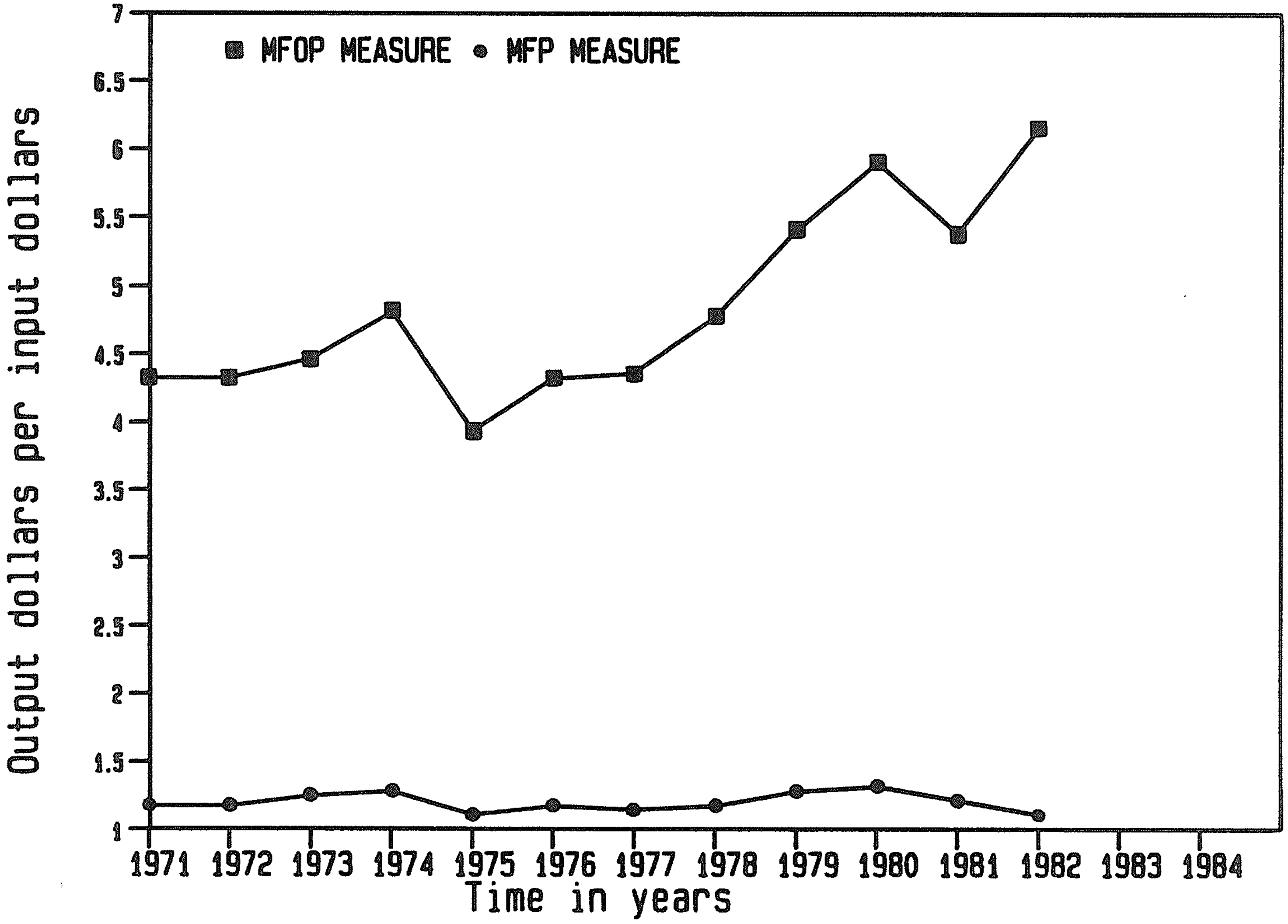

Figure 4.17 Multifactor Operational Productivity (MFOP) and Multifactor productivity (MFP) in Canadian metal fabricating industries.

CHAPTER V

TECHNOLOGY FACTOR INDEX MODEL

Technological consideration are becoming increasingly important components in all areas of strategic and operational planning and productivity improvement, particularly in the manufacturing sectors. These considerations involve the possible introduction of, and/or more effective use of, such new technological advances in manufacturing and manufacturing control as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), Flexible Manufacturing Systems (FMS), Computer-Integrated Manufacturing (CIM), Automated Storage and Retrieval Systems (ASRS), Robotics as well as other aspects of factory automation. All of these technologies are usually highly capital intensive, require significant commitment by management as well as by operating personnel. There may be major problems with skills dislocations and work-force reassignment with all accompanying problems of retraining, ageing of the work force and union opposition.

Since a greater use of these technologies is a major decision for management, it is imperative for the decision-makers to be able to put realistic, correct and useful numbers to any productivity improvement that may, and should, result from the introduction of these advanced systems. Only then can a rational and documentable decision be reached.

Unfortunately, previously available productivity measurement approaches give misleading values for productivities of new, capital-intensive systems, due to their usual approach of front-end loading of investment costs. In fact, as discussed by Ayres and Miller (1982), these methods have had negative effect on productivity indices by showing low or even decreasing levels of productivity.

Since we are interested in encouraging the introduction of technological innovations into the work place, we decided to develop a productivity index that we call the Technology Factor Index (TFI) that would be designed to highlight in a fair and realistic manner the actual contribution of technological systems to overall productivity. The relationship between TFI and TOP is investigated, and finally, a case study based on Canadian data for metal-fabricating industries is presented to illustrate the TFI concept and its relationship to the TOP. The TFI is developed by means of factor analysis techniques. Factor analysis enables us to explain the data orginally obtained on a large number of characteristics of the entity, in terms of smaller number of reference factors hypothesized as representing the hidden behaviour of the data.

5.1 Factor Analysis

Factor analysis is a branch of statistical science. The main purpose of factor analysis is to represent a set of variables in terms of a smaller number of hypothetical factors. The hypothesized factors are presumed to belong to the source of the observed variables. These factors are often divided into unique and common factors.

Factor Analysis has been applied in many disciplines including economics, medicine, physics, geography, taxonomy, and many other areas (Harman, 1976). The basic model of factor analysis is simply:

$$Z_{ji} = \sum_{p=1}^{m} a_{jp} F_{pi} + U_j Y_{ji} \qquad (5.1)$$

$(i=1,2,\ldots,N \; ; \; j=1,2,\ldots,n)$

where,

Z_{ji} = The observed measurement of the variables.
F_{pi} = The value of common factor p for individual i.
$a_{jp} F_{pi}$ = The contribution of the corresponding factor to the linear composite.
$U_j Y_{ji}$ = The residual error.

Each of the n observed variables is described linearly in terms of $m \ll n$ common factors and a unique factor U_j. The common factors account for the correlations among the variables. The correlation between two variables is the ratio of their covariance to the square root of the product of their variances. For two variables X_j, X_k the correlation is

$$r_{jk} = \frac{\sum_{i=1}^{n} (X_{ij} - X_j)(X_{ik} - X_k)}{\{ \Sigma[(X_{ij} - X_j)^2][\Sigma(X_{ik} - X_k)^2]\}1/2} \qquad (5.2)$$

Where

X_{ij} = the value for case i for variable X_j
X_j = the mean of the observations for variable j
X_{ik} = the value for case i for variable X_k
X_k = the mean of the observations for variable k.

Each unique factor U_j accounts for the remaining variations (including error) of that variable. The coefficients of these factors are frequently referred to as "loadings". Generally, it can be assumed that F's and Y's have zero mean and unit variances, since they are unknown in practice. F's are random variables, defined by probability density functions. X's have multivariate probability distributions. The method applied to find the number of factors and the "load" of each variable, is called the Principal-Factor method. The Principal Factor method with iteration is the most widely accepted factoring method and can handle most of the initial factoring needs of the user (Harman, 1976). In this method, the first step is to prepare a correlation matrix for all the variables under consideration. Initial estimates of the communality (h^2) of a variable Z_j is given by the sum of the squares of the common factor coefficients as shown in equation (5.3). The main diagonal of the correlation matrix is replaced by the communality estimates and solved for eigenvalues and eigen vectors. The number of principal factors to be retained for the final rotated solution will ordinarily be determined by the specification of minimum eigen value criteria.

The first factor coefficient a_{j1} is found by making the sum of contribution of that factor to the total communality a maximum, thus

$$h^2 = V = a_{11}^2 + a_{21}^2 + \ldots\ldots\ldots\ldots + a_{n1}^2 \qquad (5.3)$$

subject to

$$r_{jk} = \sum_{p=1}^{m} a_{jp} \, a_{kp} \qquad (5.4)$$

(j, k = 1,2,........n)

where $r_{jk} = r_{kj}$ and r_{jj} is the communality h_j^2 of variable Z_{j1}. In order to maximize equation (5.3), the method of Lagrange multipliers is employed to maximize V, as a function of the n variables a_{j1} under 1/(2n(n+1)) conditions among all the coefficient a_{jp}.

The problem of finding the coefficients a_{j1} of the first factor F_1, which will account for as much of the total communality as possible is solved as follows: The largest root λ (the root of determinant of the correlation matrix) is substituted into the partial derivative of Eq. (5.4) and any solution that can be called $\alpha_{11} + \alpha_{21} + \ldots\ldots\ldots\ldots, \alpha_{n1}$ is obtained. Then to satisfy the relation (5.3), these values are divided by the square root of the sum of their squares and then multiplied by $\sqrt{\lambda}$. The resulting quantities are:

$$aj1 = {}_{j1} / \sqrt{\alpha_{11} + \alpha_{21} + \ldots\ldots\ldots + \alpha_{n1}} \qquad (5.5)$$

j = 1,2,....,n

These are the desired coefficients of F_1 in the factor pattern Eq. (5.1). The roots (λ's) of a characteristic equation are called characteristic roots (eigenvalues).

Advantages of Factor Analysis:

1. Factor analysis has the ability to reduce the number of existing problem variables to a smaller group of characteristics that continue to account for a substantial portion of the observed relationships given by the orginal data.
2. Factor analysis assists in identifying the important parameters by computing factor weights using measurable variables having mixed dimensions.
3. Factor analysis is a valuable tool for the development of empirical topology.

Previous efforts to examine the technological effects of individual input variables through productivity function analysis have been unrewarding. Sumanth (1984) claims that considerations of single factor productivity measures and their comparison to the total productivity would be able to provide a measure of the contribution of the individual (say, technological innovations) inputs. However, this approach does not seem to be able to explain the independent contribution of each input to its share of total output and productivity.

In our attempt to motivate realistic technology measurement, we propose a step-by step approach to clarify the relation between the Total Operational Productivity and the Technology measures:

1. Identification of those variables contributing most to technology and productivity measures.
2. Deflation of the values of such variables into constant dollars to remove the effect of price changes and thereby allow the measure to reflect physical quantities only.
3. Derivation of a cluster-technology index with the help of factor analysis statistical techniques.
4. Exploration of the relationship between productivity and technology measurement indices.

5.2 The Model:

Technological changes that are most likely to affect industrial productivity are classified into the following categories, Gold (1983):

1. Alterations in the design of product(s);
2. Changes in the design and scale of operating processes;
3. Improvements in control systems;
4. Modification in the physical and chemical properties of material, inputs, as well as the introduction of new types of materials.

5.2.1 Definition of the Technology Factor Index, (TFI)

We define the Technology Factor Index as the sum of the percentage shares of quantitative and qualitative values of the variables involved in the production systems, multiplied by their factor weight (determined from factor analysis). This is done for a defined period of time, for one industry, in terms of index numbers.

Figure (5.1) illustrates how factor analysis reduces the number of variables by assigning appropriate weights (loading) to a smaller number of factors.

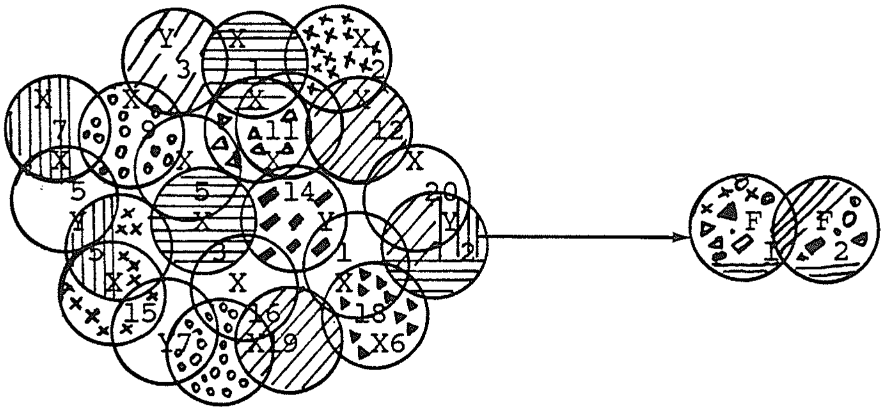

Figure 5.1 Factor loading from observed data

5.2.2 Correlation Matrix :

Our correlation matrix is simply a pairwise comparison between the quantitative and/or qualitative variables selected for study and analysis. It can be obtained directly by substitution into equation (5.2)

5.2.3 Identification of Variables:

It is to be recognized that industrial development and technological changes are linked with many broad aspects of general economic development (which themselves are dependent upon the choice of objective, policy and systems). In our present effort to develop a quantified model for measuring technology in the manufacturing sector, we have attempted to describe any given technology by three types of variables : quantitative, qualitative and decision variables. These can then be combined as indicated in Figure (5.2). Due to the lack of numerically useful data, the study of qualitative factors is not considered in this case study.

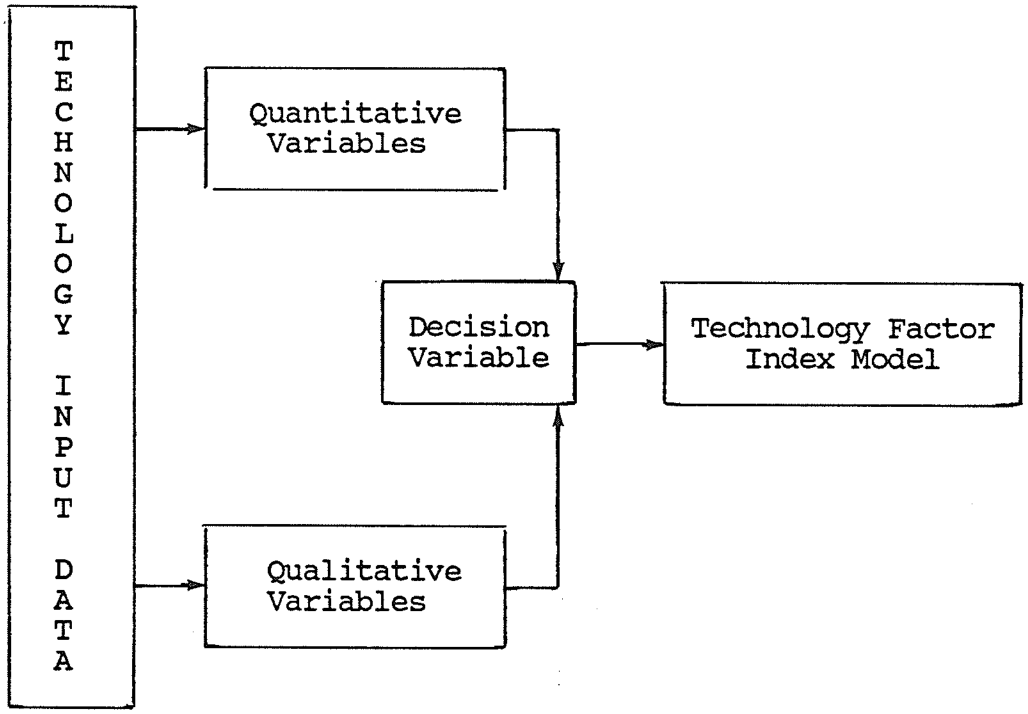

Figure 5.2 Parameters used in describing the Technology Measurement Model.

Table 5.1 Quantitative (QN) and qualitative (QL) variables influencing productivity and technology measures.

	Name of Factor	QN	QL	Units
1	Human input	*		Dollars
2	Fixed capital consumption	*		Dollars
3	Working capital consumption	*		Dollars
4	Raw materials	*		Dollars
5	Purchased materials	*		Dollars
6	Transportation costs	*		Dollars
7	Scrap value	*		Dollars
8	Inventory costs	*		Dollars
9	Energy consumption	*		Dollars
10	Marketing expenses	*		Dollars
11	Output	*		Dollars
12	Value added	*		Dollars
13	Investment	*		Dollars
14	Research and development	*		Dollars
15	Incentive plans	*		Dollars
16	Impact of government policy		*	
17	Impact of industrial laws		*	
18	Safety management		*	
19	Impact of tradition		*	
20	Reliability		*	
21	Flexibility		*	
22	Pollution		*	
23	Quality control		*	
24	Communication		*	
25	Training		*	

5.2.4 Formulation of the model:

The general model is based on a combination of the three kinds of factors for each industry i. The Technology Factor Index (TFI) is given by :

$$TFI_{it} = D_{ij} \left[\sum_{j=1}^{M} \eta_{ij} . QN_{ijt} \right] + D_{ik} \left[\sum_{k=1}^{N} \eta_{ik} . QL_{ikt} \right] \qquad (5.5)$$

where,

D_{ij}, D_{ik} = The decision variables measure for industry i = (1,0)

QN_{ijt} = The index value of quantitative variable j for the i^{th} industry at time t ($0 \leq QN_{ijt} \leq 1$)

QL_{ikt} = The index value of qualitative variable k for the i^{th} industry at time t ($0 \leq QL_{ikt} \leq 1$)

i = 1,2,........,I (Industry name)

t = 1,2,........,T (Time in years)

j = 1,2,........,M (quantitative variables)

k = 1,2,........,N (qualitative variables)

η_{ij} η_{ik} = are the weight factors corresponding to relative weights attached to quantitative and qualitative variables (assigned by factor analysis).

5.2.5 Model solution procedure:

Step 1.

Compute the loads a_{ij}, a_{ik} of variables (by means of the factor analysis statistical method) corresponding to the hypothesized factor. The assumed factor usually accounts for the highest percentage of variance among the other factors derived from the raw data.

Step 2.

For some of the variables included in the model as shown in Table (5.1), there may be some difficulty in collecting appropriate data. Decision variables D_{ij} and D_{ik} with their binary properties are used to include or exclude j and k variables in the model.

Step 3.

In order to avoid price and cost effects for all variables having monetary value, we deflate them to some reference time values by means of appropriate indices.

Step 4.

To maintain homogeneity among all variables under measurement, we normalize the variables into dimensionless indices as follows:

$$QN_{ijt} = \frac{Q_{ijt}}{\sum_{t=1}^{T} Q_{ijt}} \qquad (5.6)$$

and

$$QL_{ikt} = \frac{Q_{ikt}}{\sum_{t=1}^{T} Q_{ikt}} \qquad (5.7)$$

and from equations (5.6) and (5.7) we can say;

$$\sum_{t=1}^{T} QN_{ijt} = 1 \qquad (5.8)$$

$$\sum_{t=1}^{T} QL_{ikt} = 1 \qquad (5.9)$$

where,

Q_{ijt} = the value of quantitative variable j;
Q_{ikt} = the value of qualitative variable k.

Step 5.

The weights η_{ij} and η_{ik} can be calculated by :

$$\eta_{ij} = \frac{a_{ij1}}{\sum_{j=1}^{M} a_{ij}} \qquad (5.10)$$

$$\eta_{ik} = \frac{a_{ik1}}{\sum_{k=1}^{N} a_{ik1}} \qquad (5.11)$$

where,

a_{ij} = the "load" of the quantitative variable j for industry i in factor 1.

a_{ik} = the "load" of the qualitative variable k for industry i in factor 1.

Step 6.

We find the Technology Factor Index (TFI_{IT}) by simply substituting all parameters calculated in steps 2-5 into Equation (5.5).

As described previously in the factor analysis section, one notes that in order to arrive at a good solution, it is usually recommended that the number of cases under consideration exceed the number of variables used in the analysis.

5.3 The relationship between TOP_{it} and TFI_{it}

Regression analysis is a statistical technique for modeling and investigating the relationship between two or more variables, (Hines and Montgomery, 1980). It is appropriate to use regression analysis to find the relationship between the two measurement factors "TOP" and "TFI" derived here, and in Chapter 4.

Generally, we have assumed the relationship between the Total Operational Productivity and the Technology Factor Index to be represented by the following function :

$$TOP_{it} = f\ (TFI_{it}, \varepsilon_t) \tag{5.12}$$

Typically, this econometric model can be linear or nonlinear in its parameters. If, for example, the data happen to fit linearly, then

$$TOP_{it} = a + b\ (\ TFI_{it}\ ) + \varepsilon_t \tag{5.13}$$

If the data happen to be of a nonlinear fit, then

$$TOP_{it} = a\ e^{c(TFI_{it})} + \varepsilon_t \tag{5.14}$$

or any other nonlinear model, where a, b and c are the relevant constants and ε_t is the stochastic term.

