THE UNIVERSITY OF MANITOBA

OPERATION BASED COSTING MODEL FOR MEASURING PRODUCTIVITY IN PRODUCTION SYSTEMS

by

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A Thesis
Submitted to the Faculty of Graduate studies
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ABSTRACT

Cost, as a basic measure of productivity, and cost measurement and analysis, as a subject of study, are not considered part of academic training and practice in Industrial Engineering. This thesis provides evidence to prove that the founders of the profession recommended the use of cost to measure productivity, by measuring the cost of employed resources, in detail. Operation Based Costing, a cost measurement technique specifically designed to measure productivity and to meet the cost information requirements of engineers and shop floor management, is described in this thesis. The technique is helpful in generating detailed cost information of resources for engineers and shop floor managers, who are tasked to improve production processes for reducing the cost of production. The structure of the technique matches the typical manufacturing operation structure, and can employ a maximum of eight resource categories, i.e. Machine, Fixture, Operator, Space, Contract, Incentive, Material, and Tied Capital resources.

In this thesis, it is shown that the use of physical productivity measures is not suitable to measure productivity at functional levels, and at the firm level. A case study of a mining company shows that the use of different physical productivity measures for different parts of a production process incorrectly measures productivity. In another case study of a tractor manufacturing company, it is shown that the improvements shown in the physical productivity measures do not always mean reduction in cost.

Resource Cost Productivity, a measure of resource use efficiency, is developed in this thesis to determine the productivity loss of a production process. Synchronization problems that occur between suppliers of inputs and production operations, within production operations, between production operations at the shop floor, between customers of products and production operations, and the availability of idle plant capacity, are the main causes of productivity loss, identified in this thesis. A brief methodology is also described to determine the share of productivity loss due to any identified cause, for the purpose of designing the process improvement project for reducing the cost of production.

At the end, the Operation Based Costing technique is compared with the Activity Based Costing technique to emphasize the differences in terms of basic concepts, objectives, perceptions, structures, approaches, capabilities, and limitations.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL BACKGROUND

For manufacturing in the western economic environment, the basic question is always: How can the desired product be produced for the least money? Because of this fundamental requirement, manufacturing productivity and manufacturing cost are tightly linked to the extent that Productivity is the inverse of Cost. The definition of productivity and other productivity related terms used in this thesis are defined and explained in Appendix 1.

In this chapter, the general background of the research project is provided, and a brief introduction of the research study, is discussed. The research project on measuring productivity in terms of cost in industrial engineering area is undertaken to help bridge the gap between education & research on the one hand, and professional practice on the other.

Cost is the ultimate measure of productivity in industry, and cost reduction is one of the main objectives of industrial engineering professionals working in industry. However, during their education and training in engineering schools, engineers are not exposed to the tools of cost analysis.

Production costing and cost analysis is commonly considered as a part of the accounting and management professions. Therefore, education and training in cost measurement and cost analysis is not popular in engineering schools.

The survey of historical literature related to the evolution of industrial engineering, as a separate and distinct field, reveals that manufacturing cost analysis is a part of the industrial engineering package because cost is the ultimate measure of efficiency. However, over a period of time cost analysis as a field of study was neglected in engineering education and research, because it was not considered scientific.

Industrial engineers work on physical resources in production systems. Therefore, most often, they use physical productivity measures to measure the effect of improvements made in the system of production, with the assumption that the improvement in the physical productivity measures means the improvement in overall productivity of the production system. That assumed to mean the reduction in the cost of production.

Evidence is also available in the literature that some engineering professionals have emphasized the importance of measuring productivity in terms of cost. A few of them have made an effort to use Activity Based Costing to measure it. The Activity Based Costing technique was developed to measure the cost of production more accurately in multi-product production systems. In this research, I tried to use and improve Activity Based Costing technique to get a more detailed statement about the cost of operations in production system. However, the detailed study of this technique showed that it does not have a structure to answer the questions: Where are the costs in a given production system? What is the share of each resource in the cost of each operation? What is share of each operation in the cost of each department? What is the share of each department in the total cost of a product or service? How productive is the use of resources employed in each operation, in each department and in the total system of production? These are the questions an industrial engineer needs to answer to identify the areas where suitable improvements can be made to reduce the cost of production.

The key to successful cost reduction is to identify the areas in a production system with low productivity, and then to improve it. The identification of low productivity areas can be achieved by measuring the costs in production systems at each operation level and at each resource level. There is no costing technique available that can help measure the cost of each operation and the cost of each resource employed in the system of production. In this research, a new cost analysis system called Operation Based Costing is developed to measure the costs of operations and resources employed in production systems. With the help of this technique, the productivity and productivity loss can be measured, causes of productivity loss can be identified, and the share of productivity loss in terms of percentages and in terms of absolute dollars can be measured. This type of information can lead to identification of resources in operations where significant savings in cost can be made. It can also guide management of production systems to plan and execute savings in cost.

In this research, historical evidence is provided to show that the subject of cost measurement and cost analysis is not new in Industrial Engineering. It has been used to measure productivity in the past and it was considered an integral part of the Industrial Engineering curriculum and practice.

The improvements in physical measures of productivity do not always mean reduction in the cost of production. Cost as a measure of productivity is better than any other physical measures of productivity used in industry.

The complete list of research objectives of this study is provided below.

1.2 THE RESEARCH OBJECTIVES

1. To show that cost analysis is a part of the Industrial Engineering profession
2. To show that physical productivity measures do not always represent the cost behavior of the resources used in production.
3. To develop a general costing technique to accurately measure productivity in terms of cost in production systems.
4. To measure the productivity of a production system in terms of monetary units using the general costing technique of 3 above, with the information generated by computer simulation models.
5. To identify the causes of productivity loss and the share of each cause, in the use of resources at the operation level, department level and system level.

1.3 SCOPE OF THE RESEARCH STUDY

In a broad sense, functions of a production organization can be categorized as production and distribution, marketing, product development, human resource and other support services, and direction and control.

The focus of this research study is on the production and distribution function that includes: purchase of raw materials and supplies; receiving and inspection operations;

raw materials storage; shaping operations; assembly line operations; rework operations; product warehousing; product distribution and customer problem handling operations.