5.4 Case study

For the purpose of illustration, the proposed TFI model is applied to the problem of Technology Measurement in Canadian metal fabricating industries. All relevant data are obtained from Statistics Canada Catalogues.

The suggested list of variables is given in Table (5.1). We will concern ourselves mainly with the quantitative variables.

The correlation matrix in Table (5.2) indicates the relationship between the variables used. Table (5.3) shows the weights a_{ij} estimated from factor analysis to be used in the TFI model. Since we employed the principal factor component method, we found that the first factor accounted for more than 50 % of the total variance. Table (5.4) shows the value of the Technology Factor Index derived from Equation (5.5). All the calculations involved in the factor analysis are done by the Statistical Analysis System (SAS) computer package available at the University of Manitoba AMDAHL mainframe computer. Other results are determined by using our own Microsoft FORTRAN-77 program for IBM Pc microcomputer. This program as developed in this thesis, is listed in Appendix C.

5.6 Results and discussion

The overall results of this chapter can be divided into three parts. First, the multivariate relationship between the output and input factors for Canadian metal fabricating industries for the 12 years period selected; next, the Technology Factor Index model relevancy, and finally the relationship between the value of Total Operational Productivity and Technology Factor Index in Canadian metal fabricating industries.

The data presented in Table (4.9) was first used in the factor analysis model to develop the weights of variables in the first factor. The variables were assumed to reflect the technological characteristics as indicated in Table (5.1). The selection of these variables is influenced to some degree by the literature available. The qualitative variables are not considered initially, because it is difficult to obtain consistent data covering a wide range within the industrial sector and covering a reasonable historical time span.

Table (5.2) presents a correlation matrix which indicates the degree of linear relationship between the row and column variables of the matrix. If the coefficient is squared and multiplied by 100, it will express the percent of variation in common to observed data for the two variables. For example, the correlation coefficient of .78 between capital consumption as a percent of output (value of shipment) means that 61 percent of the variation during the selected time for these two characteristics is common for the data in Table (4.9). The principal of the correlation matrix Table (5.2) contains communality estimates (expressed as the square of the multiple correlation coefficients) which measure the variation of a variable in common with all others. The low coefficient of correlation between energy and capital input consumption is noteworthy and seems to indicate that capital requirements are not really sensitive to the amount of energy consumption in the production / productivity functions. It seems to indicate that use of highly capital-intensive equipment does not significantly affect the industries real level of energy use. Table (5.3) presents the factor loading matrix for the data in Table (4.9). The columns define the factors and the rows refer to the variables. The loading for the row variables on the column factors is given at the intersection of any row and column. The number of columns corresponds to the number of independent uncorrelated patterns of relationship among the variables. Table (5.3) shows two independent patterns corresponding to two F functions in Equation (5.1). The loadings indicate the degree to which the variables are involved in the factor patterns, and the square of the loading multiplied by 100, gives the percent variation which that variable has in common with the pattern. The loadings correspond to values of a_{jm} in Equation (5.1). It can be seen that the first factor pattern accounts for more than 50 percent of the variation through the data (Figure 5.3 shows the pattern for factor one and the variables). The data in Table (5.3), is used to calculate the weights η_{ij}. The η_{ik}, a qualititative weight factor, is not considered in this example . The values of The Technology Factor Index are simply determined by substituting into Equation (5.5). The results are shown in Table (5.4).

In order to verify the usefulness of the Technology Factor Index theoretically, a nonlinear regression analysis is used to find the relationship between the Total Operational Productivity and the quantitative measure of technology (TFI), based on the data for the two measures for the same industries and historical time as used above. The relationship is found to be as follows:

$$TOP_{it} = (1.4212)\, e^{0.6117(TFI_{it})} \qquad (5.15)$$

Equation (5.15) shows that if the Technology Factor Index increases by one unit, the Total Operational Productivity increases by $e^{.6117}$.

For this group of industries and for our standard TFI_{it} range of 0.0 to 1.00, the TOP_{it} range will be from 1.421 to 2.67 respectively.

Analysis of Variance (ANOVA) Table (5.5) presents the analysis of the statistical results. These indicate the significance of the relationship hypothesized (i.e.the t-test value is highly significant). The summary of statistics is shown in Table (5.6). The relationship between TOP_{it} and TFI_{it} is plotted in Figure (5.4).

We see thus, that the TFI_{it} can be used as another useful management tool to evaluate the impact of a specfic technology in one industry, or for various similar industries, and may be used as valuable indicator in productivity improvement techniques .

Table 5.2 Correlation matrix beween output and input variables in Canadian metal fabricating industries, 1971-1982.

	Output	Human	Capital	Material	Energy
Output	1.00				
Human	0.295	1.000			
Capital	0.778	-0.240	1.000		
Material	0.558	0.402	0.109	1.000	
Energy	0.304	0.023	0.035	0.140	1.000

Table 5.3 Factor loading derived from factor analysis

VARIABLES	1st FACTOR	2nd FACTOR
1. OUTPUT	0.97478	-0.11491
2. HUMAN	0.11559	0.86957
3. CAPITAL	0.74160	-0.55534
4. MATERIAL	0.66657	0.57228
5. ENERGY	0.38025	0.11011

Table 5.4 Technology Factor Index measure in Canadian metal fabricating industries.

Year	Technology Factor Index (Index numbers)
1971	0.0700
1972	0.0740
1973	0.0774
1974	0.0866
1975	0.0798
1976	0.0835
1977	0.0823
1978	0.0877
1979	0.0938
1980	0.0943
1981	0.0951
1982	0.0984

Table 5.5 Analysis of variance for the regression analysis

Source of variation	Sum of squares	D.F.	Mean square	F
Regression	0.049806	1	0.0498	16.15
Error	3.08×10^{-2}	10	3.08×10^{-2}	
Total	8.06×10^{-2}	11		

Table 5.6 Summary of statistics and estimated coeficients

Variables	Estimated Coefficient	Estimated St. Dev.	Computed t-Value
TFI	0.61107	0.15209	4.019
Intercept	1.4212		

Standard error = 5.55×10^{-2}
R^2 = 78.76 %

D-W = 1.639 (Durbin-Watson)
F = 16.15 (F - Test)

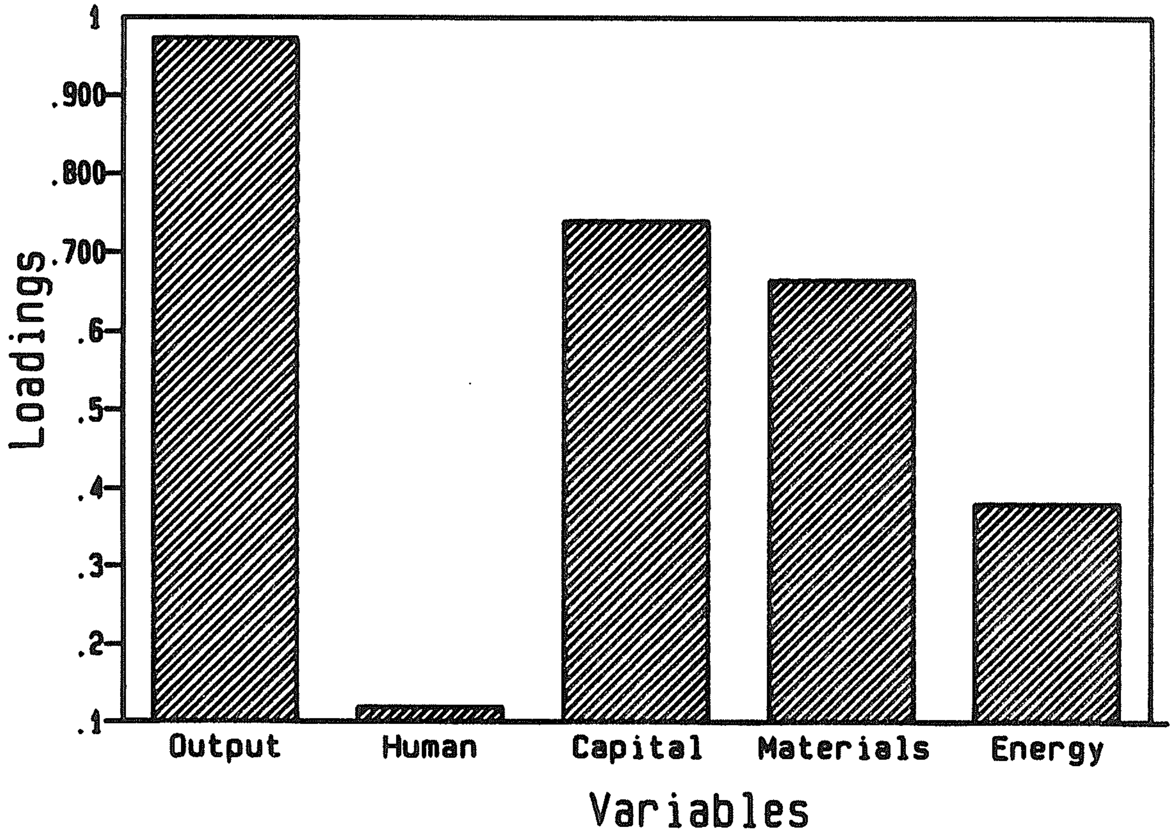

Figure 5.3 The relationship between factor one and the contributing variables.

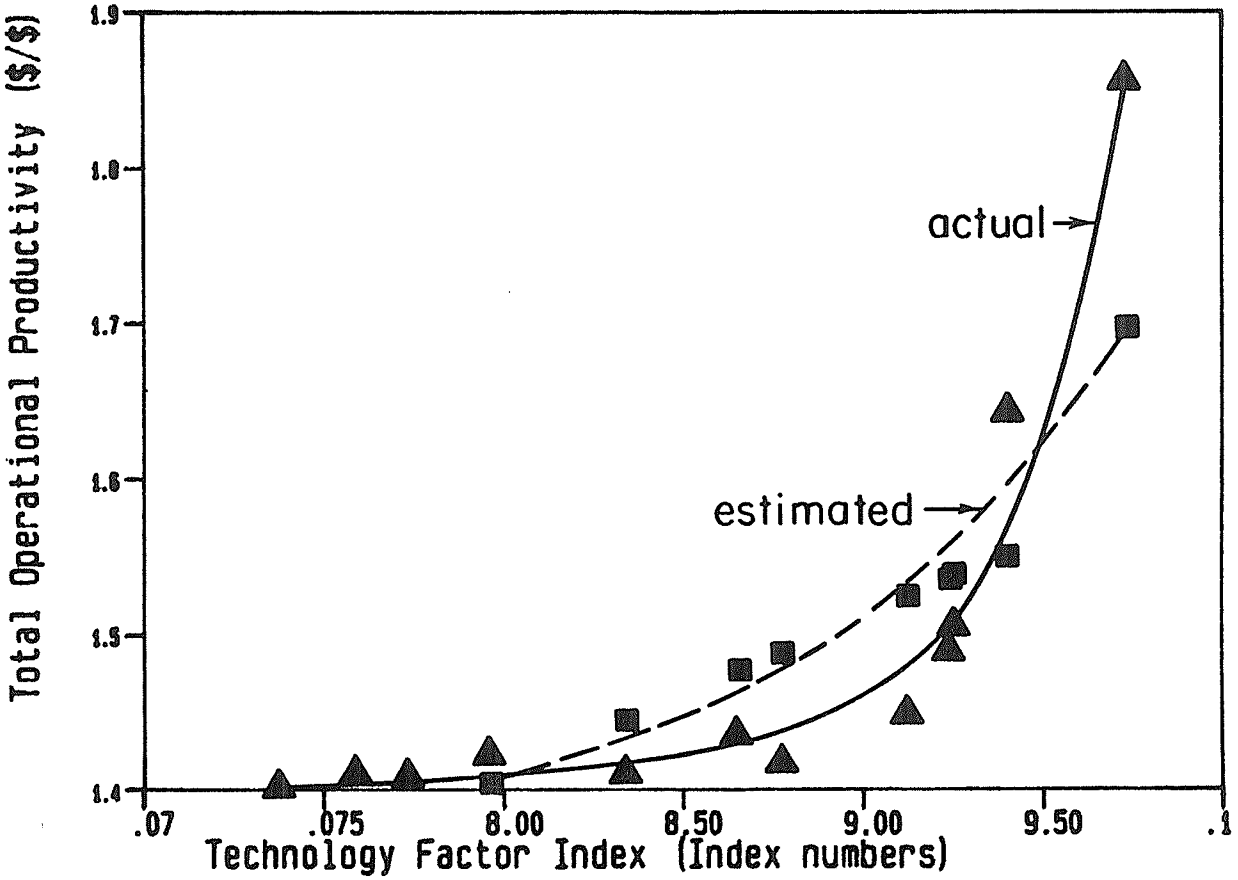

Figure 5.4 The relationship between the Total Operational Productivity (TOP) and the Technology Factor Index (TFI) in Canadian metal Fabricating industries for the period of 1971-1982.

CHAPTER VI

THE TOTAL OPERATIONAL PRODUCTIVITY PLANNING MODEL: A NONLINEAR PROGRAMMING APPROACH

Within the productivity management context, productivity planning processes can be classified into two types: short-term and long-term.

Consideration of the existing levels of sophistication of overall operating systems in manufacturing industries indicate that operations research (OR) techniques seem to be appropriate, attractive and accepted management diagnostic tools. Hence, OR methods should be equally accepted as useful for productivity improvement analysis. This ability of determining the actual best, or optimal solution of the problem under consideration is recognized as a powerful and effective tool for solving critical corporate management and engineering problems.

This chapter consists of a brief summary of what operations research can do, part II of literature review on productivity planning, development of a strategic productivity management program and the, introduction of a Total Operational Productivity Planning (TOPP) model for manufacturing industries. The major objective of this new model are also addressed.

6.1 Applicability of Operations Research

During World War II, the military management in England called on a team of scientists to study the strategic and tactical problems associated with air and land defence of the country. Their objective was to determine the most effective utilization of limited military resources. The establishment of this scientific team is considered by many to mark the first formal, interdisciplinary operations research activity.

Operations research can be defined as a scientific approach to decision making involved in the operation of organizational system (Hillier and Lieberman, 1974). It can be of great help to "management" in pointing out solutions to organizational problems. Typical applications of operation research include:

1. Constructing mathematical, economical and statistical descriptions or models of decision and controlling problems to treat situations of complexity and uncertainty.
2. Analyzing the relationships that determine the probable future consequences of decision choices, and devising appropriate measures of effectiveness in order to evaluate the relative merit of alternative actions.

Because of the characteristic scientific approach to problem-solving and the ability to find the desired or optimal solution to the problem under study, operation research techniques have the following advantages, as outlined by Wagner (1975).

1. Better decisions are featured to provide actions

that do improve on intuitive decision-making.

2. Better coordination is formulated to bring order out of chaos.
3. Better control is provided to supervise the routine decisions for the executives, who can thereby devote their attention to more pressing matters.
4. Better systems are established to analyze decision problems.

The diversity of OR applications to problem-solving is very large. Ignizio (1982) gives a list of actual implementations of linear programming. Among the applications encountered with single and multiple objective functions are: diet problems, cutting stock problems, production scheduling and inventory control problems, blending problems, routing and assignment problems as well as energy models and planning. Dynamic programming has been successfully applied to areas such as planning advertising expenditures, distributing sales efforts, capital budgeting and production scheduling. Queueing theory has major applications in traffic control, inventory control, optimal allocation of leased communications, time-shared computer operations with variable inter-arrival and service times, personnel planning in shopping centers, machine interference problems and, recently, flexible manufacturing systems. Nonlinear programming has stimulated the use of systematic approaches to problem-solving because of the rapid increase in the size and complexity of problems as a result of technological growth. The major applications of nonlinear programming include : optimal control, structural design, mechanical design, electric networks, water resource management, stochastic resource allocation and location of facilities as discussed by Bazaraa and Shetty (1979). Other techniques of operations research, such as inventory theory, game theory and simulation also have been successfully applied in a variety of situations.

Recently, the efforts of management and industrial engineers have been concentrated on utilizing various mathematical models used to improve the investment in plant and equipment, planning, measurement and prediction of future productivity at manufacturing levels. In the next section, we will explore some work related to productivity planning using mathematical models.

6.2 Part II : Review of Literature on Productivity Planning

Gilmore and Gomory (1963) are the pioneers of optimizing productivity of material usage. They showed a stock cutting problem in the paper industry that under given circumstances minimizes the ratio of wasted to useful amounts of raw material instead of just minimizing the amount of wasted material. Their stock cutting problem is formulated as a linear fractional program.

Orrbeck et. al (1968) studied the effect of worker productivity as an extension of the Hanssmann and Hess (1960) model, which presents a linear programming formulation of the aggregate planning problem. The cost elements considered in the Hanssmann-Hess model are regular payroll costs, overtime pay, costs of hiring and firing workers, and storage and shortage costs. The problem addressed is how to choose production and employment patterns in order to minimize the sum of the total relevant costs within the planning horizon. They assumed that each employee can produce exactly the same amount in a time period. Orrbeck et al drop this assumption and add the assumption that workers are assumed to have increasing labour productivity rates. Ebert (1976) proposed an aggregate planning model to labour productivity. The improvement in comparison to Orrbeck et al is due to the use of an "improvement" learning curve analysis in his aggregate planning. This model is formulated as a nonlinear programming problem, where the decision variables include the work force, production rate, constant productivity factor (output/month), other statistically estimated coefficients from accounting data, and inventory status. In this model the productivity factor in each period in the planning horizon is based on the cumulative production quantity.

Khoshnevis and Wolfe (1983) developed a methodology whereby productivity (production/work force) changes over time can be incorporated into an aggregate planning model. They also assumed that productivity increases as the cumulative output of the firm increases. However, changes to the work environment such as design changes and work force changes can cause a disruption in this productivity improvement. A heuristic procedure is developed to solve the problem by three routines which they call: PAT, PROCTV and FCT1. The PAT routine generates a sequence of levels for the decision variables for every period in the planning horizon and the PROCTV routine utilizes the information generated by PAT to generate unit cost curves applicable for each time period throughout the planning horizon. The FCT1 routine receives the information generated by PROCTV and forms the updated structure of the objective function.

Mo (1984) applied goal programming to allocate the major input resources of electric utilities so that a certain desired percentage growth in multifactor productivity as well as the satisfaction of customers' demands are met.

Sumanth (1984) proposed five forecasting methods for estimating short-term productivity level in the future, which are: Weighted partial productivity, productivity evalution tree, linear trend, comparative productivity evalution and seasonal variation model. Sink (1985) developed an eight-steps productivity management program planning process that includes : internal strategic audit, external strategic audit, planning premises, strategic planning, prioritization , consensus, identification, tactical and operational action programs, resource allocation and program review. Edosomwan (1986) developed a comprehensive productivity planning program as a continuous process consisting of four interrelated stages : productivity planning appraisal, strategic productivity planning, tactical productivity planning and operational productivity planning.

From the brief review of applicable mathematical models presented in this section, it appears that most efforts have been directed either towards only production planning or only towards resource allocation, rather than dealing with both of these factors simultaneously. Most of the mathematical models deal with maximizing profit or minimizing costs through the use of production functions derived from econometric studies based on classical economic theory. The planning of the Productivity measurement function should, however, be based on both costs and production function simultaneously. After considering the various techniques available, we believe that linear fractional (ratio) programming appears to be the most appropriate and powerful technique for handling complex decision problems involved in planning and improving the Total Operational Productivity measures. This will be described next.

6.3 Fractional programming approach:

The concept of Linear Fractional Programming was first introduced by Isbell and Marlow (1956) as a tool to resolve a class of nonlinear programming problems by generating a finite sequence of linear programming problems whose solutions are convergent.

The following optimization problem is called a fractional program :

$$[P] \quad \text{Max} \left\{ q(x) = \frac{n(x)}{d(x)} \quad x \in S \right\} \qquad (6.1)$$

where,

$$S = | \ x \in R \quad | \ A(x) \leq b, \quad x \geq 0 \ | \qquad (6.2)$$

and S is a nonempty and bounded set.
Different types of fractional programs can be distinguished by various functions of [P] :

a. [P] is called a linear fractional program if all functions n(x), d(x) and A(x) are affine, i.e. a summation of linear functions and constants.

b. [P] is called a quadratic fractional program if n(x) and d(x) are quadratic functions and A(x) are affine.

c. [P] is called a concave-convex fractional program if n(x) is concave and d(x) as well as A(x) are convex.