1.4 RESEARCH METHODOLOGY

Case Study Method

1.4.1 CASE STUDIES USED

1. The system of Nickel Ingot production from ore at INCO, Thompson, Manitoba, Canada
2. The "Touch-Up & Paint Shop System" of New Holland Canada Limited, Winnipeg, Manitoba, Canada

1.4.2 RESEARCH TECHNIQUE

1. Facts Based Process Analysis
2. Computer Simulation

In each case study, the system is studied by identifying each operation and the total number of operations. The sequence of operations on material input, the time of each operation, the buffer space and buffer capacity between two consecutive operations, the distance between operations, and the quantity and quality of resources employed in each operation, are studied in detail. The quality and quantity of inputs and outputs and the time interval of inputs and outputs is studied at both the operation level and the system level. Additional production and process related information was also collected from production supervisors and plant management.

The production processes are simulated on the basis of detailed information received from management and process related facts collected directly. The models were validated under various production conditions, and then various real production scenarios selected by management were tested and studied in detail. The information generated using simulation models under various production conditions is further used to measure productivity, productivity loss and the causes of productivity loss at the operation level and at the system level.

1.5 BRIEF OVERVIEW OF RESEARCH WORK

In Chapter 2, the historical literature related to Industrial Engineering is surveyed to demonstrate that cost measurement and cost analysis, as a field of education and research was part of Industrial Engineering. The founding fathers of Industrial Engineering also advised, in their writings, the use of cost as a measure of productivity in industry. Other recent studies cited in this chapter, also indicate the practice of cost analysis in industry by Industrial Engineering professionals.

In Chapter 3, the traditional and Activity Based Costing techniques are evaluated for their use to measure productivity of operations. The in-depth analysis of these techniques showed that these techniques are not suitable for measuring productivity of operations and resources.

In Chapter 4, computer simulation method to generate information for measuring productivity of resources used in operations is discussed in brief. In this chapter, general simulation process and procedures are developed to get more refined information about operations. A list of questions is also provided in this chapter that can be answered using computer simulation approach.

In Chapter 5, a case study of INCO, Thompson, Manitoba is discussed to demonstrate that the use of different physical productivity measures for different production segments of the production process does not provide the total picture of productivity to management. These measures fail to represent the effect of other factors in terms of cost, affecting the production process directly or indirectly.

In Chapter 6, a newly developed cost measurement and cost analysis technique, Operation Based Costing, to measure productivity of operations and the system of production, is discussed. The technique has a functional structure that matches the structure of an operation in a manufacturing system. Since the structure of each operation can be simulated, the technique can be used with computer simulated models, to study the productivity of a simulated production scenario of a production system.

In Chapter 7, the Operation Based Costing technique is used to measure the cost of manpower resources in a case study of the 'Touch-up & Paint Shop System' of a tractor manufacturing company. The cost as a measure of manpower resource productivity, is compared with physical productivity measures related to the manpower resource, to show that physical productivity measures do not always represent the real cost behavior of the resources in production systems. In this chapter it is shown that physical productivity measures are not relevant to measure productivity in terms of cost.

In Chapter 8, the information generated with the help of a computer simulation model is used in the Operation Based Costing technique to measure Resource Cost Productivity for a manufacturing system. The measure of Resource Cost Productivity is helpful in identifying and quantifying the causes of productivity loss for a given resource in a given production system. The identification and quantification of the causes of low productivity leads shop floor management to identify the areas and resources in the production system, where improvements can be made to reduce costs.

In Chapter 9, Operation Based Costing is compared with Activity Based Costing to show the primary differences in objectives, perceptions and approach.

In Chapter 10, the findings, limitations and future directions of the research study are concluded.

CHAPTER 2

COST AS A PRODUCTIVITY MEASURE IN INDUSTRIAL ENGINEERING - LITERATURE REVIEW

2.0 ABSTRACT

The founding members of the Industrial Engineering profession emphasized and used cost as the complete measure of productivity in production systems. Over a period of time, a majority of engineering professionals opted to use physical measures of productivity rather than cost, because the measurement of physical dimensions is their normal practice in industry. However, cost measurement and cost analysis, as a subject of study, remained part of the Industrial Engineering discipline, but its study and practice became less popular over time among engineering professionals. In this chapter, the use of cost as a measure of productivity in the past and its importance in the engineering profession is emphasized, so that engineering professionals will not feel out of place while studying and practicing cost measurement and cost analysis in industrial organizations.

2.1 INTRODUCTION

The profession of Industrial Engineering deals with the improvements in operations to increase productivity that results in the reduction of cost in production systems.

Engineers work to improve the efficacy of physical resources in production systems. Most often, they use physical measures of productivity to measure the efficient employment of resources. For example, units of production per unit of time, units of production per unit of machine hour or man hour, or units of output per unit of input. These physical units of productivity measurements are studied most often without taking into consideration the other factors influencing the system of production as a whole.

In section 2.2 of this chapter, the relationship between cost and physical productivity measures is visited, to expose the underlying assumptions of the relationship. Research studies are presented to indicate that physical productivity measures do not represent the cost behavior of resources in production systems.

In section 2.3, the importance of cost as a ultimate measure of productivity in industry is emphasized for the bottom line of business enterprises.

In section 2.4, an historical perspective is provided to show cost measurement and cost analysis as part of professional education and practice, and cost as a proposed measure of productivity in Industrial Engineering during various stages of its evolution.

In section 2.5, recent studies related to Activity Based Costing by engineering professionals are cited to show the continuity of interest of industrial engineering professionals in measuring productivity in terms of cost.

At the end, in section 2.6, studies cited in all parts of the chapter are summarized and concluded.

2.2 VISITING PHYSICAL PRODUCTIVITY AND COST RELATIONSHIP

The main focus of engineering professionals is to improve the system of production. Most often, reducing the cost of production is not even a consideration for them. However, if they have been told to decrease the cost of production, they tend to improve the system so that consumption and employment of physical resources in a production system is reduced, and hope that this leads to cost reduction.

Two assumptions lead to the use of physical measures for measuring productivity.

1. There exists an inverse relationship between physical measures of productivity and cost of production.
2. The cost of production of a product or a service, can be reduced by increasing the physical productivity of a resource that is used in a production operation.

These relationships may hold true provided the reduction in the physical quantity of one resource in one operation does not increase the consumption or employment of other resources in the same operation and / or in other operations of the production system.

The majority of production operations, in reality, use many types of inputs to produce many types of outputs. Inputs undergo various operations and go through various departments before they are converted into outputs. The varieties of input resources and their quantities change with changes made inside the production system, and changes that happen outside in market conditions. Under such conditions, it should not be assumed that the increase in the physical productivity of a resource actually reduces the cost of production.