Solutions of the linear fractional problem (a) have been obtained by Isbell and Marlow (1956), Charnes and Cooper (1962), Dinkelbach (1963), Martos (1964), and many others. There are four methods available for solving linear fractional programming problems. These methods are:

a. <u>Primal algorithm</u>: The first one was given by Gilmore and Gomery (1963), then by Martos (1964), and Swarp (1965):

$$q(x) = \text{Max} \quad \frac{C^t x + \alpha}{d^t x + \beta} \qquad (6.3)$$

Subject to

$$Ax \leq b \qquad (6.4)$$

$$x \geq 0 \qquad (6.5)$$

This problem is solved by carrying along a few extra rows and columns in the simplex tableau used to solve the regular linear programming problem. Further details may be found in Martos (1964).

b. Dual Algorithm : Dorn (1962), Swarp (1968), Kydland (1972), Bector (1973) and Patkar (1985) have shown how to solve the dual problem of the primal problem expressed in Equation (6.1). The dual problem to the primal problem (6.1) can be expressed as :

$$\text{Min} \quad Z \qquad (6.6)$$

Subject to

$$A^t u + dz \geq c \qquad (6.7)$$

$$b^t u \leq 0 \qquad (6.8)$$

$$u \geq 0 \qquad (6.9)$$

Some solution procedures to the dual problem begin the same way as used in Lemk's dual simplex approach. First choose an extreme point of the feasible set of the dual problem which is selected as one would for the primal problem. The primal variables u are then calculated and their signs are checked. If one or more have a negative value, optimality has not been achieved and extreme point of the dual feasible set must be tried next. This procedure is continued until $u_i \geq \forall . i \geq 0$

c. Parametric Algorithm: Marlow (1956), Isbell(1963), Joksch (1964), Jagannathan (1966) and Anzai (1974) developed a parametric method to solve linear fractional programs. Let us adopt the following formulation (Dinkelbach, 1963) :

$$F(x,q) = (c^t x + \alpha) - q(d^t x + \beta) \tag{6.10}$$

where q is a parameter that can take on any value on the real line. We first

(i) generate an extreme point of the set x, say x^o and set $k = 1$

(ii) then compute

$$q_{k-1} = \frac{c^t x^{k-1} + \alpha}{d^t x^{k-1} + \beta} \tag{6.11}$$

(iii) then solve the following linear programming problem :

$$\max_{x \in X} \left| (c^t X + \alpha) - q_{k-1} (d^t X + \beta) \right| \tag{6.12}$$

calling this solution x^k.

$$\text{If } F(x^k, q_{k-1}) = 0 \quad \text{stop} \tag{6.13}$$

Otherwise go to step (ii).

4. Transformation Method : Charnes and Cooper (1962) obtained the linear programming problem equivalent to the

linear fractional programming (P) by

Let $$Y = t\,x \tag{6.14}$$

where $t > 0$ and is chosen such that

$$d^T Y + \beta t = \gamma \tag{6.15}$$

and γ is a specified number different from zero. With the above transformation, they write the primal problem [P] as:

$$\text{Max } c^T Y + \alpha t \tag{6.16}$$

Subject to

$$A Y - bt \leq 0 \tag{6.17}$$

$$d^T Y + \beta t = \tag{6.18}$$

$$Y, \quad t \geq 0 \tag{6.19}$$

Charnes and Cooper (1962) have shown that every feasible solution (Y,t) for $t > 0$ should exist. They also proved if x^* is an optimal solution to the primal problem, then t^*, Y^* is an optimal solution for the [P] problem.

Bitran and Navaes (1973) presented an algorithm, based on the simplex method to solve linear fractional programming problems by transformation of the nonlinear objective function to a linear one and solving the problem without adding any new constraints or variables. The steps are :

1. Solve the problem

$$\text{Max } L = f(\nu, X)$$

Subject to

$$AX \leq b$$
$$X \geq 0$$

In which $\nu = \alpha - [(\alpha, \beta) / (\beta, \beta)] \beta$

2. Solve the problem

$$\text{Max } F' = \{[\alpha - L(X^{*}) \beta], X\}$$

Subject to the same constraints . This will lead to a new feasible solution X^{**} .

3. Compare X^{**} with X^{*} . If $X^{**} = X^{*}$, then X^{*} is the global optimum solution, otherwise go to step 2.

From all the methods discussed, the transformation method seems to be the most useful in our research, because of its efficiency of computer usage and adaptability to the solution of linear programming problem. These advantages make it very attractive for the solution of the productivity planning model as formulated in this chapter.

By using the features of the linear fractional programming approach, and its capability of handling ratios in the objective function with linear constraints, we are able to provide a means to obtain a valid productivity planning measure for an industry or company, based empirically on the desired output from their resource input. We present this in the following sections.

6.4 Productivity Management Strategy Program (PMSP):

A PMSP is a flow chart of specific actions. It indicates which actions can be done first, and what their contribution at each stage can be to the company or industry in terms of productivity benefit. We first have to consider productivity measurement indicators of stage one and we have done so in detail in Chapter IV. Next, one must consider productivity or production goals of stage two including the setting of the planning horizon, desired outcomes, scope of production, and interfaces with other performance measures. Usually these goals are established in order to maximize profit, provide better customer satisfaction, and minimize total cost. Corporate management has the ultimate responsibility for the productivity of an organization, and thus must provide a clear articulation of the company's goals and requirements. The third stage, that of productivity planning is the main interest of this chapter. We will explain this stage in detail in the following sections. The fourth stage of productivity improvement includes the development and implementation of the productivity planning policy. The improvement area encompasses five broad components which are : human resources availability, quality, technological advancement and capital investment, materials and supplies, and process and methods engineering techniques.

From stage four, we go back to the first stage to evaluate the productivity measurement indicators. The aim of PMSP is to indicate the direction that must be followed to achieve maximal corporate productivity improvement and to monitor the progress achieved in that direction due to the use of new technologies and techniques. The PMSP flow chart is shown in Figure (6.1).

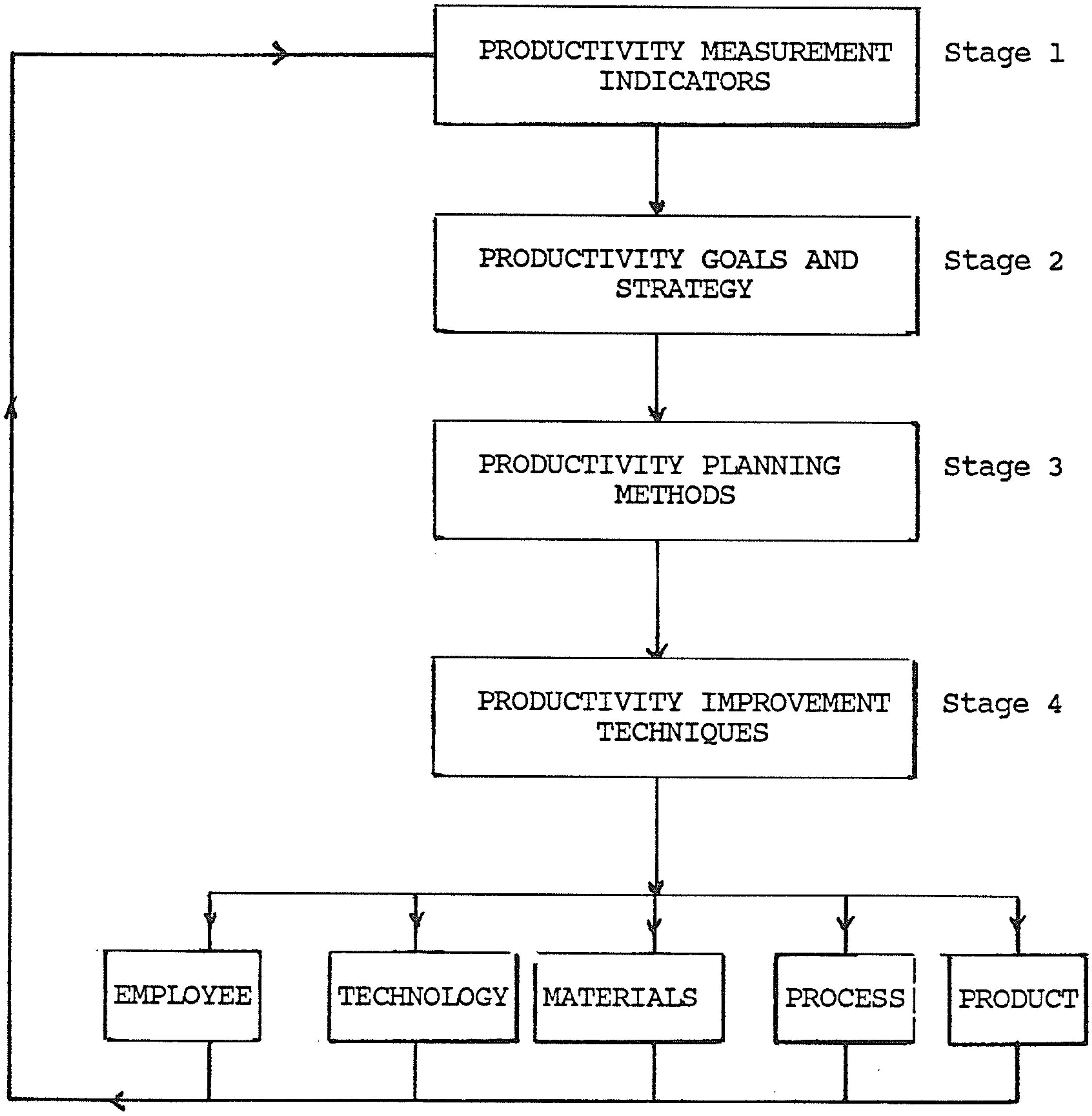

Figure 6.1 The Productivity Management Strategy Program for a manufacturing industry.

6.5 Total Operational Productivity Planning mathematical model:

We define Total Operational Productivity Planning as "the managerial tool for the prediction of the future allocation of total input consumption required and total output value that can be achieved under existing plant capacity conditions of an industry, that will maximize the Total Operational Productivity for the planning or target period". Productivity planning strategies are the possible options that managers have to choose from to tackle productivity improvement as shown in Figure (6.2). Selecting the appropriate strategy is a function of the opportunities and constraints as perceived by management in their operating environment. It is obvious that the best strategy is to increase the output and decrease the input and that following such a strategy will necessarily lead to increased profit as well as productivity. There is a need to develop appropriate and efficient mathematical models that will assist strategic decision-making by highlighting the contribution of specific decisions to productivity enhancement.

We propose the subsequent nonlinear programming formulation (fractional programming) for this purpose:

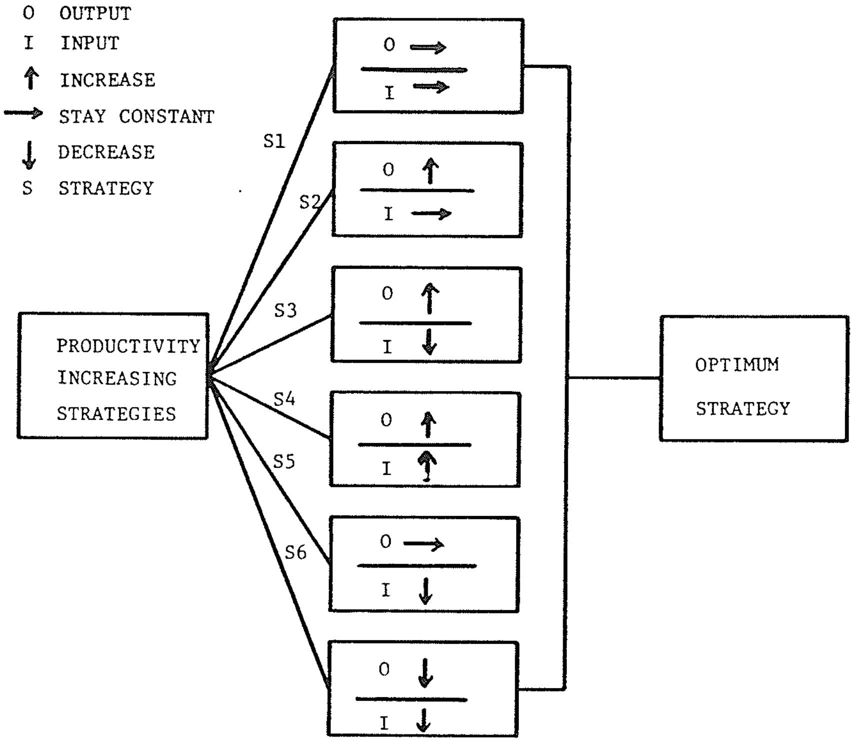

Figure 6.2 productivity improvement options.

6.5.1 Glossary of Symbols used in The Model Formulation:

i = Type of industry or group of industries ($i = 1,2,..I$)

t = Planning horizon in years ($t = 1,2,..,T$)

k = Output elements ($k = 1,2,....K$)

j = Major input elements (human resources ($j=1$), capital ($j=2$), material ($j=3$), energy($j=4$), and other costs ($j=5$).

ℓ = Elements of major input factors ($\ell = 1,2,.....L$)

Y_{ikt} = Output value in dollars

$X_{ij\ell t}$ = Input cost in dollars

TOP_{it} = Total operational productivity measure in industry i at time t.

$TOPI_{it}$ = Total operational productivity index in industry i at time t.

Y_{i1t} = Selling value of shipment of goods in industry i at time t.

Y_{i2t} = Revenue from repair in industry i at time t.

Y_{i3t} = Work done on material owned by others in industry i at time t.

Y_{i4t} = Other income in industry i at time t.

X_{i11t} = Total cost of employees in manufacturing operations in industry i at time t.

X_{i12t} = Cost of other production workers in industry i at time t.

X_{i13t} = Cost of executive staff in industry i at time t.

X_{i14t} = Cost of sales staff in industry i at time t.

X_{i15t} = Cost of administration in industry i at time t.

X_{i21t} = Consumption cost of machinery and equipment in industry i at time t.

X_{i22t} = Consumption cost of building construction in industry i at time t.

X_{i23t} = Consumption cost of engineering construction in industry i at time t.

X_{i24t} = Consumption cost of capital items charged to operating expenses in industry i at time t.

X_{i31t} = Cost of raw materials in industry i at time t.

X_{i32t} = Cost of purchased materials used in industry i at time t.

X_{i33t} = Total cost of maintenance and repair supplies in industry at time t.

X_{i41t} = Cost of coal and coke in industry i at time t.

X_{i42t} = Cost of electricty purchased in industry i at time t.

X_{i43t} = Cost of gasoline in industry i at time t.

X_{i44t} = Cost of diesel oil in industry i at time t.

X_{i45t} = Cost of light fuel oil in industry i at time t.

X_{i46t} = Cost of heavy fuel oil in industry i at time t.

X_{i47t} = Cost of natural gas in industry i at time t.

X_{i48t} = Cost of other fuel including steam, consumed in in industry i at time t.

X_{i51t} = Cost of travel expenses in industry i at time t.

X_{i52t} = Cost of research and development in industry i at time t.

X_{i53t} = Cost of marketing and advertising in industry i at time t.

C_{it} = The capacity of industry i at time t.

t-1 = the previous period .

δ = fraction of change in employment $1 > \delta > 0$.

6.5.2 The objective function:

The definition of Total Operational Productivity is known from Equation (4.1). In order to achieve a certain percentage of increase in TOP for the next period, the objective function is expressed as

$$\text{MAX } TP_{it} = \frac{\sum_{k=1}^{K} Y_{ikt}}{\sum_{j=1}^{J} \sum_{\ell=1}^{L} X_{ij\ell t}} \qquad (6.20)$$

$i = 1,2,\ldots\ldots,I$

$t = 1,2,\ldots\ldots,T$

This objective function is subject to the constraints discussed below.

6.5.3 Total Operational Productivity Index constraint:

By definition, from Equation (4.3)

$$TOPI_{it} = \frac{TOP_{it}}{TOP_{it-1}}$$

Also, we know that $(TOP_{it-1})/(TOP_{it-1}) = 1$

In order to achieve a certain percentage increase in $TOPI_{it}$, TOP_{it} has to be greater than TOP_{it-1}, or

$$\frac{TOP_{it}}{TOP_{it-1}} \geq 1$$

By direct substitution for TOP_{it}

$$\frac{\sum_{k=1}^{K} Y_{ikt}}{\sum_{j=1}^{J} \sum_{\ell=1}^{L} X_{ij\ell t}} \geq TOP_{it-1}$$

By rearranging the above equation, we obtain an overall constraint

$$\left(\sum_{k=1}^{K} Y_{ikt} \right) / \left(TOP_{it-1} \right) - \left(\sum_{j=1}^{J} \sum_{\ell=1}^{L} X_{ij\ell t} \right) \geq 0 \qquad (6.21)$$

6.5.4 Output constraints:

It is clearly desirable to increase the total output more than the input in the total operational productivity function within the productive capacity limitation of the industry concerned. Based on this, the output constraints are:

$$\sum_{k=1}^{K} Y_{ikt} \geq \sum_{k=1}^{K} Y_{ikt-1} \qquad (6.22)$$

and, since the output value is finite and limited to the capacity of the industry,

$$\sum_{k=1}^{K} Y_{ikt} \leq C_{it} \qquad (6.23)$$

$i = 1,2,.....,I$

$t = 1,2,.....,T$

6.5.5 Human resources constraints:

The problem of production and employment scheduling may be stated as : given a range of production output required, what should be the work force level costs in order to minimize the total cost of production? The following constraints are assumed:

(i) The total cost of human resource inputs for the planning period should be less than or equal to the total cost of human resources input in the previous period.

$$\sum_{\ell=1}^{L} X_{il\ell t} \leq \sum_{\ell=1}^{L} X_{il\ell t-1} \qquad (6.24)$$

(ii) Since one could, in essence reduce employment (human input) to nearly zero (e.g. Automated Factory of the Future), consideration should be given by enlightened management to sociological and other implications of its productivity improvement decisions. Hence, we suggest that the decision-maker limit the social impact of his human input to within a factor δ that reflects the existing state of " unemployment" within the national context.

$$\sum_{\ell=1}^{L} X_{il\ell t} \geq (1 - \delta) \sum_{\ell=1}^{L} X_{il\ell t-1} \qquad (6.25)$$

$$\sum_{\ell=1}^{L} X_{il\ell t} \leq (1 + \delta) \sum_{\ell=1}^{L} X_{il\ell t-1} \qquad (6.26)$$

and $0 \leq \delta \leq 1$ (typically 4-12 % for Western Countries).

6.5.6 Capital consumption constraints:

Due to the properties of the total Operational Productivity model (4.1), and the difficulty of measuring capital input,

it is assumed that capital consumption for the next year should be more efficient than for the previous year, as expressed in the following constraints :

$$\sum_{\ell=1}^{L} X_{i2\ell t} \leq \sum_{\ell=1}^{L} X_{i2\ell t-1} \qquad (6.27)$$

and

$$\sum_{\ell=1}^{L} X_{i2\ell t} \geq \frac{C_{it} - C_{(sal)i}}{n} \qquad (6.28)$$

Where C_{it} is the initial capital, C_{sal} is the salvage value and n is the economic life of the capital up to t years.

6.5.7 Material and supplies constraints:

The materials and supplies input represents a large part of the total production input in an industry such as the steel industry, and the metal fabricating industry.

For example, the effect of stock length on the percent of raw material waste is a question of considerable practical importance. All companies that have to cut new materials to appropriate sizes, sometimes control the percent waste either through raw materials size / shape or by more efficient pattern utilization.

The "supplies" component is often considered as part of the transportation problem. For the productivity planning problem, the material and supplies input factor constraints can be expressed by :

$$\sum_{\ell=1}^{L} X_{i3\ell t} \leq \sum_{\ell=1}^{L} X_{i3\ell t-1} \qquad (6.29)$$

If the standard consumption of materials and supplies is set by the engineering department, then

$$\sum_{\ell=1}^{L} X_{i3\ell t} \geq \sum_{\ell=1}^{L} X_{i3\ell ts} \qquad (6.30)$$

Where s refers to the standard consumption of $X_{i3\ell t}$.

6.5.7 Energy constraints:

Energy is also an important component of the total operational productivity function . Rapidly increasing prices and dwindling supplies are like the twin jaws of a vice closing in on productivity. Energy planning models have gone through a series of developments in operations research techniques, specifically in linear programming formulations of the demand and supply problem. The energy input constraints have been assumed by us as follows :

$$\sum_{\ell=1}^{L} X_{i4\ell t} \leq \sum_{\ell=1}^{L} X_{i4\ell t-1} \qquad (6.31)$$

Since we cannot reduce the amount of energy needed to operate the industry to a zero value, a standard minimum amount of consumption should be allocated to this factor as a lower bound.

$$\sum_{\ell=1}^{L} X_{i4\ell t} \geq \sum_{\ell=1}^{L} X_{i4\ell ts} \qquad (6.32)$$

Here s refers to the standard amount of consumption.

6.5.8 Other Costs constraints :

Even though the costs of travel, taxes, and research and development in operating and production are less important than the amount of the other four inputs, they must be considered. These costs are dependent on the other four major inputs. In fact, all input factors are limited by the available funds.

The model developed in this section can be used to analyze how these input resources and the production and service output should be allocated and utilized respectively so that the total operational productivity can be increased by a certain percentage subject to the engineering standards and funds available.