Gain in the physical productivity of one resource may cause loss in others. For example, increase in the productivity of labor by employing high production capacity machines may cause loss in the productivity of machinery employed or vice versa. In a similar fashion, within a production system, gain in the physical productivity measure of one functional area may cause loss in other functional areas.

Sometimes, for different functional areas of an organization, different physical productivity measures are used. For example, in one functional area productivity measurement may be in terms of tons per hour, in another it may be in terms of pounds per machine hour, and yet in an another it may be kilograms or liters per man hour. In such cases, it is difficult to measure the effect of increase in physical productivity in one department over the productivity of the other department.

Sumanth (1979) in his findings on measures of productivity, has labeled physical measures of productivity as partial productivity measures. These measures provide partial information on productivity and can overemphasize one input factor over others to such an extent that the effect of other factors either can be underestimated or ignored.

Managers involved in production decisions, generally, tend to take decisions on the basis of information generated using physical measures of productivity at shop floor level.

Rantanen, Hannu Juhani, (1995), in a case study of a firm, found that decisions based on measures of productivity used at operational levels incorrectly suppose that improvement in these measures leads to reduced cost of production. According to him, productivity improvemenat at the firm level, not just at the functional level, can only be helpful in reducing the cost of production.

2.3 COST AS A MEASURE OF PRODUCTIVITY

One of the main objectives of commercial and business organizations, is to generate profit for their existence and growth. In a competitive business environment, companies cannot afford to increase prices of their products and services to increase the margin of profit. Under such business circumstances, increase in profit can only be achieved by increasing sales and reducing cost of production by efficient employment of resources in a production system.

The objective of industrial engineering professionals involved in commercial production, is to reduce the cost of production. Engineers are exposed only to physical measurements in engineering schools during their education and training, therefore, they tend to measure productivity in physical terms only. To measure productivity in terms of cost, they have to be exposed to cost measurement and cost analysis techniques in engineering schools. Cost is the only measure of productivity that can be relied upon to measure improvements in production systems.

2.4 HISTORICAL PERSPECTIVE

The use of cost as a measure of productivity is not new among engineering professionals. Literature describing the history of engineering, provides significant evidence of its use and promotion among engineers by the founding members of the engineering discipline.

Henry C. Metcalf (1885), an engineering graduate of West Point in 1868, was captain in the US Army Ordnance Department. As a superintendent of ordnance depots, he realized the importance of cost measurement and cost analysis in manufacturing over other measures of performance. To him, cost was the universal measure of productivity. He proposed to measure costs to the minutest detail possible within the organization. His interest was to measure the efficiency of manufacturing and administration on the basis of cost. He was also interested in the future planning of cost of production by knowing the detailed elements of cost involved for each operation performed on a product during manufacturing process. He wrote and got published a book titled "*The Cost of Manufactures and the Administration of Workshops, Public and Private*" in 1885. This book by engineer Metcalf provides sufficient evidence of the use of cost as a productivity measure in the engineering profession more than a hundred years ago.

Henry Towne (1886) was another engineering professional who wrote a paper titled '*Engineer as an Economist*' for one of the meetings of The American Society of Mechanical Engineers in New York. He explained to his audience that in a majority of cases, whatever an engineer does in the business organization, is ultimately measured in terms of monetary units e.g. dollars and cents. He outlined the various duties and responsibilities of an engineer to successfully conduct the business of an enterprise. Determination of cost on the part of an engineer was one of the important duties, Henry Towne stressed, in that meeting. To achieve this end he proposed the establishment of a separate shop accounting section at the work shop level to collect cost information, to meet the cost information needs of engineers.

According to the reference cited by Hugo Diemer (1910), an engineering graduate of Ohio State University and later professor of industrial engineering at Pennsylvania State

College, in his writings, F.W. Taylor, the founding father of Scientific Management and modern Industrial Engineering appealed that the investigation of shop statistics and cost data, should be taken care of by professionals of industrial engineering. Hugo Diemer, himself held similar views and he proposed that an industrial engineer should have the competence of providing good business advice to the corporation, in addition to his technical expertise.

Charles Buxton Going (1911), managing editor of the Engineering Magazine and lecturer at Columbia University in the Department of Mechanical Engineering, published a book titled, "*Principles of Industrial Engineering*" in 1911. In this book, he defined the term industrial engineering as "*A formulated science of management that directs the efficient conduct of manufacturing, transportation, or even commercial enterprises of any undertaking, indeed, in which human labor is directed to accomplishing any kind of work.*" He called it, "*New branch of engineering grown out of the rise of, and enormous expansion of the manufacturing system.*" This branch of engineering, according to him, "*Has drawn upon mechanical engineering, economics, sociology, psychology, philosophy and accountancy to form a distinct body of science of its own*". In his definition of industrial engineering, inclusion of the subjects of economics and accountancy testify the fact that cost measurement and cost analysis were considered part of industrial engineering theory and practice at that time. Charles Going (1911) also emphasized that the management of men, and definition and direction of policies in financial and commercial fields are also included in the duties of industrial engineers in addition to the "*technical counsel and superintendence*" of technical elements of a business enterprise.

Close to the end of the 19th and the beginning of the 20th century, the scientific Industrial Engineering movement led by F.W. Taylor was gaining momentum among engineering professionals. During this period, partly because of Taylor's ideas and efforts, the Science of Management was also emerging as a new discipline, distinct from engineering. The issues related to the Science of Management were also presented to The American Society of Mechanical Engineers and in the Engineering Magazine. According to Hugo Diemer (1910), some engineering professionals opposed discussions on management and cost issues at various meetings of engineering societies and in engineering publications. They argued that engineers should discuss technical matters dealing directly with pure mechanics. The issues related to management and cost should only be discussed by accountants and book keepers. On the other hand, book-keepers, accountants, auditors and statisticians practicing their professions were of the view that engineering professionals are not trained enough to discuss and practice the issues related to cost. In this process, the study of cost and other newly emerging human and organizational concepts in the engineering field were put together to be studied as part of the Management discipline rather than the parts of Industrial Engineering discipline.

Later on, the study of cost in the engineering discipline was neglected, and it was considered as part of the management discipline. In the management discipline, financial accounting gained more importance among practitioners and academicians and cost accounting got relegated to the background. Vollmers (1994), provided evidence to this effect in the findings of her Ph.D. thesis. She analyzed the financial and engineering literature related to the period from 1925 to 1950 of the United States. One of her findings was that financial accounting dominated cost accounting in the period between 1925 and 1950 in industry and in academic institutions in the United States of America. In her words, " *Financial accounting dominated and academia supported that dominance.*" According to her, domination of financial accounting over cost accounting, restricted the spread of costing knowledge among professionals in that period. In her research she also discovered that there was a general tendency among engineers during that period to drift away from the study of cost. This finding of Vollmers reinforces the similar views expressed by Hugo Diemer (1910) in the first decade of 20th century. Even now, at the end of the 20th century, a similar tendency is visible among engineering professionals.

Though the general tendency among engineers was to drift away from the study of cost and not to use it as the primary measure of productivity, yet, a few of them were still interested in it. Henry Metcalf (1885), Henry Towne (1886), Hugo Diemer (1910), F.W. Taylor and Buxton Going (1911) were the prominent engineering professionals who advocated the study of cost at the end of the 19th and beginning of the 20th century. Vollmers (1994), also reported similar findings in her survey of literature from the period of 1925 to 1950. Oswald and Toole (1978), also reported similar results of a survey conducted on 104 small, medium and large scale companies in United States. They observed engineering professionals working as members of the groups involved in the estimation of cost at shop floor levels. However, Oswald and Toole also mentioned that in engineering schools, cost as a field of study is not offered to engineers as part of their professional education. They proposed that the cost estimation, as a part of the engineering discipline should be given more attention in engineering schools.

The research findings by Oswald and Toole (1978) provide evidence that the cost estimation is a part of the industrial engineering professional practice in industry, but, cost estimation as a part of academic discipline is neglected in engineering schools. Howell (1995) also expressed similar views in his comments on industrial engineering education and on the responsibilities of industrial engineering professionals, in his presentation at the 1995 International Industrial Engineering Conference. He advised industrial engineers to reclaim the traditional industrial engineering responsibilities, such as, measurements of labor costs, manufacturing methods, and productivity improvement along with other new emerging responsibilities so that their demand in industry, job title and functional identity remains intact. According to him, cost estimation should be one of the areas for which an industrial engineer should be responsible and accountable. In his view, Industrial engineering professional's responsibility and accountability for traditional areas leads to their success and importance in industry.

2.5 ENGINEERING PROFESSIONALS AND ACTIVITY BASED COSTING

The recent emergence of Activity Based Costing, has attracted the attention of engineering professionals, and a few of them have ventured to study the cost aspect of industrial operations themselves. Activity Based Costing, also known as 'ABC', was developed by Robert Kaplan and Robin Copper, to address the limitations of the traditional costing approach and to provide management with better product cost information.

Activity Based Costing has made it possible, to some extent, to cost products more accurately by distributing the overhead costs on the basis of activities that are involved for the manufacture of products.

The basic reasons of attraction of some engineering professionals towards Activity Based Costing is that it provides an opportunity to allocate overhead costs in a more rational way as compared to traditional costing techniques. Activity Based Costing provides better cost information about an activity or a product, so that the activities and products with higher cost get their immediate attention for cost reduction. Recent studies by Barnes (1991), Dhavale (1992), Eftekhar et al (1995), and Eaglesham (1998), found in the Industrial Engineering literature, broadly provide evidence in this direction.

Lenz and Neitzel (1995), have even gone beyond the study of Activity Based Costing. To evaluate and compare strategic manufacturing alternatives before their actual implementation, they developed their own methodology to develop a cost simulation model. In this model, they have used a cost equation that consists of eight components, such as station cost; labor cost; overhead cost; inventory cost; automation cost; capacity cost; material cost; and indirect cost. In this type of modeling, they claimed, all performance measures can be translated into costs by applying cost equations to the results of factory model.

These studies provide reasonable evidence that at least a few engineering professionals were and are interested in cost measurement in industry as the measurement of productivity. However, the available costing methods are not robust enough to help find the cost information needed at the shop floor level. The methods do not match the production structure of the organizations; therefore, the professionals involved in operations most often fail to exactly pin point the resources, operations, processes, and subsystems that need their immediate attention to reduce the cost of production. Moreover, accounting and finance departments within the organizations are designed to collect and pool cost information for stock holders, bankers, taxation departments, top management and other government agencies outside the firm. Most of their time and energy is spent in meeting the needs of these external customers of information. For internal customers at the shop floor level, either the cost information system is not in place, or they do not have sufficient time to meet their requirements.

2.6 CONCLUSIONS

Cost as a productivity measure in the engineering profession, is as old as the engineering profession itself. However, over a period of time, engineering professionals neglected this measure in favor of physical productivity measures. Cost measurement and cost analysis as a field of study were grouped with other subjects of the newly emerged Science of Management. In the Management discipline, the subject of financial management attracted more attention from practitioners and academicians, and the subject of cost measurement and cost analysis was relegated to the background.

Cost is the most common denominator to which all resources used, can be translated throughout the manufacturing system, and this measure is also used directly to evaluate the bottom line of a manufacturing system. Therefore, the measurement of productivity in terms of cost should not be ignored by those who are involved in manufacturing and are also responsible and accountable for reducing the cost of production. It can help identify the resources and operations that could be improved to raise productivity, not only of a functional area but also of the system as a whole. Cost is the direct measure of productivity that can help engineering professionals evaluate their decisions and actions in terms of money saved in production. Cost measurement can work as a motivating force for all those who are involved in improving the cost effectiveness of manufacturing systems.

CHAPTER 3

COST ANALYSIS TECHNIQUES – A REVIEW

3.0 ABSTRACT

The Traditional Costing techniques only provide information about the cost of production of products and services. The Activity Based Costing technique provides additional information about the cost of activities. The technique helps in distributing the cost of overheads to products and services in a more rational way, that has attracted the attention of engineering professionals to use it to measure costs in production systems.

The Activity Based Costing technique is not suitable for measuring productivity of operations and resources, employed in production systems. The structure of the technique does not match the structure of a production operation and it reflects the perception of an outsider looking into a production system. The concept and definition of an 'activity' provided in Activity Based Costing literature is vague and unclear. The cost of an activity is also measured on an average basis. The depreciation policy and cost measurement procedures used are similar to traditional costing techniques. In this chapter, the technique is evaluated from an Industrial Engineering perspective (Insider looking inside the system), to make its technical limitations clear to engineering professionals who may consider using it to measure productivity in terms of cost, in production systems.

3.1 INTRODUCTION

The history of cost analysis, described in Chapter 2, is restated briefly to give a reference for the rest of the chapter.