6.5.9 Productivity planning goals :

Some of the major goals of this particular model as formulated for manufacturing industries may be listed as follows:

1. To achieve constant rate of total operational productivity growth.
2. To maximize the efficiency of the output produced.
3. To maintain a constant employment rate within socially acceptable bounds.
4. To minimize the quantity of material and supplies consumption input.
5. To minimize the cost of capital consumption input.
6. To minimize the cost of energy consumption input.

7. To minimize the expenses of the other costs.

Of course, once these goals are established, the profit will be increased because the revenue will be growing faster than the total cost to the industry .

Before we proceed to the solution, the model must meet the following requirements :

1. The objective function must be in a linear fractional programming form.
2. The constraints must all have linear relationships.
3. The output and input factors must be deterministic.
4. The operation of the industry is under " normal" conditions.

CHAPTER VII

A CASE STUDY OF THE FRACTIONAL PROGRAMMING MODEL

The Total Operational Productivity Planning model introduced in Chapter VI is solved by the transformation algorithm developed by Charnes and Cooper (1962) and Bitran and Navaes (1973). For the first algorithm, we used LINDO (Linear and Discrete Optimizer) an interactive programming system written by Lins Schrage of the University of Chicago. In the second algorithm, we have written a TURBO PASCAL program which can be used on variety of microcomputers using PCDOS, MSDOS, CP/M-86, or CP/M-80 operating system. In addition the program would be able to use the Intel 8087 math coprocessor for additional computional power. The simplification of the initial problem, the results, and the discussion are also presented in this Chapter.

7.1 Input Data:

The TOPP model can be used for long-range planning of output and input allocation with the objective of achieving a certain percentage growth in total operational productivity. However, for the sake of our demonstration and due to the limited of data available, a number of restrictions are assumed as follows:

1. The planning period is assumed to be one year, i.e. 1983.
2. A variety of companies are grouped together as per

classification by Statistics Canada, i.e. Metal fabricating industries (group number 13).

3. There are five types of inputs (Human, Capital, Materials, Energy and Other Costs).
4. The output is the sum of all finished goods sold and other income as specified in output elements.
5. The employment factor assumed is based on the unemployment figures in Canada.
6. The lower bounds of inputs are estimated according to forecasting analysis. In the case of small companies, standard data can be easily obtained by human factor engineering methods and accounting department data.

Originally the model contained 28 constraints and 40 variables. With the above assumptions, the model will have only 13 constraints and 7 variables. Using this reduced model, some precision is bound to be lost, e.g., the actual amount of some input elements. However, the model objective is to check the change and sensitivity of the aggregate data to productivity growth, and thus this simplification is acceptable.

As an illustrative example, this reduced model is valid to show the capability of fractional programming when used as a tool for productivity planning. In real practice, this model can give nation-wide insight into productivity planning.

We can write the full model as follows:

$$\text{Maximize } P = \frac{\sum_{k=1}^{4} Y_{ikt}}{\sum_{J=1}^{5} \sum_{\ell=1}^{L} X_{ij\ell t}} \tag{7.1}$$

Subject to

$$\left(\sum_{j=1}^{5} \sum_{\ell=1}^{L} X_{ij\ell 1} \right) \left(TOP_{10} \right) - \left(\sum_{k=1}^{4} Y_{ik1} \right) \leqq 0 \tag{7.2}$$

$$\sum_{k=1}^{4} Y_{1k1} \geqq \sum_{k=1}^{4} Y_{1k0} \tag{7.3}$$

$$\sum_{k=1}^{4} Y_{1k1} \leqq C_{11} \tag{7.4}$$

$$\sum_{\ell=1}^{L} X_{11\ell 1} \geqq (1-\delta) \left(\sum_{\ell=1}^{L} X_{11\ell 0} \right) \tag{7.5}$$

$$\sum_{\ell=1}^{L} X_{11\ell 1} \leqq (1+\delta) \left(\sum_{\ell=1}^{L} X_{11\ell 0} \right) \tag{7.6}$$

$$\sum_{\ell=1}^{L} X_{12\ell 1} \leqq \sum_{\ell=1}^{L} X_{12\ell 0} \tag{7.7}$$

$$\sum_{\ell=1}^{L} X_{12\ell 1} \geqq \sum_{\ell=1}^{L} X_{12\ell s} \tag{7.8}$$

$$\sum_{\ell=1}^{L} X_{13\ell 1} \leqq \sum_{\ell=1}^{L} X_{13\ell 0} \qquad (7.9)$$

$$\sum_{\ell=1}^{L} X_{13\ell 1} \geqq \sum_{\ell=1}^{L} X_{13\ell s} \qquad (7.10)$$

$$\sum_{\ell=1}^{L} X_{14\ell 1} \leqq \sum_{\ell=1}^{L} X_{14\ell 0} \qquad (7.11)$$

$$\sum_{\ell=1}^{L} X_{14\ell 1} \geqq \sum_{\ell=1}^{L} X_{14\ell s} \qquad (7.12)$$

$$\sum_{\ell=1}^{L} X_{15\ell 1} \leqq \sum_{\ell=1}^{L} X_{15\ell 0} \qquad (7.13)$$

$$\sum_{\ell=1}^{L} X_{15\ell 1} \geqq \sum_{\ell=1}^{L} X_{15\ell s} \qquad (7.14)$$

$$Y_{ikt},\ X_{ij\ell t} \geqq 0 \quad \text{for} \quad \begin{aligned} J &= 1,2,\ldots\ldots\ldots,5. \\ k &= 1,2,\ldots\ldots\ldots,4. \\ \ell &= 1,2,\ldots\ldots\ldots,L \end{aligned}$$

The above formulation of the model involves a nonlinear programming problem. As Charnes and Cooper (1962) showed, it may be replaced by an ordinary linear programming problem by means of the theory of linear fractional programming. We do not repeat that development here, but merely replace the above formulation by the following:

Let $Z = g$ (X's or Y's)

$g \geq 0$ such that

$$\sum_{j=1}^{5} \sum_{\ell=1}^{L} X_{ij\ell 1} \cdot Z = \gamma \qquad (7.15)$$

γ is a specified positive number assumed by the user.

On multiplying numerator and denominator and the system inequalities in equations (7.2) to (7.14) by g and taking equation (7.15) into account, we obtain the linear programming formulation

$$\text{Maximize} \quad P = \sum_{k=1}^{4} Z_{1k1}$$

Subject to

$$(TOP_{10})(Z_{111} + Z_{121} + Z_{131} + Z_{141} + Z_{151}) - \sum_{k=1}^{4} Z_{1k1} \leqslant 0$$

$$\sum_{k=1}^{4} Z_{1k1} - g.Z_{1k0} \geqslant 0$$

$$\sum_{k=1}^{4} Z_{1k1} - gC_{11} \leqslant 0$$

$$Z_{111} \quad -g.(1-\delta)Z_{110} \geqslant 0$$

$$Z_{111} \quad -g.(1+\delta)Z_{110} \leqslant 0$$

$$Z_{121} \qquad -g.Z_{120} \leqslant 0$$

$$Z_{121} \qquad -g.Z_{12s} \geqslant 0$$

$$Z_{131} \qquad -g.Z_{130} \leqslant 0$$

$$Z_{131} \qquad -g.Z_{13s} \geqslant 0$$

$$Z_{141} \qquad -g.Z_{140} \leqslant 0$$

$$Z_{141} \qquad -g.Z_{14s} \geqslant 0$$

$$Z_{151} \qquad -g.Z_{150} \leqslant 0$$

$$Z \qquad -g.Z \geqslant 0$$

$$Z_{111} + Z_{121} + Z_{131} + Z_{141} + Z_{151} = \gamma$$

$$Z_{ij1} , g, , Z_{1k1} \geq 0$$

$j = 1,2,....,5.$

$k = 1,2,..,4.$

The initial maximization problem [P] dealt with a ratio type of formulation. In order to provide a lower bound for all the denominators in the objective function, a number of methods are available to us from management and statistics literature. Such techniques include : budgetary constraints, standard work costs (Industrial engineering approaches, e.g. work time study and engineering economy), statistical estimation, forecasting analysis, projections, and finally heuristics method. In our case study, because of the nature of data is in aggregate form, a moving average forecasting method is applied in order to fill in the missing data collected from Statistics Canada Catalogues (various issues). However, if complete data is available for a specific company, a budget target can be identified from "company data accounting records which reflect the history of customer demands as well as production and control facilities available to the company. The relevant data for the case study is prepared in Table (7.1) for the year 1982 for Canadian metal fabricating industries.

7.2 Results and Discussion of the Case Study :

For the inputs and outputs presented in Table (7.1), we calculated the values of input and output components for the planning year 1983, the total operational productivity value and the percentage of changes in outputs and inputs. These are shown in Table (7.2).

The results indicate the following : If we decrease total human input by 7.5 %, capital input by 11.6 %, materials and supplies input by 21.7 %, energy input by 6.7 % and other costs input by 24.1 % and increase the total output by 53 %, the Total Operational Productivity will increase by 34 % for the next planning year. These results can be used as a useful guide line for the implementation of corporate productivity improvement budgeting systems. The rate of change in percentage from the current period to the planning period of the utilization of resources and possible output improvement are shown in Figures (7.1) through (7.7). Several conclusion can be drawn from the results of this fractional programming application to the Total Operational Productivity Planning :

1. The fractional programming technique has fully demonstrated its ability of reaching the optimal solution through the seven productivity planning objectives addressed in Chapter VI.
2. It provides a deterministic approach to the resource and output allocation problem simultaneously.
3. With the incorporation of Total Operational Productivity Planning objectives, TOP is assured to attain a certain percentage of growth, under the assumption that the allocations of the output and the input are utilized according to the initial data given.

Our proprietary computer program can also solve the nonlinear programming (fractional) problem in general, and the productivity problem as a special case directly, in a user friendly manner. The structure of the program and method of using it is presented in Appendix D.

Table 7.1 Output and Input data for the fractional programming model.

Categories	Value in Constant 10^6 1971 dollars
Output	4160.00
Capacity	7338.44
Total human input cost	542.59
Total materials and supplies consumption input	2483.09
Total energy consumption input	38.28
Total other costs input	40.00
Total capital input lower bound	117.316
Total material and supplies input lower bound	1933.733
Total energy input lower bound	35.53
Total other costs lower bound	30.20
Unemployment rate	8 %[a]
Total operational productivity	1.859

a = Percentage

Table 7.2 Total Operational Productivity and related elements values and indices for the current and planning period (1983).

		1982	1983
Total Operational Productivity	Value*	1.859	2.58
	Index	1.00	1.34
Total Output	Value	4167	6382.0
	Index	1.00	1.534
Human Input	Value	542.59	502.105
	Index	1.00	0.925
Capital Input	Value	134.00	118.8
	Index	1.00	0.884
Materials and Supplies input	Value	2483.09	1945.27
	Index	1.00	0.7834
Energy Input	Value	38.28	37.53
	Index	1.00	0.9334
Other Costs Input	Value	40.0	30.38
	Index	1.00	0.7595

* Expressed on 000,000 constant dollars = 1971

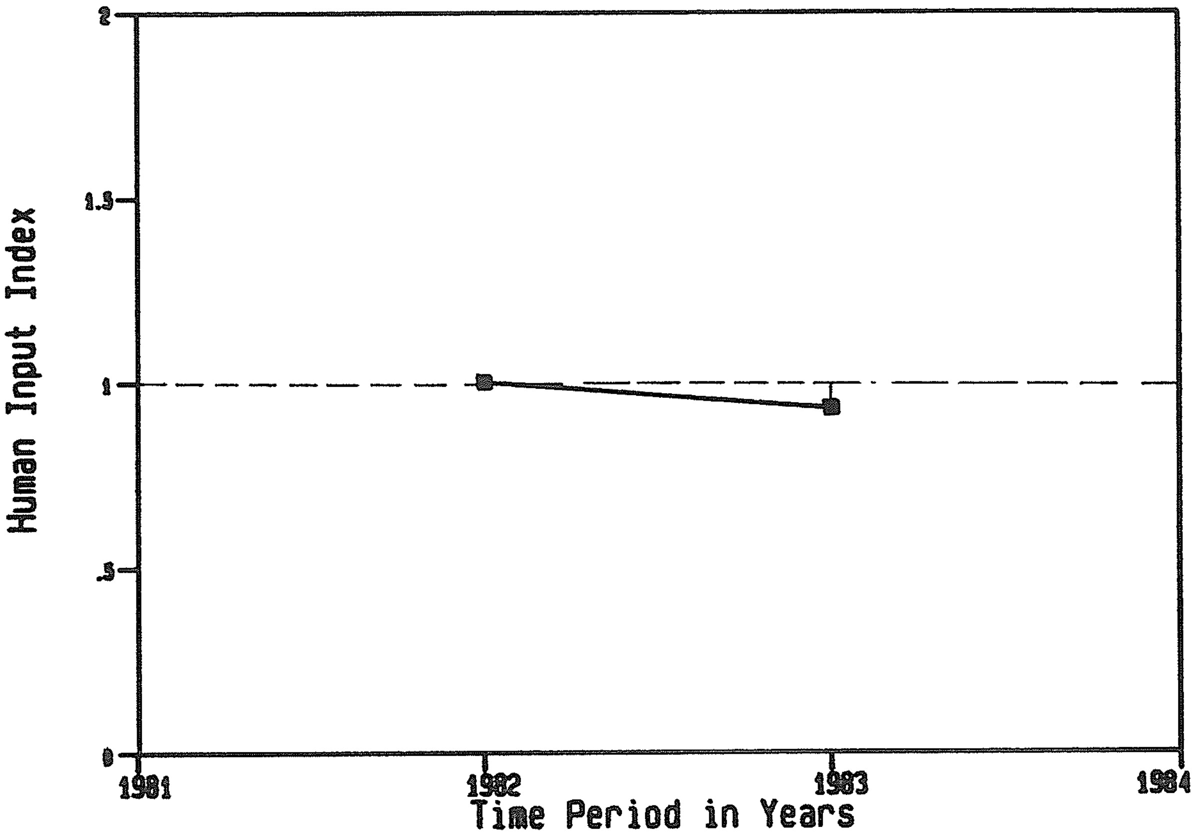

Figure 7.1 Human input indices for the current and planning periods in Canadian metal fabricating industries.

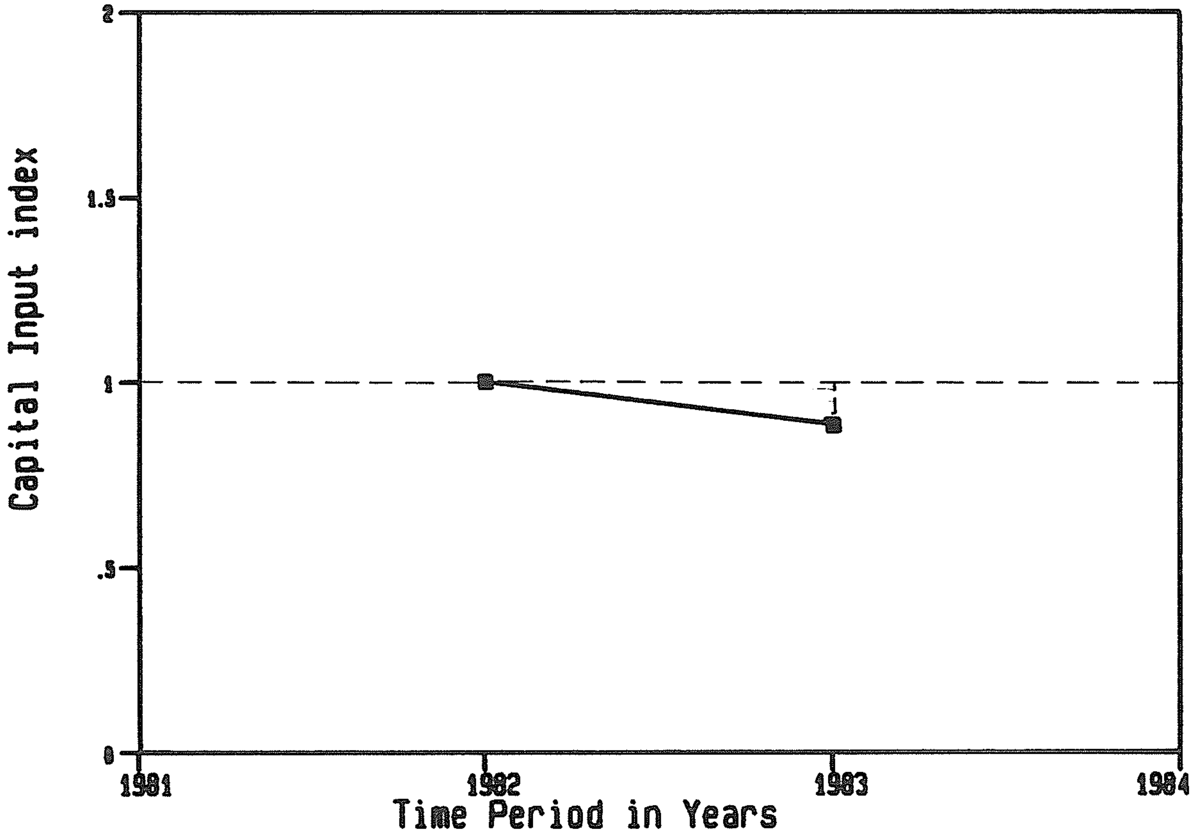

Figure 7.2 Capital input indices for the current and planning periods in Canadian metal fabricating industries.

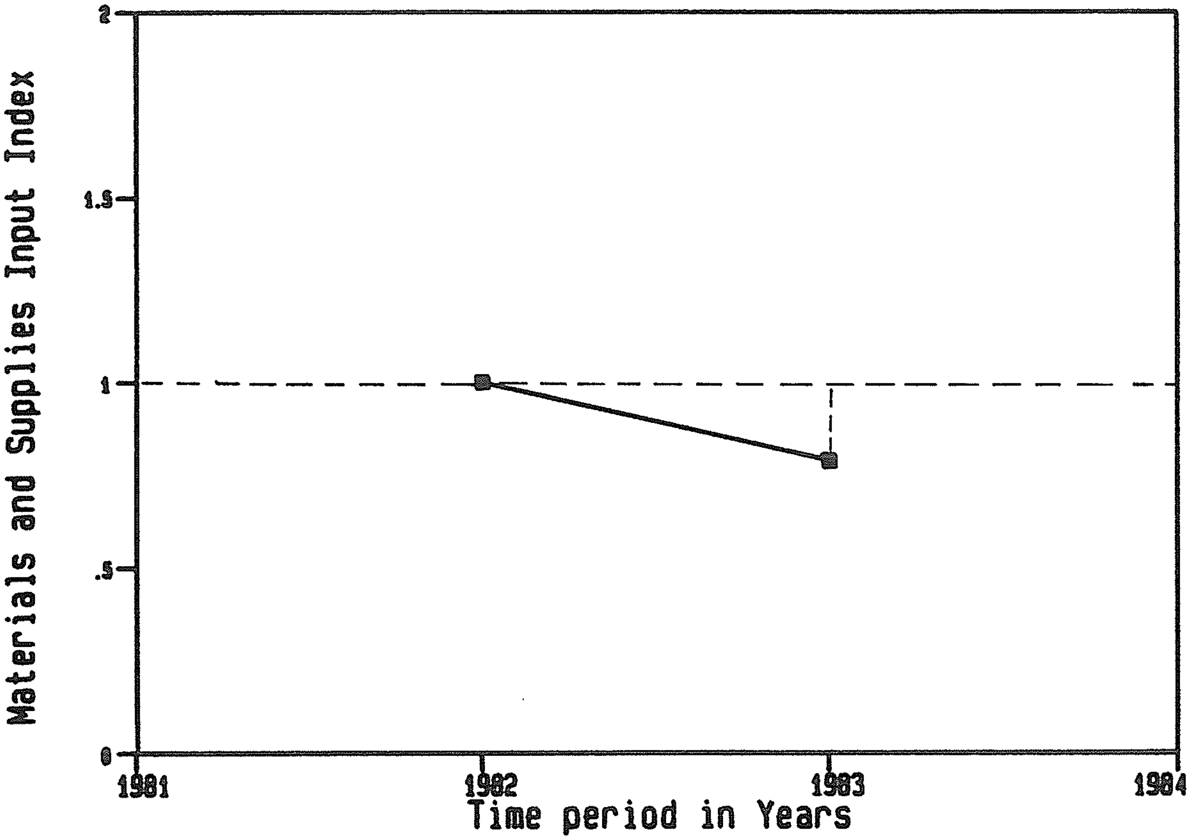

Figure 7.3 Materials and supplies input indices for the current and planning periods in Canadian metal fabricating industries.