The founders of the industrial engineering profession emphasized and used cost as one of the important measures, to measure the productivity of production systems. Over a period of time, a majority of engineering professionals opted for other physical productivity measures, and cost as a productivity measure was dropped. Later on, cost measurement as a field of study was considered to be a part of the management discipline

In the management discipline, financial accounting gained more importance than cost accounting, among practitioners and academicians during its initial evolution and development period. Cost accounting as a field of study was relegated to the background. The engineering professionals also kept drifting away from the study of cost and kept moving towards the use of physical measures to measure productivity. However, as discussed in some detail in Chapter 2, a few of them were still interested in cost measurement. Henry Metcalf (1885), Henry Towne (1886), Hugo Diemer (1910), F.W. Taylor, and Buxton Going (1911) were the prominent engineering professionals who advocated the study of cost by engineering professionals, at the end of the 19th and beginning of the 20th century. Gloria Lucey Vollmers (1994) also reported similar findings in her survey of literature from the period of 1925 to 1950. Again, Oswald and Toole (1978) reported similar results of a survey conducted on 104 small, medium and large scale companies in United States. The Oswald and Toole study also indicates that, in practice, engineering professionals do become involved in estimating cost at the shop floor level as part of the cost estimation team.

Though management and engineering professionals were involved in the measurement of costs at various levels of organizations, no serious research effort has been made by them to look into the cost measurement techniques for a long time. In this chapter, traditional and Activity Based Costing techniques are discussed in detail to evaluate their suitability for measuring productivity of operations in terms of cost.

In section 3.2 of this chapter, the traditional costibg technique is described and explained in brief. In section 3.3, the Activity Based Costing is described and explained in brief along with its strength over the traditional costing technique. In section 3.4, factors affecting the adoption and implementation of Activity Based Costing in organization are summarized.

In section 3.5, an accountant's perception of a production system from traditional, and Activity Based Costing perspective is described. An industrial engineer perception of a production system is also described in this section for making comparison.

In section 3.6, the limitations of Activity Based Costing technique are described to show its unsuitability for measuring productivity for production systems. At the end, in section 3.7, the limitations of Activity Based Costing are summarized.

3.2 TRADITIONAL COSTING TECHNIQUES

The traditional cost measurement technique was evolved to measure the cost of an old type production system, a system where a single type of product is mass produced, with a relatively very low share of overheads and a high share of direct costs. The overhead costs are related to the installation and maintenance of machinery and other infrastructure required to produce the products. The cost of direction, supervision and training of workers can also be included in the overheads. The cost related to work facilities such as cafeteria, wash rooms, first aid facilities and parking lot, are also part of overhead costs. The direct costs are related to the cost of direct operator time or any other direct input used to produce a product item.

The technological development, competition for the market, and computerization have forced production systems to become more flexible and complex. Therefore, a manufacturing system may be used to produce more than one type of product. Each product is now made in various styles, shapes, colors, and with host of other variations. In these type of manufacturing systems, the relative share of overhead cost is more than that of direct cost.

The traditional costing technique assumes that different products produced on the same shop floor use common overheads proportionate to their direct labor time or any other direct resource employed. Practically, this assumption is not true for modern production systems, because different types of products produced in the same work facility, and these different products may rarely use common overheads proportionate to the direct labor time use. Therefore, cost figures calculated with this technique may provide a very distorted picture of production cost to the users of information.

In actual practice, in a majority of the cases, different products or different styles of a product may use common overhead resources, but not in proportion to the direct labor time or any other direct resource employed. In such cases, there is a possibility that the real cost of production of each product type, may be more or less than the cost calculated by using the traditional costing technique. For example, a company produces two products, 'A' & 'B', in equal quantities employing equal number of workers for each product and these products use a common overhead worth of $1000. If the common overhead is actually used 60 % for product 'A' and 40 % for product 'B' then 60 % of the overhead cost should go to product 'A' and 40 % should go to product 'B'. However, in this example, traditional costing technique will distribute half of the cost to product 'A' and the other half to product 'B', thus subsidizing product 'A' at the cost of product 'B'.

The selling price of product, often, is set at a certain margin of profit over the cost of production. Thus, there is every possibility that the traditional costing technique could generate cost information leading to a margin of profit which is much lower or higher than planned. However, if the cost information generated is close to its real cost then the product price can be made more rational and uniformly profitable.

In 1980s', a new costing technique called Activity Based Costing (ABC) has been developed and a small percentage of organizations have adopted it. The use of traditional costing technique is still prevalent in most of the organizations.

3.3 ACTIVITY BASED COSTING TECHNIQUE

The development of the Activity Based Costing technique, in the 1980s' by Robert Kaplan and Robin Cooper, renewed the research interest in costing methods among engineering professionals. A few of them published their ideas about Activity Based Costing in engineering literature. This is evident from some studies related to Activity Based Costing by Barnes (1991), Dhavale (1992), and Eftekhar et al (1995), found in recent Industrial Engineering literature.

The Activity Based Costing technique measures the cost of goods and services produced more accurately than the traditional costing technique does. It paves the way for a relatively rational distribution of the overhead costs for the various kinds of products and services produced in a manufacturing system.

In the Activity Based Costing technique, an activity is taken as the basic unit of work that drives overhead cost to products through cost drivers. The activities that cause overhead costs may be independent of the volume of production. It is the volume of these activities rather than the volume of production that consume overhead resources and determine the level of overhead cost used. For example, the cost of a common wash room in a system of production is an overhead cost and the use of a common wash room by the workers is an activity. The cost driver that drives overhead cost to the product through the use of the activity is the number of times the wash room has been used by the department workers. The cost driver is not driven by the number of units produced in production.

A product or service produced in a system of production uses different overheads through different kinds of activities during its course of production. In Activity Based Costing the cost pools are identified and measured for each kind of activity. The data related to quantity of activity cycles performed in each activity, is collected and the average cost for one activity cycle is calculated. The calculated average cost of an activity cycle, for each activity, is used to pool its share of cost to the product cost pool through the use of cost drivers. The product cost pool is then divided over the volume of production. For example, the cost of wash room used is $1000 a year and one worker from department 'A' used this washroom for 360 times in a year and the other worker from department 'B' used it for 440 times in a year. In this case the total volume of activities of using the wash room are 800 and the over head cost is $1000 per year. The average cost of each activity is $1.25. The cost driver that drives overhead cost to department 'A' is 360, because the wash room have been used by its worker for 360 times in a year. The cost driver that drives the overhead cost of using the wash room to department 'B' is 440. Thus the wash room cost distributed to department 'A' is $450, and to department 'B' is $550. If the wash room overhead cost is not distributed on the basis of activity, then the cost to each department would have been $500 under the traditional costing technique.