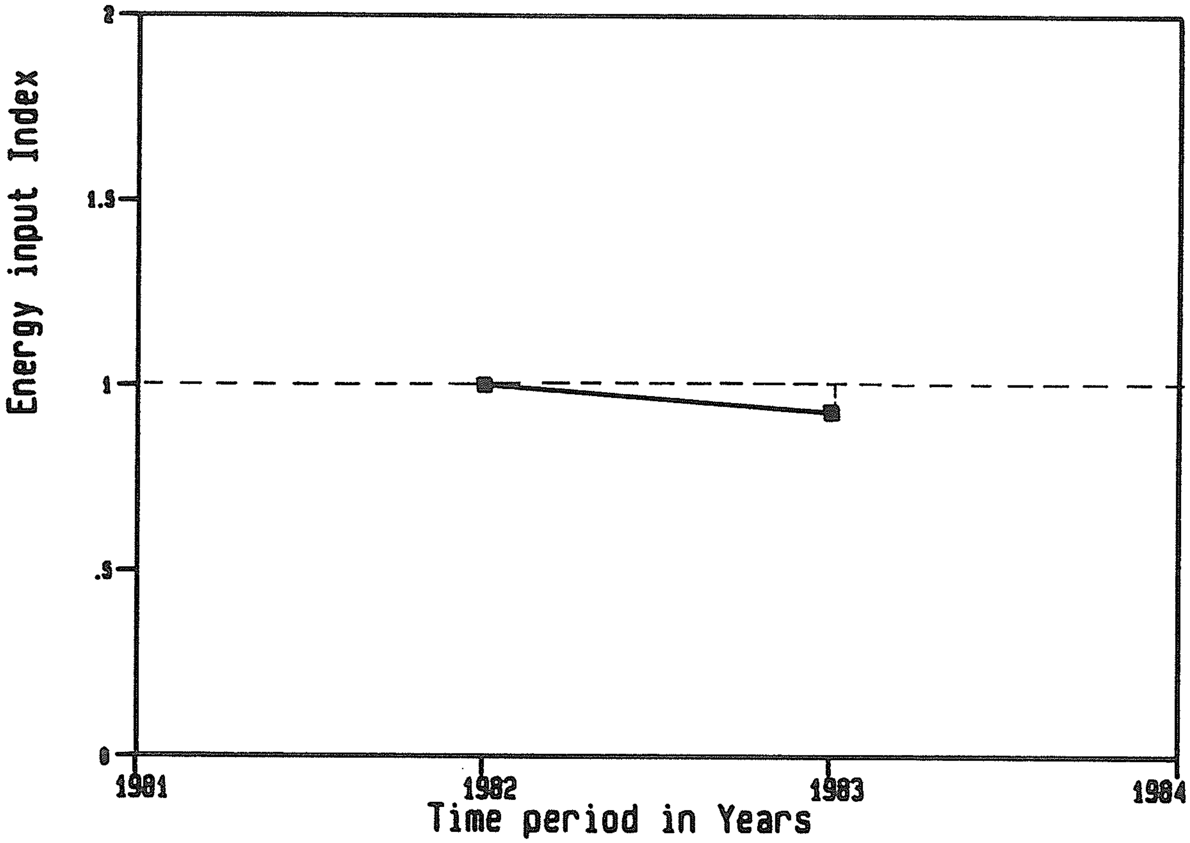

Figure 7.4 Energy input indices for the current and planning periods in Canadian metal fabricating industries.

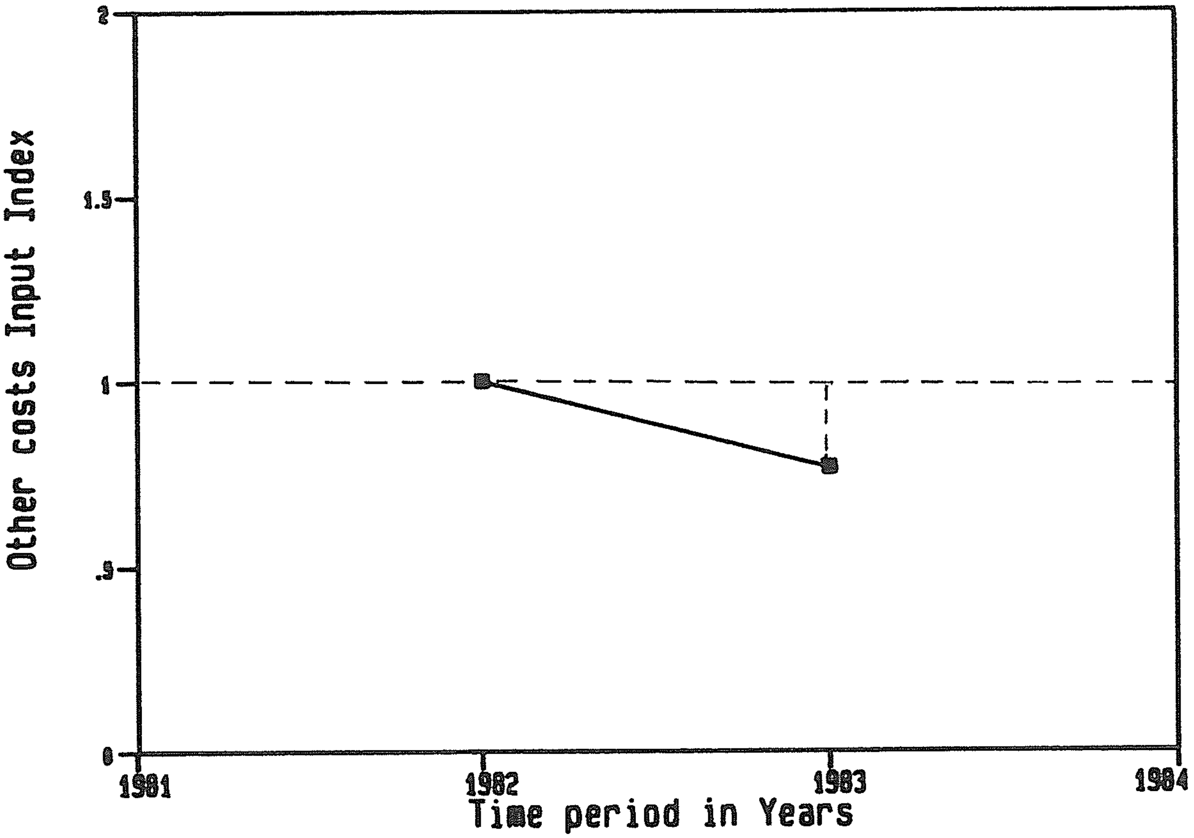

Figure 7.5 Other costs input indices for the current and planning periods in Canadian metal fabricating industries.

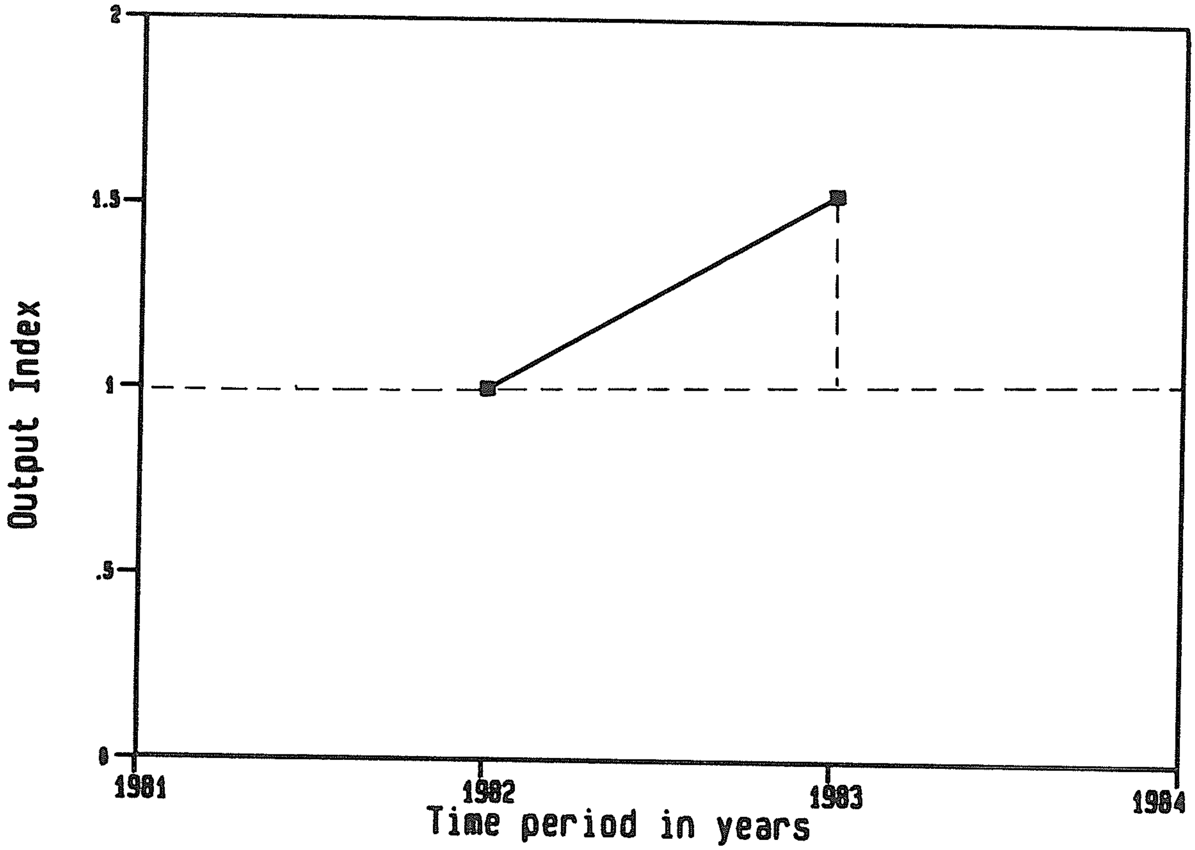

Figure 7.6 Total output indices for the current and planning periods in Canadian metal fabricating industries.

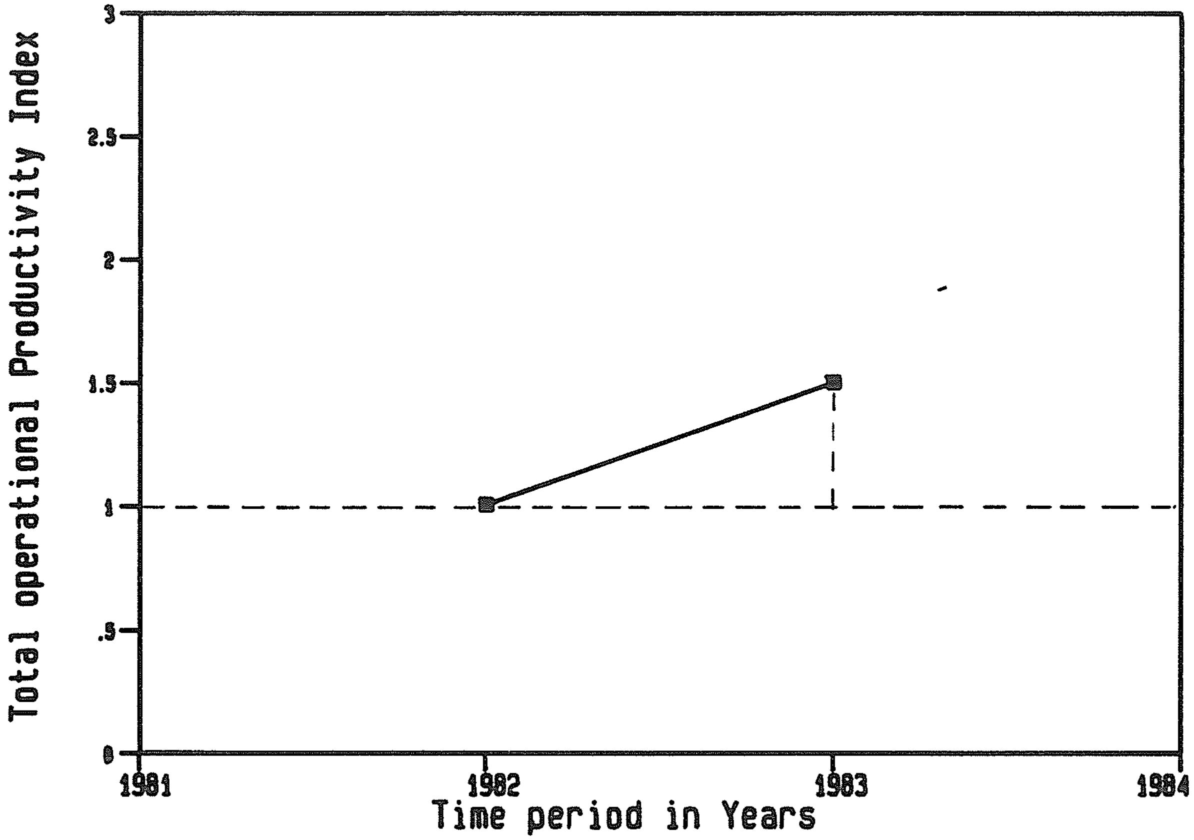

Figure 7.7 Total Operational Productivity Indices for the current and planning periods in Canadian metal fabricating industries.

CHAPTER VIII

SUMMARY, CONCLUSIONS AND RECOMMENDATION

This chapter consists of three sections : a summary of what has been accomplished, conclusions regarding the contributions of this research and the results obtained, as well as some recommendations for further study in this research area.

8.1.1 Summary of Reasearch Accomplishments:

In this research, a new Total Operational Productivity (TOP) measure and associated measures such as, Single Factor Operational Productivity (SFOP) and Multifactor Operational Productivity (MFOP) are developed for manufacturing industries, based on the total productivity measurement concept. Five main input factors in terms of constant dollars are considered at the corporate level of measurement. Four major output factors are measured also in constant dollars. A case study based on Canadian metal fabricating industries is presented to show the usefulness of the productivity measures developed .

Technological advancements are becoming increasingly important components in all areas of strategic planning and productivity improvement, particularly in the manufacturing sectors. A mathematical procedure is introduced to quantify and cluster the appropriate technological parameters by means of a novel Technology Factor Index (TFI) concept. The statistical relationship between TOP and TFI is investigated. A case study, applied to the same industrial data is used to show the workability of the procedures introduced.

Productivity planning or productivity enhancement is most likely to happen by reductions in the input requirement per unit of total output. It may also happen by either increasing the output and keeping the input unchanged, or keeping the output constant while decreasing the input in the productivity ratio. Since previous researches have failed to determine clearly these influences, we introduce an optimization approach to the Total Operational Productivity measure in a fractional programming formulation. The methods of solution have been implemented directly on the IBM pc using a micro computer program developed by us, and by transformation to a linear programming formulation (Charnes and Cooper, 1962) using the mainframe computer. A case study using the same industrial data is used to show the benefit of the methodology derived.

Three micro computer programs were developed to handle the computations of the solutions of all models proposed throughout this research.

8.1.2 Comparison with Previous Studies:

1. TOP focusses on the industrial level;
2. TOP provides a new definition of the total productivity concept at the operational level.
3. The Technology Factor Index (TFI) provides a new measurement

method for production variables incorporated in productivity measurement techniques.

4. The fractional programming planning model presents a new approach for allocating productivity components during the planning period.
5. Some components of the output and the input in the TOP measure are similar to the other total productivity models.
6. TFI and TOPP models are concepts new to productivity management literature.

8.2 Significance of this Research:

The main contributions resulting from this thesis are:

1. The new Total Operational Productivity concept has shown a unique features in regards to output and input factors, in terms of the total coverage of all production system components and their methods of measurement.
2. The new Total Operational Productivity measure shows significantly higher values than other existing total productivity measures for the same type of industries, (Figure 4.8). The author believe that TOP measure gives more realistic results.
3. The new Technology Factor Index (TFI) provides a simple method of clustering quantitative and qualitative variables used in production systems.
4. Through the establishment of the Technology Factor Index the multivariate relationship between output and input factors (Table 5.2) may be used as a valuable tool to

help management with better decisions in regards to productivity improvement by highlighting the real contributions to productivity resulting from the introduction and use of advanced technological production systems.

5. The Technology Factor Index shows a positive exponential relationship with the Total Operational Productivity measure in one industry throughout one planning horizon, (Figure 5.4). This supports conclusion (4).
6. The Total Operational Productivity Planning (TOPP) model allows the decision maker to determine the output and the input changes required for a given planning period, in order to achieve optimal productivity changes.
7. With the incorporation of the TOPP model, the Total Operational Productivity can be used to achieve a desired percentage of growth during the planning period, if the allocations of the output and the input are made by management according to the indications of the TOPP model. This reinforces conclusion (6).

8.3.1 Limitations of the Research Work:

Every research work has its limitation, and this research is no exception. During the development of this research, a need for a strong data base for the various quantitative and qualitative variables reflecting the Technology Factor Index measurement was identified. Corporate data bases, if appropriately designed, will provide more realistic results to help decision makers in their productivity improvement programs. One requires standard data for industries of interest so as to obtain more realistic results in the nonlinear resource allocation required by using the fractional programming model.

8.3.2 Project Maintenance :

The models developed in this research can be used in other industrial sectors as well as in service with special consideration. The author suggests a ten steps procedure that can help decision makers interested in using these models:

1. Define the level of productivity measurement and planning, e.g. firm, industry or national.
2. Collect the appropriate data for the output and the input components according to the elements defined in the Total Operational Productivity model.
3. Determine the value of Total Operational Productivity.
4. Identify the relationship between the output and the input in terms of their weights by using the method of Technology Factor Index.
5. Collect standard input data to define the lower bounds of total input consumption.
6. Determine the capacity of the production system under study.
7. Optimize the Total Operational Productivity measure using the fractional programming formulation developed.
8. Implement the results obtained for the planning period.
9. Evaluate the value of Total Operational Productivity.

10. If planned Total Operational Productivity is achieved, the plan is successful, otherwise, the standard data, and the method of improvement have to be reviewed by the management and engineering departments.

8.3.3 Scope for Further Investigation:

It is recommended to develop a methodology to define and collect appropriate and useful industrial data that may be used effectively and easily in the productivity models introduced in this thesis. Cooperation with industry will be essential if this is to be achieved. For example an extension of the proposed models to the plant and firm levels of productivity measurement and planning would become possible.

An attempt can be made to develop a sensitivity analysis for the Total Operational Productivity Planning Model in order to estimate the effect of variation, without an expensive effort to resolve the problem again in its entirety.