3.4 THE ADOPTION & IMPLEMENTATION OF ACTIVITY BASED COSTING

The Activity Based Costing technique is better than the traditional costing technique in providing better cost information about products by distributing the overhead cost on the basis of volume of activities used. This type of information provides a good background to management for making good price and product mix decisions. However, the technique is implemented only in a small percentage of the total number of companies (Platt, 1997).

Basuki (1995), identified high overhead costs, low direct labor, high diversity and variety of products, as environmental factors that help gain the benefits of Activity Based Costing System. According to Krumwiede (1996), high potential for cost distortions and high usefulness of cost information, large size of organizations, top management support and training, and information technology sophistication, are some of the common factors that determine the adoption and implementation of Activity Based Costing System.

Morakul (1999), found that an ABC system that causes empowerment and redistribution of power encounter a higher level of resistance in organizations.

Caudle (1999), observed in his study that most of the firms reported improved information for decision making, using Activity Based Costing system. However, the management of these organizations were not sure about the relationship between the improvement of their competitive positions in their respective markets with that of 'ABC' generated data use in decision making.

3.5 PRODUCTION STRUCTURE - DIFFERENT PERCEPTIONS

A production costing technique reflects the perception of its creator about the structure and function of the production system for which the technique is developed.

3.5.1 TRADITIONAL COSTING TECHNIQUE - ITS PERCEPTION OF A PRODUCTION SYSTEM

Accountants are interested in the cost of a unit of product or service produced in a production system. They look at a system as outsiders, and the traditional costing techniques developed by them reflect their perception of a system i.e. a system made of fixed capital resources (Land, Buildings and Machinery) that takes in variable resources (Labor and materials) to produce outputs. These costing techniques, look at fixed resources as the causes of indirect costs, and variable resources as the causes of direct costs. The employment of variable resources change with the variations in the volume of production. The change in the use of variable resources cause variation in the direct cost, while indirect costs caused by the fixed resources remain more or less constant, for a certain range of production volume. The direct and indirect cost categories defined, are used to calculate the cost per unit of output.

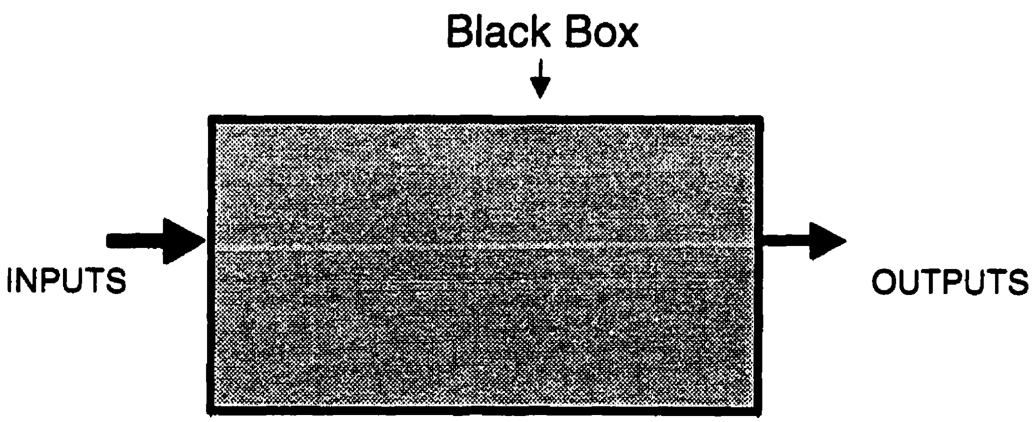

Figure 3.1. Showing production system as a black box

The traditional costing techniques consider internal structures of production systems as black boxes to which material inputs are fed at one end to get outputs at the other. It is silent about the process of production that converts raw materials into finished products. The diagrammatic representation of the perception of a production structure is shown in Figure 3.1.

3.5.2 ACTIVITY BASED COSTING - ITS PERCEPTION OF A PRODUCTION SYSTEM

The Activity Based Costing technique reflects the perception of a production system with a bit more functional detail. The technique is developed to accurately measure the cost of a unit of output in a multi-product production system, where all products do not use the common overhead resources to the same level. The technique is designed to allocate the cost of overhead resources to different products on the basis of activities used. In this technique, it is assumed that it is the quantity of activities performed on products, not the quantity of output, that determine the use of overhead resources (Fixed resources) in a production system. The use of this technique allows more rational distribution of overhead costs to the products and services produced. However, this technique does not look inside each activity, and assumes an activity as a black box function inside a production system.. It is silent about the mechanism and involvement of resource use in activities that transforms inputs into outputs. The diagrammatic representation of the perception of an activity inside the production system is shown in Figure 3.2.

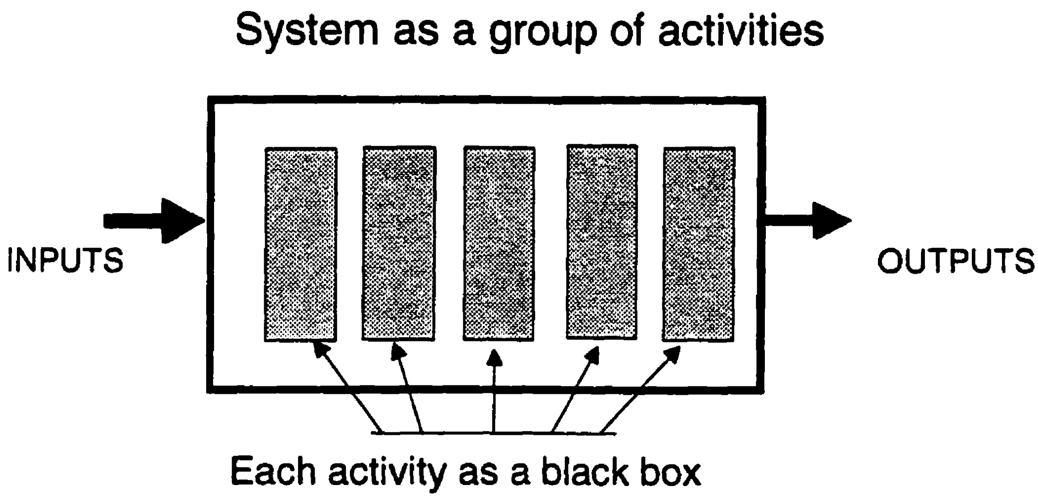

Figure 3.2. Showing production system as a group of activities

3.5.3 PRODUCTION SYSTEM - AN INDUSTRIAL ENGINEERING PERCEPTION

The objective of engineering professionals involved in commercial production, is to reduce the cost of production by improving the productivity of the system. Therefore, cost can be used as a measure to measure improvement in the productivity of a production system.

Engineering professionals are interested in identifying operations and resources in which they can make improvements to raise productivity and reduce costs. They look at the structure of a production system as insiders and view it as a combination of real operations that consume and use resources to produce outputs. A system of production with the operation as a basic unit of work is represented in Figure 3.3.

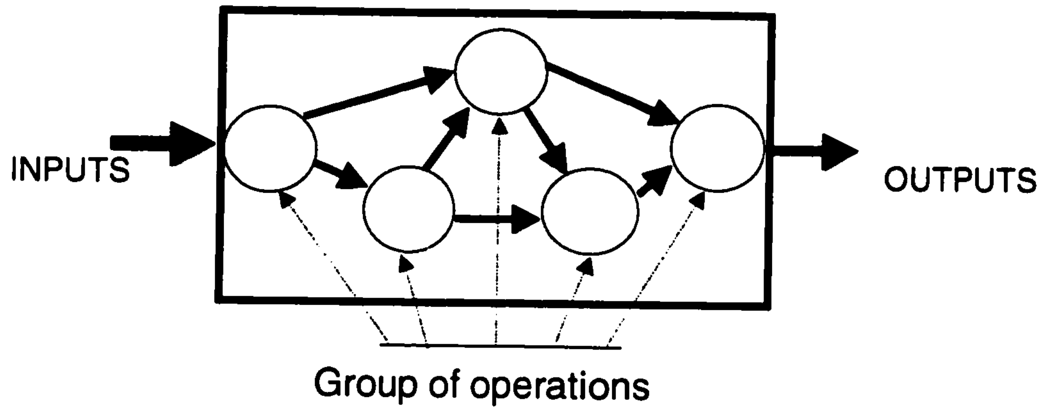

Figure 3.3. Showing production system as a group of operations

Inputs fed to a production system, undergo different operations, and each operation takes some specific quantity of time, called operation time, for its completion from start to finish. During the operation time, employed resources work on material inputs to make a required product.

Engineers also look inside each operation to improve its structure as well. They look at machinery, fixtures, and operators employed. They look at the area of work space used, incentives paid, contracts involved, materials used, and inventory of raw materials required in and around each operation, to raise productivity. The diagrammatic representation of an operation in detailed form is shown in Figure 3.4.

In the course of an operation, sometimes input materials get damaged and are then recycled. In some cases, input materials get damaged beyond repair and are scrapped. In other cases, some piece of material is either scrapped or wasted.

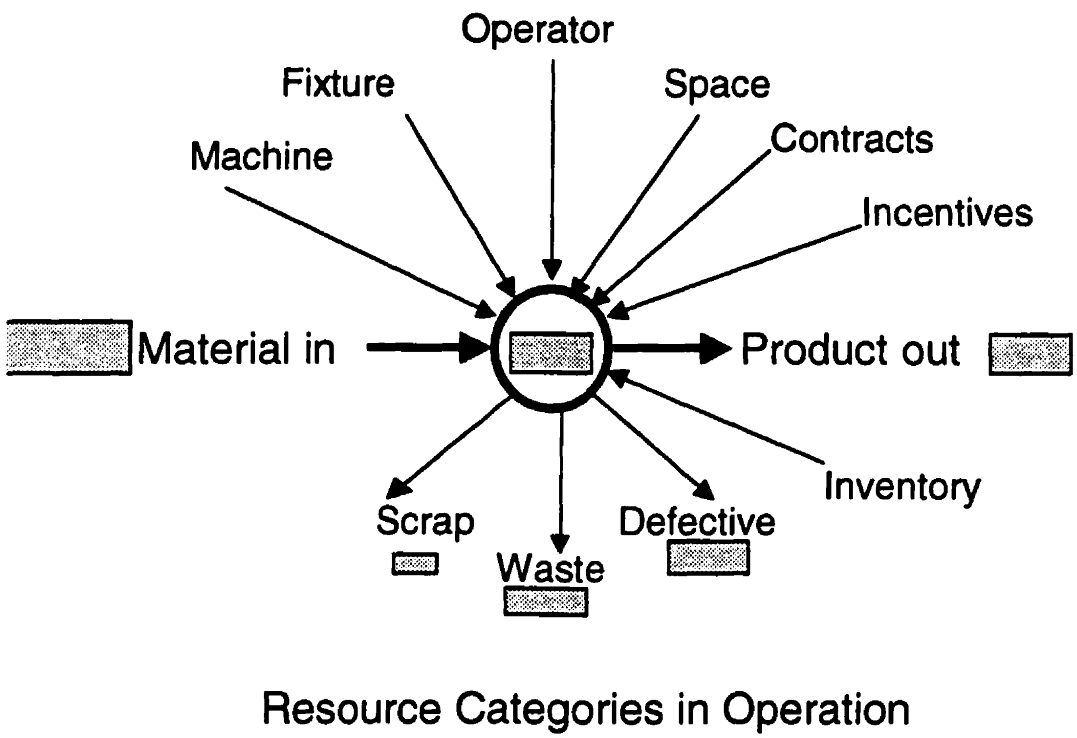

Figure 3.4. Showing 8 resources categories in a production operation

Based on the reality of a production system, engineers are interested in knowing the cost of each operation in the total system of production, and the cost of each resource employed in each operation. They intend to identify the operations and resources where loss of productivity is great and the potential of cost savings is high. Their main task is to identify and then fix the causes of productivity loss, to raise productivity and reduce cost of production. They are also interested in measuring cost of operations and resources used under different production scenarios, to identify a scenario with less cost of production.

Traditional and Activity Based Costing techniques are designed to measure the cost of final outputs. In Activity Based Costing, an activity is considered as a basic unit of work to allocate overhead costs, and in this process, measurement of the cost of an 'Activity' is the basic requirement to arrive at the cost of a final product. Some engineering professionals have tried to use the 'Activity' cost concept to measure costs in production systems. But, an 'Activity' concept has its technical limitations in generating information data that is required by engineering professionals at the shop floor level, to raise productivity and reduce production costs.

The limitations of Activity Based Costing from an engineering perspective are discussed in section 3.6.

3.6 LIMITATIONS OF ACTIVITY BASED COSTING

The following technical limitations of Activity Based Costing have been identified that make it unsuitable for measuring productivity in production systems.