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APPENDIX A

Examples of Partial-Factor Productivity Ratio

EXAMPLES OF OVERALL RATIOS (Mali)

1. Business and industry

(a) $\frac{\text{Sales}}{\text{Employees}}$

(b) $\frac{\text{Space utilized}}{\text{Space available}}$

(c) $\frac{\text{Market share now}}{\text{Market share in base year}}$

(d) $\frac{\text{Sales lost}}{\text{Customer complaints}}$

(e) $\frac{\text{Profit}}{\text{Equity capital}}$

(f) $\frac{\text{Actual price paid}}{\text{Market price}}$

2. Government

(a) $\frac{\text{Benefits}}{\text{Costs}}$

(b) $\frac{\text{Legislation authorized}}{\text{Legislation proposed}}$

(c) $\frac{\text{Quits}}{\text{Employees}}$

(d) $\frac{\text{Budget performance}}{\text{Authorized budget}}$

(e) $\frac{\text{Prices now}}{\text{Prices at base year}}$

(f) $\frac{\text{Gains from legislative enactments}}{\text{Cost of enactments}}$

3. Education

(a) $\frac{\text{Enrollment}}{\text{Faculty}}$

(b) $\frac{\text{Class count x credit hours}}{\text{Direct costs}}$

(c) $\frac{\text{Personnel costs}}{\text{Employees}}$

(d) $\frac{\text{Income/expense}}{\text{Faculty}}$

(e) $\frac{\text{Research projects completed}}{\text{Costs of projects}}$

(f) $\frac{\text{Tuition}}{\text{Administrative staff}}$

4. Health and human services

(a) $\frac{\text{Cost of patient care}}{\text{Number admitted}}$

(b) $\frac{\text{Treatment plans implemented}}{\text{Total treatment plans}}$

(c) $\frac{\text{Client caseload}}{\text{Professional staff}}$

(d) $\frac{\text{Beds occupied}}{\text{Beds available}}$

(e) $\frac{\text{Revenues}}{\text{Patients}}$

(f) $\frac{\text{Training costs}}{\text{Employees}}$

EXAMPLES OF OBJECTIVE RATIOS (Mali)

1. Business and industry

(a) $\frac{\text{Projects completed}}{\text{Projects planned}}$

(b) $\frac{\text{Progress in labor negotiations}}{\text{Expected schedule}}$

(c) $\frac{\text{Marketing products adopted}}{\text{Feasible ideas}}$

(d) $\frac{\text{Work packages}}{\text{Expected work packages}}$

(e) $\frac{\text{Sales level}}{\text{Expected inventory}}$

(f) $\frac{\text{Quits}}{\text{Desired level of quits}}$

2. Government

(a) $\frac{\text{Highways built}}{\text{Highways needed}}$

(b) $\frac{\text{Actual contributed value}}{\text{Expected contributed value}}$

(c) $\frac{\text{Settlement of claims}}{\text{Total claims}}$

(d) $\frac{\text{Convictions}}{\text{Arrests}}$

(e) $\frac{\text{Benefits}}{\text{Expected benefits}}$

(f) $\frac{\text{Contracts renegotiated}}{\text{Needed renegotiated}}$

EXAMPLES OF OBJECTIVE RATIOS (Mali)

3. Education

- (a) $\dfrac{\text{Benefits from research projects}}{\text{Expected benefits}}$
- (b) $\dfrac{\text{Skills prevailing}}{\text{Skills needed}}$
- (c) $\dfrac{\text{Behavioral outcomes}}{\text{Behavioral outcome desired}}$
- (d) $\dfrac{\text{Handicapped children trained}}{\text{Total to be trained}}$
- (e) $\dfrac{\text{Minorities completing program}}{\text{Expected completions}}$
- (f) $\dfrac{\text{Faculty ratings in current year}}{\text{Expected ratings}}$

4. Health and human services

- (a) $\dfrac{\text{Steps completed in treatment}}{\text{Total steps}}$
- (b) $\dfrac{\text{Treatment plans}}{\text{Budget allocation}}$
- (c) $\dfrac{\text{Prescriptions filled}}{\text{Expected prescriptions filled}}$
- (d) $\dfrac{\text{Preventive medical programs}}{\text{Total desired}}$
- (e) $\dfrac{\text{Client caseloads}}{\text{Expected total}}$
- (f) $\dfrac{\text{Patients admitted}}{\text{Patients needed}}$

EXAMPLES OF COST RATIOS (Mali)

1. Business and industry

- (a) $\dfrac{\text{Sales}}{\text{Operating costs}}$
- (b) $\dfrac{\text{Borrowed capital}}{\text{Borrowing costs}}$
- (c) $\dfrac{\text{Investory}}{\text{Advertising costs}}$
- (d) $\dfrac{\text{Rejets}}{\text{Costs}}$
- (e) $\dfrac{\text{Turnover}}{\text{Costs}}$
- (f) $\dfrac{\text{Rework}}{\text{Costs}}$

2. Government

- (a) $\dfrac{\text{Transactions}}{\text{DP costs}}$
- (b) $\dfrac{\text{Renegotiated contracts}}{\text{Costs of renegotiations}}$
- (c) $\dfrac{\text{Recruits selected}}{\text{Costs}}$
- (d) $\dfrac{\text{Mail processed}}{\text{Payroll cost}}$
- (e) $\dfrac{\text{Benefits from proposal}}{\text{Cost of proposal}}$
- (f) $\dfrac{\text{Legislative enactments}}{\text{Cost of enactments}}$

3. Education

- (a) $\dfrac{\text{Tuition generated}}{\text{Cost of generation}}$
- (b) $\dfrac{\text{Dropouts}}{\text{Cost of enrollment}}$
- (c) $\dfrac{\text{Benefits of research projects}}{\text{Cost of projects}}$
- (d) $\dfrac{\text{Students graduating}}{\text{Annual costs}}$
- (e) $\dfrac{\text{Budget value}}{\text{Allocated budget}}$
- (f) $\dfrac{\text{Meals served}}{\text{Cost of cafeteria operation}}$

4. Health and human services

- (a) $\dfrac{\text{Trainees completing programs}}{\text{Training costs}}$
- (b) $\dfrac{\text{Design of therapeutic treatment}}{\text{Cost of design}}$
- (c) $\dfrac{\text{Research reports}}{\text{Allocated budget}}$
- (d) $\dfrac{\text{Clients caseloads}}{\text{Cost of interviews}}$
- (e) $\dfrac{\text{Beds occupied}}{\text{Cost of bed occupancy}}$
- (f) $\dfrac{\text{Patients admitted}}{\text{Cost of admission}}$

EXAMPLES OF WORK STANDARDS RATIOS (Mali)

1. Business and industry

(a) $\frac{\text{Machines operating}}{\text{Setup time}}$

(b) $\frac{\text{Value of returned goods}}{\text{Purchases}}$

(c) $\frac{\text{Grievances settled}}{\text{Grievances investigated}}$

(d) $\frac{\text{Workload assignments}}{\text{Engineering staff}}$

(e) $\frac{\text{Actual labor per unit}}{\text{Scheduled labor per unit}}$

(f) $\frac{\text{Accepted products}}{\text{Products produced}}$

2. Government

(a) $\frac{\text{Benfits from a project}}{\text{Total task required}}$

(b) $\frac{\text{Settlement of unfair labor charges}}{\text{Investigation of charges}}$

(c) $\frac{\text{Compliance of board orders}}{\text{Investigation of on-compliance}}$

(d) $\frac{\text{Board adjudications}}{\text{Total hearings}}$

(e) $\frac{\text{Buying costs}}{\text{Purchases}}$

(f) $\frac{\text{Value added}}{\text{Contract changes}}$

3. Education

(a) $\frac{\text{Research projects completed}}{\text{Procedure used}}$

(b) $\frac{\text{Achievement attainment}}{\text{Standardized test}}$

(c) $\frac{\text{Graduates}}{\text{Standardized curriculum}}$

(d) $\frac{\text{Graduates reading in 50th percentile}}{\text{Standardized reading test}}$

(e) $\frac{\text{Implemented recommendations}}{\text{Committees}}$

(f) $\frac{\text{Graduates}}{\text{Curriculums}}$

4. Health and human services

(a) $\frac{\text{Client caseload}}{\text{Standard caseload}}$

(b) $\frac{\text{Prescriptions filled}}{\text{Standard procedure}}$

(c) $\frac{\text{Patients admitted}}{\text{Standard admissions}}$

(d) $\frac{\text{Absenteeism}}{\text{Industry standard}}$

(e) $\frac{\text{Skills displayed in a situation}}{\text{Skills trained for in a procedure}}$

(f) $\frac{\text{Rework backlog}}{\text{Rework procedure}}$

EXAMPLES OF TIME STANDARDS RATIOS (Mali)

1. Business and industry

(a) $\frac{\text{Production}}{\text{Working days}}$

(b) $\frac{\text{Actual machine hours per unit}}{\text{Scheduled machine hours per unit}}$

(c) $\frac{\text{Reject work}}{\text{Standard hours to produce}}$

(d) $\frac{\text{Inventory buildup}}{\text{Average daily purchases}}$

(e) $\frac{\text{Overtime hours}}{\text{Total hours}}$

(f) $\frac{\text{Rework}}{\text{Time for rework}}$

2. Government

(a) $\frac{\text{Working time}}{\text{Total time}}$

(b) $\frac{\text{Person-days lost}}{\text{Person-days worked}}$

(c) $\frac{\text{Gains from legislative enactments}}{\text{Time period of the gain}}$

(d) $\frac{\text{Service to noncrime calls}}{\text{Time devoted to noncrime calls}}$

(e) $\frac{\text{Benefits from project}}{\text{Time for renegotiation}}$

(f) $\frac{\text{Renegotiated contracts}}{\text{Time for renegotiation}}$

EXAMPLES OF WORK STANDARDS RATIOS (Mali)

3. Education

(a) $\frac{\text{Teaching days in a schedule}}{\text{Teaching days lost}}$

(b) $\frac{\text{Research projects completed}}{\text{Time required}}$

(c) $\frac{\text{Faculty plans submitted}}{\text{Time required}}$

(d) $\frac{\text{Minorities in program}}{\text{Standard time required}}$

(e) $\frac{\text{Skills level attained}}{\text{Standard time required}}$

(f) $\frac{\text{Benefits from project}}{\text{Total hours}}$

4. Health and human services

(a) $\frac{\text{Meals served}}{\text{Standard time}}$

(b) $\frac{\text{Implementation of new therapeutic treatment}}{\text{Person-hours to complement}}$

(c) $\frac{\text{Prescriptions filled}}{\text{Average person-hours}}$

(d) $\frac{\text{Patients admitted}}{\text{Person-hours to admit}}$

(e) $\frac{\text{Client caseloads}}{\text{Person-hours to complete}}$

(f) $\frac{\text{Sickness treatment}}{\text{Standard time}}$

MATERIALS HANDLING (FUNCTIONAL) PRODUCTIVITY RATIOS (White, 1979)

	Resource Utilization Measures	
Labor	MHL Ratio =	$\frac{\text{Personnel assigned to materials handling duties}}{\text{Total Operating Workforce}}$
	DLMH Ratio =	$\frac{\text{Materials handling time spent by direct labor}}{\text{Total direct labor time}}$
Equipment	Production Equipment Utilization =	$\frac{\text{Actual output}}{\text{Theoretical output}}$
	Handling Equipment Utilization =	$\frac{\text{Weight moved/hour}}{\text{Theoretical capacity}}$
Space	Storage Space Utilization =	$\frac{\text{Storage space occupied by material}}{\text{Total storage space}}$
	Aisle Space Percentage =	$\frac{\text{Space occupied by aisles}}{\text{Total space}}$
Energy	EUI =	$\frac{\text{BTUs consumed/day}}{\text{Cubic space}}$
	Management Control Measures	
Materials	Inventory Turnover Ratio =	$\frac{\text{Annual salaes}}{\text{Average annual investory investment}}$
	Inventory Fill Ratio =	$\frac{\text{Line item demands filled/day}}{\text{Line item demands/day}}$

MATERIALS HANDLING (FUNCTIONAL) PRODUCTIVITY RATIOS (White, 1979)

Management Control Measures

Movement, Flow	Movement/Operation Ratio	$= \dfrac{\text{Total number of moves}}{\text{Total number of productive operations}}$
	Average Distance/ Move Ratio	$= \dfrac{\text{Total distance traveled/day}}{\text{Total number of mvoes/day}}$
Loss	Damaged Loads Ratio	$= \dfrac{\text{Number of damaged loads}}{\text{Number of loads}}$
	Inventory Shrinkage Ratio	$= \dfrac{\text{Inventory investment verified}}{\text{Inventory investment expected}}$

Operating Efficiency

Receiving and Shipping	RP Ratio	$\dfrac{\text{Pounds received/day}}{\text{Labor hours/day}}$
	SP Ratio	$\dfrac{\text{Pounds shipped/day}}{\text{Labor hours/day}}$
Storage and Retrieval	OP Ratio	$\dfrac{\text{Equivalent lines or orders picked/day}}{\text{Labor hours required/day}}$
	TPI	$\dfrac{\text{Throughput achieved/day}}{\text{Throughput capacity/day}}$
Manufacturing	Manufacturing Cycle Efficiency (MCE)	$\dfrac{\text{Total time spent on machines}}{\text{Total time spent in production system}}$
	Job Lateness (JL) Ration	$\dfrac{\text{Number of jobs completed or in process that are late/week}}{\text{Number of jobs completed/week}}$

APPENDIX B i

Microsoft FORTRAN-77 computer program for Total Operational Productivity

```
      PROGRAM PRODY
C     PROGRAM TITLE   TOTAL OPERATIONAL PRODUCTIVITY (TOP) MEASUREMENT M
C     WRITTEN BY      A. MOHAMED AND PROF. O. HAWALESHKA
C     DATA WRITTEN    JAN.,1986
C     WRITTEN FOR     DEPARTMENT OF INDUSTRIAL ENG.,UNIVERSITY
C                     OF MANITOBA, WINNIPEG, CANADA.
C
C     ****************************************************************
C     *                        PROGRAM INTENT                        *
C     ****************************************************************
C     * THIS PROGRAM CONSISTS OF SIX SUBROUTINES AND THE MAIN PROGRAM*
C     * USER HAVE TO MODIFY THE I/O FORMAT AND THE DIMENSION OF THE  *
C     * DATA SIZE. THE PURPOSE OF THE PROGRAM IS TO CALCULATE THE    *
C     * TOTAL OPERATIONAL PRODUCTIVITY (TOP), MULTIFACTOR PRODUCT-   *
C     * IVITY, AND SINGLE FACTOR PRODUCTIVITY MEASURES AND THEIR     *
C     * ASSOCIATED INDICES FOR 12 PERIOD OF TIME IN YEARS BASED ON   *
C     * THE DATA COLLECTED FROM STATISTICS CANADA FOR METAL FABRIC-  *
C     * ATING INDUSTRIES IN CANADA. HOWEVER, THE PROGRAM CAN HANDLE  *
C     * A LONGER TIME PERIOD AND FITS DIFFERENT TYPES OF COMPANIES   *
C     * OR INDUSTRIES .                                              *

C     * ************************************************************ *
      DIMENSION Y(12),X1(12),X2(12),X3(12),X4(12),X5(12),SFOPH(12)
     1          ,SFOPC(12),SFOPM(12),SFOPE(12),SFOPO(12),SFOP(12)
     2          ,MFOP(12),TOP(12),SFOPI(12),MFOPI(12),TOPI(12)
     3          ,SFOPHI(12),SFOPCI(12),SFOPMI(12),SFOPEI(12)
     4          ,SFOPOI(12)
      REAL       MFOP,MFOPI,Y,X1,X2,X3,X4,X5,SFOPH,SFOPC,SFOPM,
     3           SFOPE,SFOPO,SFOP,TOP
      CHARACTER*23 DATA
      CHARACTER*9 ANS
      INTEGER I, IOUTPT
      WRITE(*,10)
   10 FORMAT(19X,'OPERATIONAL PRODUCTIVITY MEASURES')
      WRITE(*,11)
   11 FORMAT(30X,'Version 1.0')
      WRITE(*,20)
   20 FORMAT(22X,'Using MICROSOFT FORTRAN 77')
      WRITE(*,30)
   30 FORMAT(30X,'Version 3.2')
      WRITE(*,40)
   40 FORMAT(/////)
      WRITE(*,50)
   50 FORMAT(35x,'By')
      WRITE(*,60)
   60 FORMAT(//)
      WRITE(*,70)
   70 FORMAT(23X,'A.Mohamed and O.Hawaleshka')
      WRITE(*,80)
   80 FORMAT(13X,'Department of Mechanical/Industrial Engineering')
      WRITE(*,90)
   90 FORMAT(25X,'University of Manitoba')
      WRITE(*,100)
  100 FORMAT(28X,'Winnipeg,Canada')
      WRITE(*,110)
  110 FORMAT(34X,'1986')
      PAUSE 'ENTER'
      WRITE(*,111)
  111 FORMAT(//////////)
      WRITE(*,60)
```

```
      WRITE (*,'(A40,3X,\)')      'INPUT DATA FILE NAME?'
      READ (*,'(A23)') DATA
      OPEN(8,FILE = DATA)
      WRITE(*,120)
 120  FORMAT('--------------------------------------------------
     3----------')
      WRITE(*,'(A)')              'OUTPUT OPTION 3'
 130  WRITE(*,140)                'SELECT AN OUTPUT DEVICE:',
     4 '                           1- "CONSOLE:"',
     5 '                           2 -"PRINTER:"',
     6 '                           3 - DISK FILE - "USER01:AB1.TEXT"',
     7 '                           PLEASE ENTER SELECTION :'
140   FORMAT(A/A/A/A/A\)
      READ(*,'(BN,I7)') IOUTPT
      IF (IOUTPT .LT. 1. OR.IOUTPT.GT.3) THEN
      WRITE(*,'(A)') CHAR(12)
      GO TO 130
      END IF
C     **********************************************************
C     *                                                        *
C     ***************** OPEN OUTPUT FILES **********************
C     *                                                        *
C     **********************************************************
      IF (IOUTPT .EQ. 1)THEN
      WRITE (*,150)'                         UNIT 1 -> "CONSOLE:"'
 150  FORMAT(A)
      OPEN (4,FILE = 'CON:')
      WRITE(*,120)
      ELSE IF (IOUTPT .EQ. 2 )THEN
      WRITE(*,150)'                           UNIT 1 ->  PRINTER: '
      OPEN (4,FILE = 'PRN:')
      ELSE
      WRITE(*,150)'                           UNIT  1 -> DISK FILE'
      WRITE(*,150)'                     MAXIMUM OF 10 BLOCKS ALLOC.)'
      OPEN(4,FILE ='A:AB1.TEXT',
     5STATUS ='NEW')
      WRITE(*,150)'(OPEN WORKED)'
      CLOSE (4,STATUS = 'KEEP')
      OPEN(4,FILE ='A:AB1.TEXT[10]',
     6STATUS ='OLD')
      END IF
C
      WRITE(*,151)
 151  FORMAT(22X,'SELECT PRODUCTIVITY MEASUREMENT METHOD:')
      WRITE(*,152)
 152  FORMAT(22X,'1  :OPERATIONAL PRODUCTIVITY MEASURE')
      WRITE(*,153)
 153  FORMAT(22X,'2  :TRADITIONAL PRODUCTIVITY MEASURE')
      READ(*,'(I1)')IP
      WRITE(*,158)
 158  FORMAT(////////////)
C
C     ****************************************************
C     *             READ AND WRITE INPUT DATA            *
C     ****************************************************
C
      WRITE(*,157)
 157  FORMAT(25X,'READING INPUT DATA FILE')
      WRITE(*,162)
```

```
  162 FORMAT(//)
      WRITE(4,159)
  159 FORMAT('OUTPUT',4X,'HUMAN',3X,'CAPITAL',2X,'MATERIAL'
     1,2X,'ENERGY',3X,'OTHERS')
      WRITE(*,162)
      READ(8,160)(Y(I),X1(I),X2(I),X3(I),X4(I),X5(I),I=1,12)
      WRITE(4,160)(Y(I),X1(I),X2(I),X3(I),X4(I),X5(I),I=1,12)
  160 FORMAT(5(F7.2,2X),F7.2)
      WRITE(*,300)
      READ(*,'(A1)') ANS
  300 FORMAT(//,'DO YOU WANT TO CHANGE THE INPUT DATA ?
     2(Y or N):',\)
      IF (ANS.EQ.'N'.OR.ANS.EQ.'n') THEN
C----------------------------------------------------------------
      WRITE(*,181)
      END IF
      READ(*,'(A1)') ANS
  181 FORMAT(//,'DO YOU WANT TOTAL OPERATIONAL PRODUCTIVITY
     2 MEASURE ? (Y or N):',\)
      IF (ANS.EQ.'Y'.OR.ANS.EQ.'y') THEN
      WRITE(*,162)
      CALL SINGLE(Y,X1,SFOP)
      CALL MULTI(Y,X1,X2,MFOP)
      CALL TOTAL (Y,X1,X2,X3,X4,X5,TOP)
      CALL TABLE1(SFOP,MFOP,TOP,IP)
      ELSE
      GOTO 177
      END IF
      WRITE(*,162)
  177 WRITE(*,167)
      READ(*,'(A1)') ANS
  167 FORMAT(//,'DO YOU WANT TOTAL OPERATIONAL PRODUCTIVITY
     3 INDICES? (Y or N):',\)
      IF (ANS.EQ.'Y'.OR.ANS.EQ.'y') THEN
      WRITE(*,162)
      CALL INDEX(SFOP,MFOP,TOP,SFOPI,MFOPI,TOPI)
      CALL TABLE2(SFOPI,MFOPI,TOPI,IP)
      ELSE
      GOTO 188
      END IF
  188 WRITE(*,200)
      READ(*,'(A1)') ANS
  200 FORMAT(//,'DO YOU WANT SINGLE FACTOR OPERATIONAL
     4 PRODUCTIVITIES ?(Y or N):',\)
      IF(ANS.EQ.'Y'.OR.ANS.EQ.'y') THEN
      WRITE(*,162)
      CALL SINFAC(Y,X1,X2,X3,X4,X5,SFOPH,SFOPC,
     4SFOPM,SFOPE,SFOPO)
      CALL TABLE3(SFOPH,SFOPC,SFOPM,SFOPE,SFOPO)
      ELSE
      GOTO 201
      END IF
  201 WRITE(*,301)
      READ(*,'(A1)') ANS
  301 FORMAT(//,'DO YOU WANT SINGLE FACTOR OPERATIONAL PRODUCTIVITY
     5 INDICES ? (Y or N):',\)
      IF(ANS.EQ.'Y'.OR.ANS.EQ.'y') THEN
      CALL SININD(SFOPH,SFOPC,SFOPM,SFOPE,SFOPO,SFOPHI,SFOPCI,
     6SFOPMI,SFOPEI,SFOPOI)
```

```
       178          CALL TABLE4(SFOPHI,SFOPCI,SFOPMI,SFOPEI,SFOPOI)
       179          END IF
       180          STOP
       181          END

  Name     Type         Offset P Class

  ANS     CHAR*9          1836
  CHAR                              INTRINSIC
  DATA    CHAR*23         1372
  I       INTEGER*4       1810
  IOUTPT  INTEGER*4       1480
  IP      INTEGER*4       1624
  MFOP    REAL             962
  MFOPI   REAL            1010
  SFOP    REAL             914
  SFOPC   REAL             722
  SFOPCI  REAL             866
  SFOPE   REAL             770
  SFOPEI  REAL             818
  SFOPH   REAL             290
  SFOPHI  REAL             674
  SFOPI   REAL             626
  SFOPM   REAL             338
  SFOPMI  REAL             578
  SFOPO   REAL             386
  SFOPOI  REAL             530
  TOP     REAL             434
  TOPI    REAL             482
  X1      REAL              50
  X2      REAL              98
  X3      REAL             146
  X4      REAL             194
  X5      REAL             242
  Y       REAL               2


       182 C-------------------------------------------------------------
       183          SUBROUTINE SINGLE(Y,X1,SFOP)
       184          DIMENSION Y(12),X1(12),X2(12),X3(12),x4(12),
       185         1X5(12),SFOP(12),MFOP(12),TOP(12)
       186          REAL MFOP,Y,X1,X21,X3,X4,X5
       187 C
       188          DO 10 I=1,12
  1    189          SFOP(I)=Y(I)/X1(I)
  1    190  10      CONTINUE
       191          RETURN
       192          END

  Name     Type         Offset P Class

  I       INTEGER*4       2552
  MFOP    REAL            2504
  SFOP    REAL               8 *
  TOP     REAL            2456
  X1      REAL               4 *
  X2      REAL            2264
  X21     REAL           *****
  X3      REAL            2312
```

```
X4      REAL             2360
X5      REAL             2408
Y       REAL                0 *


     193 C-----------------------------------------------------------------
     194 C
     195          SUBROUTINE MULTI(Y,X1,X2,MFOP)
     196          DIMENSION Y(12),X1(12),X2(12),X3(12),x4(12),X5(12),
     197         1SFOP(12),MFOP(12),TOP(12)
     198          REAL MFOP,Y,X1,X2,X3,X4 ,X5
     199 C
     200 C
     201          DO 10 I=1,12
1    202          MFOP(I)=Y(I)/(X1(I)+X2(I))
1    203    10    CONTINUE
     204          RETURN
     205          END

Name     Type          Offset P Class

I       INTEGER*4        2796
MFOP    REAL               12 *
SFOP    REAL             2700
TOP     REAL             2748
X1      REAL                4 *
X2      REAL                8 *
X3      REAL             2556
X4      REAL             2604
X5      REAL             2652
Y       REAL                0 *


     206 C-----------------------------------------------------------------
     207 C
     208          SUBROUTINE TOTAL(Y,X1,X2,X3,X4,X5,TOP)
     209          DIMENSION Y(12),X1(12),X2(12),X3(12),x4(12),
     210         1SFOP(12),MFOP(12),TOP(12),X5(12)
     211          REAL MFOP,Y,X1,X2,X3,X4,X5
     212 C
     213 C
     214          DO 10 I=1,12
1    215          TOP(I)=Y(I)/(X1(I)+X2(I)+X3(I)+X4(I)+X5(I))
1    216    10    CONTINUE
     217          RETURN
     218          END

Name     Type          Offset P Class

I       INTEGER*4        2896
MFOP    REAL             2848
SFOP    REAL             2800
TOP     REAL               24 *
X1      REAL                4 *
X2      REAL                8 *
X3      REAL               12 *
X4      REAL               16 *
X5      REAL               20 *
Y       REAL                0 *
```

```
   C------------------------------------------------------------
         SUBROUTINE TABLE1(SFOP,MFOP,TOP,IP)
         DIMENSION Y(12),X1(12),X2(12),X3(12),x4(12),
        1SFOP(12),MFOP(12),TOP(12),X5(12)
         REAL MFOP,Y,X1,X2,X3,X4 ,X5
   C
   C
         WRITE(4,10)
      10 FORMAT(15X,49('-'))
         WRITE(4,20)
      20 FORMAT(15X,'|',8X,'|',3(12X,'|'))
         WRITE(4,30)
      30 FORMAT(15X,'|',13X,'PRODUCTIVITY MEASURES',13X,'|')
         WRITE(4,10)
         WRITE(4,20)
         GO TO (35,45) IP
      35 WRITE(4,40)
         GO TO 55
      45 WRITE(*,65)
      40 FORMAT(15X,'|',2X,'YEAR',2X,'|',4X,'SFOP',4X,'|',4X,'MFOP',4X,
        2'|',4X,'TOP',5X,'|')
      65 FORMAT(15X,'|',2X,'YEAR',2X,'|',5X,'SFP',4X,'|',5X,'MFP',4X,
        3'|',5X,'TP',5X,'|')
      55 WRITE(4,20)
         WRITE(4,10)
         WRITE(4,20)
         II=1971
         DO 50 I=1,12
1        WRITE(4,60) II,SFOP(I),MFOP(I),TOP(I)
1        II=II+1
1        WRITE(4,20)
1     50 CONTINUE
      60 FORMAT(15X,'|',2X,i4,2X,'|',3(2X,F8.4,2X,'|'))
         WRITE(4,10)
         WRITE(4,70)
         WRITE(4,105)
      70 FORMAT(15X,'OPERATIONAL PRODUCTIVITY MEASURES FOR')
     105 FORMAT(15X,'PRODUCTIVITY MEASURES FOR METAL FABRICATING')
         WRITE(4,90)
      90 FORMAT(15X,'INDUSTRIES IN CANADA, IN CONSTANT DOLLARS')
         RETURN
         END

Name     Type          Offset P Class

I        INTEGER*4       3440
II       INTEGER*4       3436
IP       INTEGER*4         12 *
MFOP     REAL               4 *
SFOP     REAL               0 *
TOP      REAL               8 *
X1       REAL            2948
X2       REAL            2996
X3       REAL            3044
X4       REAL            3092
X5       REAL            3140
Y        REAL            2900
   C-------------------------------------------------------------------
         SUBROUTINE INDEX(SFOP,MFOP,TOP,SFOPI,MFOPI,TOPI)
```

```
     ne             7                              Microsoft FORTRAN77 V3.20 02/84
     263            DIMENSION SFOP(12),SFOPI(12),MFOP(12),MFOPI(12),TOP(12),TOPI(12)
     264            REAL MFOP,MFOPI
     265 C
     266            DO 10 I=1,12
 1   267            SFOPI(I)=SFOP(I)/SFOP(1)
 1   268  10        CONTINUE
     269            DO 20 I=1,12
 1   270            MFOPI(I)=MFOP(I)/MFOP(1)
 1   271  20        CONTINUE
     272            DO 30 I=1,12
 1   273            TOPI(I)=TOP(I)/TOP(1)
 1   274  30        CONTINUE
     275            RETURN
     276            END

Name    Type         Offset P Class

I       INTEGER*4      3632
MFOP    REAL              4 *
MFOPI   REAL             16 *
SFOP    REAL              0 *
SFOPI   REAL             12 *
TOP     REAL              8 *
TOPI    REAL             20 *


     277 C          ------------------------------------------------------
     278            SUBROUTINE TABLE2(SFOPI,MFOPI,TOPI,IP)
     279            DIMENSION SFOPI(12),MFOPI(12),TOPI(12)
     280            REAL MFOPI,MFOP
     281 C
     282 C
     283            WRITE(4,10)
     284    10      FORMAT(15X,49('-'))
     285            WRITE(4,20)
     286    20      FORMAT(15X,'|',8X,'|',3(12X,'|'))
     287            WRITE(4,30)
     288    30      FORMAT(15X,'|',14X,'PRODUCTIVITY INDICES ',12X,'|')
     289            WRITE(4,10)
     290            WRITE(4,20)
     291            GO TO (35,45) IP
     292    35      WRITE(4,40)
     293            GO TO 55
     294    45      WRITE(4,65)
     295    40      FORMAT(15X,'|',2X,'YEAR',2X,'|',3X,'SFOPI',4X,'|',3X,'MFOPI',4X,
     296           1'|',4X,'TOPI',4X,'|')
     297    65      FORMAT(15X,'|',2X,'YEAR',2X,'|',4X,'SFPI',4X,'|',4X,'MFPI',4X,
     298           2'|',5X,'TPI',4X,'|')
     299    55      WRITE(4,20)
     300            WRITE(4,10)
     301            WRITE(4,20)
     302            II=1971
     303            DO 50 I=1,12
 1   304            WRITE(4,60) II,SFOPI(I),MFOPI(I),TOPI(I)
 1   305            II=II+1
 1   306            WRITE(4,20)
 1   307  50        CONTINUE
     308  60        FORMAT(15X,'|',2X,i4,2X,'|',3(2X,F8.4,2X,'|'))
     309            WRITE(4,10)
```

```
     310          WRITE(4,70)
     311          WRITE(4,105)
     312   70     FORMAT(15X,'OPERATIONAL PRODUCTIVITY INDICES FOR METAL')
     313  105     FORMAT(15X,'PRODUCTIVITY INDICES FOR METAL')
     314          WRITE(4,80)
     315   80     FORMAT(26X,' FABRICATING INDUSTRIES IN CANADA ')
     316          RETURN
     317          END

Name     Type          Offset P Class

I       INTEGER*4       3890
II      INTEGER*4       3886
IP      INTEGER*4         12 *
MFOP    REAL           *****
MFOPI   REAL               4 *
SFOPI   REAL               0 *
TOPI    REAL               8 *


     318          SUBROUTINE SINFAC(Y,X1,X2,X3,X4,X5,SFOPH,SFOPC,SFOPM,
     319         1SFOPE,SFOPO)
     320          DIMENSION Y(12),X1(12),X2(12),X3(12),X4(12),X5(12),
     321         *SFOPH(12),SFOPC(12),SFOPM(12),SFOPE(12),SFOPO(12)
     322          REAL Y,X1,X2,X3,X4,X5,SFOPH,SFOPC,SFOPM,SFOPE,SFOPO
     323          DO 10 I=1,12
1    324          SFOPH(I)=Y(I)/X1(I)
1    325   10     CONTINUE
     326          DO 21 I=1,12
1    327          SFOPC(I)=Y(I)/X2(I)
1    328    21    CONTINUE
     329          DO 30 I=1,12
1    330          SFOPM(I)=Y(I)/X3(I)
1    331   30     CONTINUE
     332          DO 40 I=1,12
1    333          SFOPE(I)=Y(I)/X4(I)
1    334   40     CONTINUE
     335          DO 50 I=1,12
1    336          SFOPO(I)=Y(I)/X5(I)
1    337   50     CONTINUE
     338          RETURN
     339          END

Name     Type          Offset P Class

I       INTEGER*4       4070
SFOPC   REAL              28 *
SFOPE   REAL              36 *
SFOPH   REAL              24 *
SFOPM   REAL              32 *
SFOPO   REAL              40 *
X1      REAL               4 *
X2      REAL               8 *
X3      REAL              12 *
X4      REAL              16 *
X5      REAL              20 *
Y       REAL               0 *
     340          SUBROUTINE TABLE3 (SFOPH,SFOPC,SFOPM,SFOPE,SFOPO)
     341          DIMENSION SFOPH(12),SFOPC(12),SFOPM(12),SFOPE(12),SFOPO(12)
```

```
         INTEGER I,II
         WRITE(4,10)
    10   FORMAT(5X,75('-'))
    20   FORMAT(5X,'|',8X,'|',5(12X,'|'))
         WRITE(4,30)
    30   FORMAT(5X,'|',10X,'SINGLE FACTOR OPERATIONAL PRODUCTIVITIES'
        1,20X,'|')
         WRITE(4,10)
         WRITE(4,20)
         WRITE(4,40)
    40   FORMAT(5X,'|',2X,'YEAR',2X,'|',4X,'SFOPH',3X,'|',4X,'SFOPC'
        2,3X,'|',4X,'SFOPM',3X,'|',4X,'SFOPE',3X,'|','SFOPO',6X,'|')
         WRITE(4,20)
         WRITE(4,10)
         WRITE(4,20)
         II=1971
         DO 50 I=1,12
1        WRITE(4,60) II,SFOPH(I),SFOPC(I),SFOPM(I),SFOPE(I),SFOPO(I)
1        II=II+1
1        WRITE(4,20)
1   50   CONTINUE
    60   FORMAT(5X,'|',2X,I4,2X,'|',5(2X,F8.4,2X,'|'))
         WRITE(4,10)
         WRITE(4,70)
    70   FORMAT(15X,'SINGLE FACTOR OPERATIONAL PRODUCTIVITIES MEASURE')
         WRITE(4,90)
    90   FORMAT(15X,'FOR METAL FABRICATING INDUSTRIES IN CANADA')
         RETURN
         END

Name     Type           Offset P Class

I        INTEGER*4        4308
II       INTEGER*4        4304
SFOPC    REAL                4 *
SFOPE    REAL               12 *
SFOPH    REAL                0 *
SFOPM    REAL                8 *
SFOPO    REAL               16 *


         SUBROUTINE SININD(SFOPH,SFOPC,SFOPM,SFOPE,SFOPO,SFOPHI,SFOPCI
        1,SFOPMI,SFOPEI,SFOPOI)
         REAL SFOPH(12),SFOPHI(12),SFOPC(12),SFOPCI(12),SFOPM(12)
        2,SFOPMI(12),SFOPE(12),SFOPEI(12),SFOPO(12),SFOPOI(12)
    C
         DO 10 I=1,12
1        SFOPHI(I)=SFOPH(I)/SFOPH(1)
1   10   CONTINUE
         DO 20 I=1,12
1        SFOPCI(I)=SFOPC(I)/SFOPC(1)
1   20   CONTINUE
         DO 30 I=1,12
1        SFOPMI(I)=SFOPM(I)/SFOPM(1)
1   30   CONTINUE
         DO 40 I=1,12
1        SFOPEI(I)=SFOPE(I)/SFOPE(1)
1   40   CONTINUE
         DO 50 I=1,12
```

```
1    389           SFOPOI(I)=SFOPO(I)/SFOPO(1)
1    390      50   CONTINUE
     391           RETURN
     392           END

Name      Type          Offset P Class

I        INTEGER*4       4460
SFOPC    REAL               4 *
SFOPCI   REAL              24 *
SFOPE    REAL              12 *
SFOPEI   REAL              32 *
SFOPH    REAL               0 *
SFOPHI   REAL              20 *
SFOPM    REAL               8 *
SFOPMI   REAL              28 *
SFOPO    REAL              16 *
SFOPOI   REAL              36 *


     393           SUBROUTINE TABLE4 (SFOPHI,SFOPCI,SFOPMI,SFOPEI,SFOPOI)
     394           DIMENSION SFOPHI(12),SFOPCI(12),SFOPMI(12),SFOPEI(12)
     395          1,SFOPOI(12)
     396           INTEGER I,II
     397           WRITE (4,10)
     398      10   FORMAT(5X,75('-'))
     399      20   FORMAT(5X,'|',8X,'|',5(12X,'|'))
     400           WRITE(4,30)
     401      30   FORMAT(5X,'|',8X,'SINGLE FACTOR OPERATIONAL PRODUCTIVITIES
     402          1INDICES',5X,'|')
     403           WRITE(4,10)
     404           WRITE(4,20)
     405           WRITE(4,40)
     406      40   FORMAT(5X,'|',2X,'YEAR',2X,'|',3X,'SFOPHI',3X,'|',3X
     407          2,'SFOPCI',3X,'|',3X,'SFOPMI',3X,'|',3X,'SFOPEI',3X,'|'
     408          3,'SFOPOI',4X,'|')
     409           WRITE(4,20)
     410           WRITE(4,10)
     411           WRITE(4,20)
     412           II=1971
     413           DO 50 I=1,12
1    414           WRITE(4,60) II,SFOPHI(I),SFOPCI(I),SFOPMI(I),SFOPEI(I),
1    415          3SFOPOI(I)
1    416           II=II+1
1    417           WRITE(4,20)
1    418      50   CONTINUE
     419      60   FORMAT(5X,'|',2X,I4,2X,'|',5(2X,F8.4,2X,'|'))
     420           WRITE(4,10)
     421           WRITE(4,70)
     422      70   FORMAT(15X,'SINGLE FACTOR OPERATIONAL PRODUCTIVITIES INDICES')
     423           WRITE (4,90)
     424      90   FORMAT(15X,'FOR METAL FABRICATING INDUSTRIES IN CANADA')
     425           RETURN
     426           END

Name      Type          Offset P Class

I        INTEGER*4       4728
II       INTEGER*4       4724
```

```
SFOPCI REAL            4 *
SFOPEI REAL           12 *
SFOPHI REAL            0 *
SFOPMI REAL            8 *
SFOPOI REAL           16 *


Name     Type          Size   Class

INDEX                         SUBROUTINE
MULTI                         SUBROUTINE
PRODY                         PROGRAM
SINFAC                        SUBROUTINE
SINGLE                        SUBROUTINE
SININD                        SUBROUTINE
TABLE1                        SUBROUTINE
TABLE2                        SUBROUTINE
TABLE3                        SUBROUTINE
TABLE4                        SUBROUTINE
TOTAL                         SUBROUTINE

 Pass One     No Errors Detected
             426 Source Lines
```

APPENDIX B ii

Sample of calculation for productivity measures

SAMPLE OF PRODUCTIVITY MEASUREMENT CALCULATIONS

The following data are taken from Table (4.9), for the year of 1982, expressed in base-period dollars, (1971) in Canadian metal fabricating industries.

$$\text{Total output} = \sum_{k=1}^{K} Y_{1kt} = \$4{,}160.90 \times 10^6$$

$$\text{Total human input} = \sum_{\ell=1}^{L} X_{11\ell}(1982) = \$542.59 \times 10^6$$

$$\text{Total capital input} = \sum_{\ell=1}^{L} X_{12\ell}(1982) = \$134.30 \times 10^6$$

$$\text{Total material and supplies input} = \sum_{\ell=1}^{L} X_{13\ell}(1982) = \$1{,}483.09 \times 10^6$$

$$\text{Total energy input} = \sum_{\ell=1}^{L} X_{14\ell}(1982) = \$38.28 \times 10^6$$

$$\text{Total other costs input} \sum_{\ell=1}^{L} X_{14\ell}(1982) = \$40.00 \times 10^6$$

Then, the Total Operational Productivity (TOP) for these industries in 1982 is given by:

$$TOP_1(1982) = \frac{\sum_{k=1}^{K} Y_{1k}(1982)}{\sum_{j=1}^{5} \sum_{\ell=1}^{L} X_{1j\ell}(1982)}$$

$$TOP_{1(1982)} = \frac{\$4,160.90 \times 10^6}{\$(542.59 + 134.30 + 1,483.09 + 38.28 + 40.)\ 10^6}$$

$TOP_{1(1982)}$ = \$/\$1.8590 (as shown in Table 4.10 col. 3) and Total Operational Productivity Index for 1982 is:

$$TOPI_{1(1982)} = \frac{TOP_{1(1982)}}{TOP_{1(1971)}}$$

$$TOPI_{1(1982)} = \frac{1.8590}{1.4104} = 1.3181 \text{ (as shown in Table 4.11 col. 3)}$$

The Multifactor Operational Productivity (MFOP) for these industries in 1982 is given by:

$$MFOP_{1(1982)} = \frac{\sum_{k=1}^{K} Y_{1k(1982)}}{\sum_{j=1}^{2} \sum_{\ell=1}^{L} X_{1j\ell(1982)}}$$

$$MFOP_{1(1982)} = \frac{\$4,160.90 \times 10^6}{\$(542.59 + 134.30)\ 10^6}$$

$MFOP_{1(1982)}$ = \$/\$6.1471 (as shown in Table 4.10)

and Multifactor Productivity Index (MFOPI) for 1982 is:

$$MFOPI_{1(1982)} = \frac{MFOP_{1(1982)}}{MFOP_{1(1971)}}$$

$$MFOPI_{1(1982)} = \frac{6.1471}{4.3343} = 1.4182$$

(As shown in Table 4.11)

The Single Factor Operational Productivity (SFOP) of the five input for these industries in 1982 are given by:

$$SFOP(J)_{i(1982)} = \frac{\sum_{k=1}^{K} Y_{1k(1982)}}{\sum_{\ell=1}^{L} X_{1j\ell(1982)}}$$

Where j = 1 for human input

j = 2 for capital input

j = 3 for materials and supplies input

j = 4 for energy input

j = 5 for other costs input

$$SFOPH_{1(1982)} = \frac{\$4,160.90 \times 10^6}{\$542.59 \times 10^6} = \$/\$7.6685$$

$$SFOPC_{1(1982)} = \frac{\$4,160.90 \times 10^6}{\$134.30 \times 10^6} = \$/\$30.981$$

$$SFOPM_{1(1982)} = \frac{\$4,160.90 \times 10^6}{\$1,483.09 \times 10^6} = \$/\$2.8056$$

$$SFOPE_{1(1982)} = \frac{\$4,160.90 \times 10^6}{\$38.28 \times 10^6} = \$/\$108.694$$

$$SFOPO_{1(1982)} = \frac{\$4,160.90 \times 10^6}{\$40.00 \times 10^6} = \$/\$104.0225$$

As shown in Table 4.14 in the text.

APPENDIX C

Microsoft FORTRAN-77 computer program for Technology Factor Index

```
      PROGRAM TECH
C     PROGRAM : Solve the Technology factor Index (TFI)
C     FILENAME: Factor.for
C     VERSION : 1.1
C     REVISED : 01/06/86
C     BY      : A.M. Mohamed and O. Hawaleshka
C     ADRESS  : Department of Mechanical/Industrial Engineering
C               University of Manitoba, Winnipeg, Canada
C     ______________________________________________________________
C
C     PURPOSE :
C               This program calculates the Technology Factor Index
C     in Canadian metal fabricating industries, by using the solution
C     procedures derived in chapter5. This version can handle six
C     variables and tweleve period of time in years.
C     ______________________________________________________________
C
      DIMENSION A(5),M(5),SUMQ(5),Q(5,12),QM(5,12),TFI(12)
      INTEGER T
      REAL A,M,Q,QM,TFI
      INTEGER I, IOUTPUT
      CHARACTER*23 DATA
C
C
      WRITE(*,'(A40,3X,\)')      'INPUT FILE NAME?'
      READ(*,'(A23)') DATA
      OPEN(8,FILE=DATA)
      WRITE (*,'(A)')                   'OUTPUT OPTION 3'
   10 WRITE(*,20)                       'SELECT AN OUTPUT DEVICE:',
     1'                                    1-"CONSOLE:"',
     2'                                    2-"PRINTER:"',
     3'                                    3-DISK FILE-"USER01:MH.TXT"',
     4'                                  PLEASE ENTER YOUR SELECTION:'
   20 FORMAT(A/A/A/A/A\)
      READ (*,'(BN,I7)') IOUTPUT
      IF (IOUTPUT.LT.1.OR.IOUTPUT.GT.3) THEN
      WRITE(*,'(A)') CHAR(12)
      GO TO 10
      END IF
      IF (IOUTPUT.EQ.1) THEN
      WRITE(*,30)'                UNIT 1-> "CONSOLE:"'
   30 FORMAT(A)
      OPEN (4, FILE= 'CON')
      ELSE IF (IOUTPUT.EQ.2) THEN
      WRITE (*,30)'               UNIT 1-> "PRINTER:"'
      OPEN (4, FILE='PRN')
      ELSE
      WRITE(*,30)'                UNIT 1-> DISK FILE'
      OPEN (4,FILE ='MH.TXT[10]', STATUS ='OLD')
      END IF
C
C
      READ(8,60)( A(J),J=1,5)
      WRITE(*,60)(A(J),J=1,5)
   60 FORMAT(4(F6.4,2X),F6.4)
      READ(8,70)((Q(J,T),J=1,5),T=1,12)
      WRITE(*,70)((Q(J,T),J=1,5),T=1,12)
   70 FORMAT(4(F7.2,2X),F7.2)
C____________________________________________________________
```

```
       C
              CALL FACTOR(A,M,SUMQ,Q,QM,TFI)
              CALL REPORT(TFI)
              STOP
              END
```

```
Name    Type          Offset P Class

A       REAL               2
CHAR                             INTRINSIC
DATA    CHAR*23          590
I       INTEGER*4      *****
IOUTPU  INTEGER*4        626
J       INTEGER*4        634
M       REAL              22
Q       REAL             110
QM      REAL             350
SUMQ    REAL              42
T       INTEGER*4        660
TFI     REAL              62
```

```
       C______________________________________________________________
       C
              SUBROUTINE FACTOR(A,M,SUMQ,Q,QM,TFI)
              DIMENSION A(5),M(5),SUMQ(5),Q(5,12),QM(5,12),TFI(12)
              INTEGER T
              REAL A,M,SUMQ,Q,QM,TFI
       C
       C
              SUMA = 0.00
              DO 10 J=1,5
1             SUMQ(J) =0.00
1         10  CONTINUE
              DO 20 T=1,12
1             TFI(T) =0.00
1         20  CONTINUE
              DO 30 J=1,5
1             SUMA=SUMA+A(J)
1         30  CONTINUE
              DO 40 J=1,5
1             M(J)= A(J)/SUMA
1         40  CONTINUE
              DO 50 J=1,5
1             DO 50 T=1,12
2             SUMQ(J)=SUMQ(J)+Q(J,T)
2         50  CONTINUE
              DO 60 T=1,12
1             DO 60 J=1,5
2             QM(J,T)=Q(J,T)/SUMQ(J)
2         60  CONTINUE
              DO 70 T=1,12
1             DO 70 J=1,5
2             TFI(T)=TFI(T)+QM(J,T)*M(J)
2         70  CONTINUE
              RETURN
              END
```

```
Name     Type          Offset P Class

A        REAL              0 *
J        INTEGER*4       732
M        REAL              4 *
Q        REAL             12 *
QM       REAL             16 *
SUMA     REAL            728
SUMQ     REAL              8 *
T        INTEGER*4       736
TFI      REAL             20 *


     100 C_______________________________________________________________
     101 C
     102          SUBROUTINE REPORT(TFI)
     103 C
     104          DIMENSION TFI(12)
     105          INTEGER T
     106          REAL TFI
     107          WRITE(4,10)
     108   10     FORMAT(20X,40('-'))
     109   20     FORMAT(20X,'|',8X,'|',29X,'|')
     110          WRITE(4,20)
     111          WRITE(4,30)
     112   30     FORMAT(20X,'|',2X,'YEAR',2X,'|',3X,'TECHNOLOGY FACTOR INDEX'
     113         #,3X,'|')
     114          WRITE(4,20)
     115          WRITE(4,10)
     116          WRITE(4,20)
     117          II=1971
     118          DO 40 T=1,12
1    119          WRITE(4,50)II,TFI(T)
1    120          II=II+1
1    121          WRITE(4,20)
1    122   40     CONTINUE
     123   50     FORMAT(20X,'|',2X,I4,2X,'|',12X,F5.4,12X,'|')
     124          WRITE(4,10)
     125          WRITE(4,60)
     126   60     FORMAT(//)
     127          WRITE(4,70)
     128   70     FORMAT(20X,'Table 5.4 Technology Factor Index Measure')
     129          WRITE(4,80)
     130   80     FORMAT(20X,'in Canadian metal fabricating industries')
     131          RETURN
     132          END

Name     Type          Offset P Class

II       INTEGER*4       846
T        INTEGER*4       850
TFI      REAL              0 *


     133

Name     Type             Size   Class
```

```
FACTOR                        SUBROUTINE
REPORT                        SUBROUTINE
TECH                          PROGRAM

 Pass One    No Errors Detected
            133 Source Lines
```

APPENDIX D

A description of Micro Computer program for fractional programming

MICRO COMPUTER PROGRAM FOR SOLVING LINEAR FRACTIONAL PROGRAMMING

PROGRAM DESCRIPTION

The method for the solution of linear fractional programming (LFP) utilizes the "Two-phase" Simplex method. Thus, as a by-product of solutions of Nonlinear (Fractional) Programs, Linear Program solutions can also be found. Figure (1) shows a structure chart of the program. It shows the functions available to the operator (ie. Help, Clear, Input, Solve, Print).

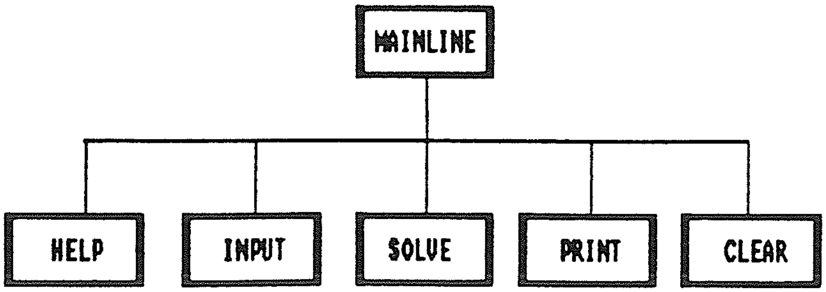


Figure 1 Program commands

When the INPUT command is selected, the operator may choose to input or edit the type of problem, the objective function, or the constraint equations as shown in Figure (2).

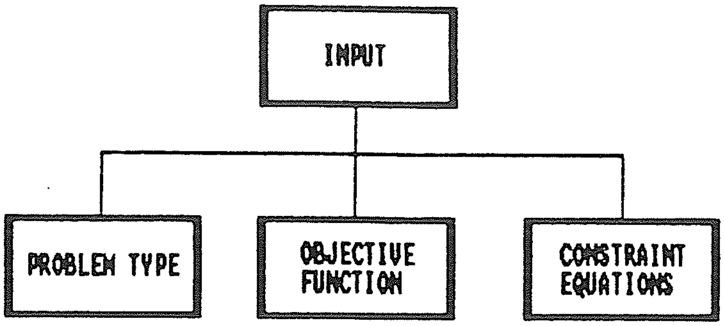


Figure 2 Data input

Figure 3 shows the relationship of the Two-Phase Simplex method to the solution of Nonlinear (Fractional) and Linear programs.

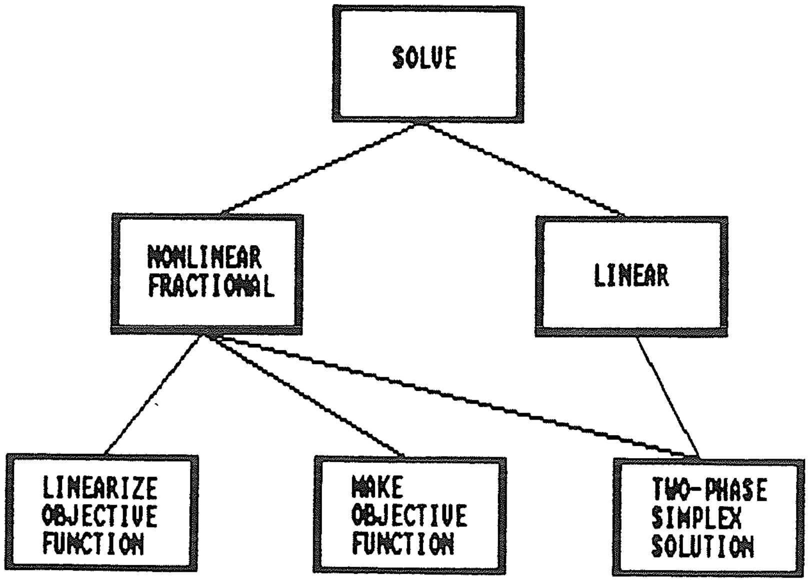
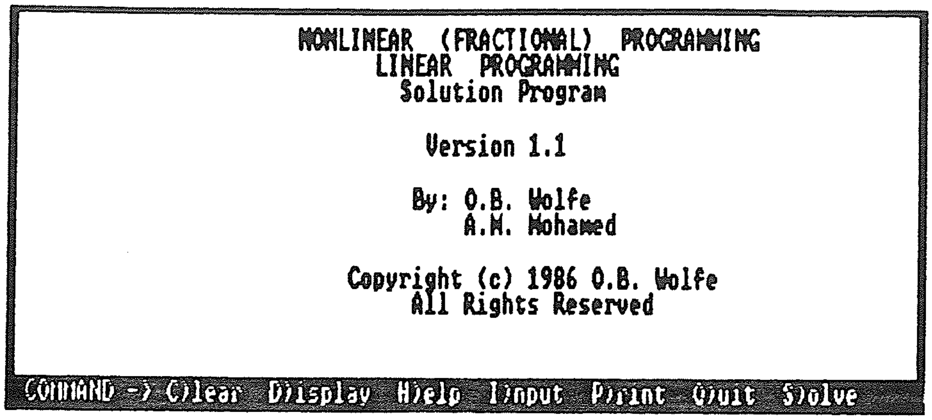


Figure 3 Calculation module structure chart

Since the program was created on the assumption that the operator may wish to edit the input data to explore different solutions, the input data is left intact during calculations. If the set of input data is small (for example the data set consisting only of the symbols : Less-than, Greater-than, Equal-to), then a menu selection dialogue is used, with the operator pressing a key corresponding to the desired choice. If the set of input data is large (for example, the set of real numbers for equation coefficients), then a form filling dialogue is used. In this case the user fills in the real numbers corresponding to the values of coefficients in the objective function and the constraint equations. A decision was made to implement the program using the TURBO PASCAL compiler. This results in a compact, executable program, compatible with a wide variety of microcomputers using (PCDOS,MSDOS,CP/M-86,CP/M-80) operating systems. In addition the program would be able to use the Intel 8087 math coprocessor for additional computational power.

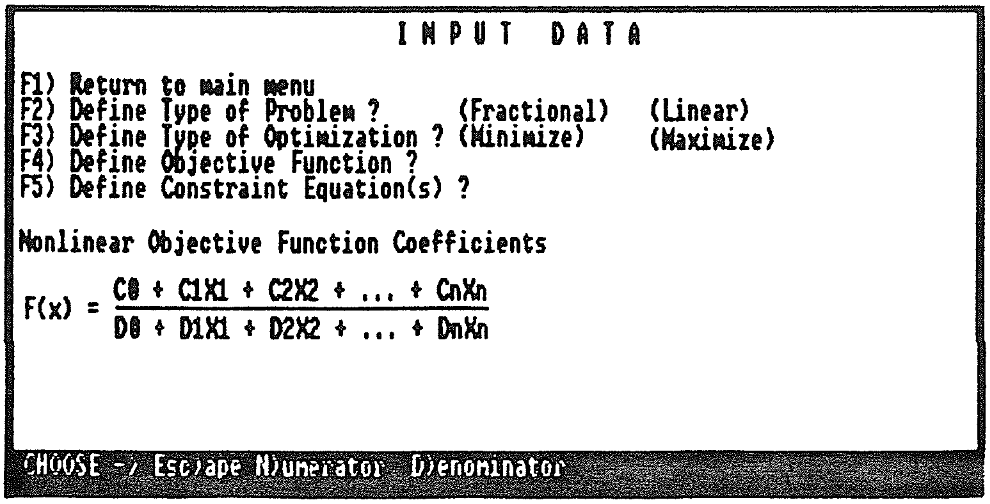
DESCRIPTION OF FEATURES

Figure (4) shows the main functions available to the operator when the program begins. The CLEAR command re-initializes all input data values and is used when the operator wishes to enter a new problem. The INPUT command is used to input the type of optimization and objective function coefficients as shown in Fig. (5), and the constraint equations seen in Fig. (6).



```
NONLINEAR (FRACTIONAL) PROGRAMMING
LINEAR PROGRAMMING
Solution Program

Version 1.1

By: O.B. Wolfe
    A.M. Mohamed

Copyright (c) 1986 O.B. Wolfe
All Rights Reserved

COMMAND -> C)lear D)isplay H)elp I)nput P)rint Q)uit S)olve
```

Fig. 4 Initial program screen

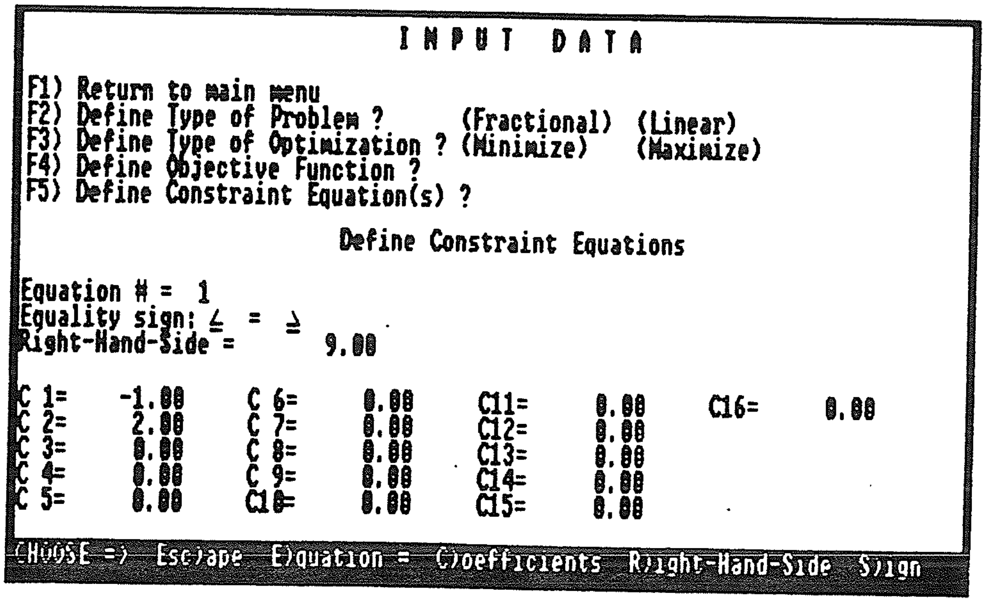


```
I N P U T   D A T A

F1) Return to main menu
F2) Define Type of Problem ?      (Fractional)   (Linear)
F3) Define Type of Optimization ? (Minimize)     (Maximize)
F4) Define Objective Function ?
F5) Define Constraint Equation(s) ?

Nonlinear Objective Function Coefficients
```

$$F(x) = \frac{C0 + C1X1 + C2X2 + \ldots + CnXn}{D0 + D1X1 + D2X2 + \ldots + DnXn}$$

```
CHOOSE -> Esc)ape N)umerator D)enominator
```

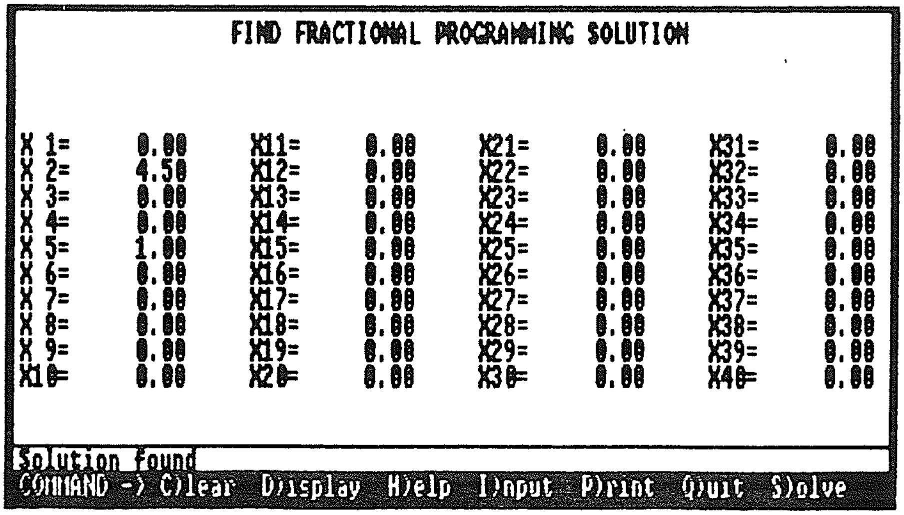
Fig. 5 Input objective function coefficients



```
I N P U T   D A T A

F1) Return to main menu
F2) Define Type of Problem ?      (Fractional)  (Linear)
F3) Define Type of Optimization ? (Minimize)    (Maximize)
F4) Define Objective Function ?
F5) Define Constraint Equation(s) ?

                 Define Constraint Equations

Equation # =  1
Equality sign: ≤  =  ≥
Right-Hand-Side =       9.00

C 1=    -1.00    C 6=     0.00    C11=     0.00    C16=     0.00
C 2=     2.00    C 7=     0.00    C12=     0.00
C 3=     0.00    C 8=     0.00    C13=     0.00
C 4=     0.00    C 9=     0.00    C14=     0.00
C 5=     0.00    C10=     0.00    C15=     0.00

CHOOSE => Esc)ape E)quation = C)oefficients R)ight-Hand-Side S)ign
```

Fig. 6 Input constraint equation data

The SOLVE command attempts to find a solution to the program entered and displays a summary of the problem and the solution found as shown in Figure (10). For LFP, the program linearizes the objective function then calls the Two-Phase Simplex routine repeatedly until there is convergence on a solution. The first step in the Simplex method analyses the constraint equations, and adds surplus, slack and artificial variables as required. The next step follows the Simplex method for solution of the linear program.



```
                     FIND FRACTIONAL PROGRAMMING SOLUTION


X 1=      0.00      X11=      0.00      X21=      0.00      X31=      0.00
X 2=      4.50      X12=      0.00      X22=      0.00      X32=      0.00
X 3=      0.00      X13=      0.00      X23=      0.00      X33=      0.00
X 4=      0.00      X14=      0.00      X24=      0.00      X34=      0.00
X 5=      1.00      X15=      0.00      X25=      0.00      X35=      0.00
X 6=      0.00      X16=      0.00      X26=      0.00      X36=      0.00
X 7=      0.00      X17=      0.00      X27=      0.00      X37=      0.00
X 8=      0.00      X18=      0.00      X28=      0.00      X38=      0.00
X 9=      0.00      X19=      0.00      X29=      0.00      X39=      0.00
X10=      0.00      X20=      0.00      X30=      0.00      X40=      0.00

Solution found
```

Fig. 7 Solution to the Fractional Programming Problem

The PRINT command produces a paper copy of the problem and of the solution found.