1. Subjectivity in the definition of an activity

Turney, B.B (1991), in his book on Activity Based Costing, has defined an 'Activity', as a 'Unit of work'. The definition of an 'Activity' provided in his book refers to a broad category of work, without any indication of a detailed structural boundary. For example, an activity called 'Ordering of supplies' does not indicate its structural contents and boundary in terms of work components. The various possible work components that a person can include in this activity are:

1. Collection of price quotations
2. Evaluation of quotations
3. Short listing suppliers
4. Researching the short listed suppliers
5. Selecting the suppliers
6. Placing the order for supplies.

It is difficult for different persons to agree on the work components of the activity. Some persons may exclude 'Collection of price quotations', 'Evaluation of Quotations' and 'Short Listing of suppliers' from the activity. Others may only consider 'Placing the order for supplies' as a work component of the activity named "Ordering of Supplies". Therefore, the concept of an 'Activity' definition will vary from person to person, from department to department and from company to company. The activities defined in the form of a broad categorization having similar labels, but with different work components, are not comparable within companies and between companies. The activities having different work components will also have different costs.

2. Activity and sub-activity definition problem

Each activity may have sub-activities representing sub-units of work. The definition of an activity does not help differentiate the components of work between activities and sub-activities. The distinction between an activity and sub-activity is subjective. For one person, a unit of work may be an activity and for an other it may be a sub-activity. For example, in Ore mining, for one person, loading of Ore onto a truck is an activity, and for an other it may be a sub-activity of the Ore hauling activity. Dhavale (1992) expressed a similar concern related to the aggregation of many activities into an identifiable discrete activity and vice versa.

3. Unique nature of each cycle of activity

In production systems, an activity performed in different situations uses different amounts and mixes of resources, which causes the cost of each activity to be different. For example, use of a rail system to haul Ore below the surface level is a different kind of work activity than the use of dump trucks to haul Ore at the surface level.

'Ore hauling' can be defined as an activity but, the activity of 'Ore hauling below the surface of the mine', and activity of 'Ore hauling at the surface of the mine' are two different kind of operations employing different kind of resources, described by the common activity label, 'Ore hauling'. However, in Activity Based Costing the cost of the 'Ore hauling' activity could be an average cost of the two different type of haulage activities.

It is also possible that each cycle of an activity in a group of activity cycles, may use a different quantity of the same group of resources, causing a unique cost for each cycle of activity. For example, for an 'Ore hauling' activity, each cycle of Ore haulage by a truck, from one point to the other, may travel a different length of distance and may haul a different quantity of load.

4. Allocation of cost to products from cost pools

Application of the Activity Based Costing procedure assumes that for a specific activity, each cycle of the activity carries an average quantity of cost from its cost pool to the product cost pool. In reality, the assumption of average quantity of cost allocation from activity cost pools to product cost pools may distort the cost distribution. The activity cycles for two different kinds of products, product A and product B, or for two different styles of the same product, product A1 and Product A2, may use or consume different quantities of the same group of resources employed. For example, in a welding operation, welding together two different products, product A and product B, from parts or subassemblies, may take different times for the set up, and the welding processes. Therefore, each kind or style of product welded together, with the use and consumption of different quantities of the same inputs, will have a different cost of welding. However, in Activity Based Costing, each cycle of an activity (Cost driver) will drive the same average amount of overhead cost to the two different products.

5. Subjective grouping of cost Items

The basic cost data used for Activity Based Costing, is collected by using traditional costing procedures. It involves grouping various costs together under a few cost headings, on the basis of accounting assumptions and the subjective judgement of data processors. For example, the cost of machinery may include only the price of machinery paid to the supplier. The cost of transportation of that machinery might have been allocated somewhere else under the heading of general expenses related to the transportation of goods and materials. In fact, this segment of cost should always be part of the cost of machinery because transportation of machinery is a required step in making the machinery available for operations. Similarly, the cost of installation of machinery, which should be part of machinery, might have been grouped under the general 'Maintenance and Repair' cost heading. This type of cost allocation under different headings of cost, also has its effect on the cost information generated using the Activity Based Costing technique.

Innes, J. & Mitchell, F. (1989), have also shown similar concern about the cost allocation procedures that are not only based on economic considerations but are also motivated by political, behavioral and organizational control factors. Some managers using their power and influence, can transfer some part of their overhead costs to the costs of other departments. In doing so, they can show the reduction in the cost of their activities.

Moreover, the rules of grouping production related cost data under cost headings, may vary from company to company, therefore, the cost information generated using Activity Based Costing, may not be comparable between two different companies producing the same kind of products and services.

6. The nature of cost data used

The nature of the data used in the Activity Based Costing technique is historical and relates to a specific production scenario that has been used in the past. The outcome of the use of past data, can only explain the working of the production method used in the past period. If the production process is changed by reorganization of the resources within the departments, then 'Activity' based generated cost information becomes irrelevant for the new production scenario. The reorganization of resources may change the proportion of their use for each activity. For example, installing electronic water valves in rest room water tanks can reduce the consumption of water for each flushing and thus can reduce the cost of the rest room by saving a large quantity of water each year. If no one in the accounting department notes and adjusts the costs for the structural and water use changes, then there is a possibility of using old cost figures to calculate the future cost of wash room use.

According to Innes, J. & Mitchell, F. (1989), the use of past information as a basis for future cost estimation is useful but its use as a direct input to future decision making is harmful for the organization. The authors have also mentioned about the tendency among manufacturing executives to use the past information as a direct input for developing the future production cost scenarios, because they do not want to upset the cost pools and cost drivers as far as possible. The authors have suggested to make use of the past information as a basis to estimate future costs, but, they also warned that the use of past information as a direct input to a future production scenario could be highly misleading..

7. Depreciation policy for assets

The Activity Based Costing technique uses the same principle of assets depreciation as is used in the traditional costing techniques. In some cases, the depreciation policy used to depreciate assets does not provide the real value of assets at the end of a depreciation period. For example, land and buildings are generally shown as depreciating over time. However, in certain cases the market value of land and buildings may increase over time.

In some cases, the fall in value of a machine is more in the first year of its purchase than in the following years. For example, the market price of passenger cars fall more after its first year of purchase than in the following years. The real value of some machines also depends upon their level of use in a given time period. For example, the fall in value of a mill will be more if it is heavily used than if it is lightly used over a given time period.

For machines, there is two type of value loss: the loss in value due to time and the loss in value due to use. These two types of loss in value of machines are also not taken into consideration for determining the value of assets at the end of a depreciation period.

Moreover, management of companies use different depreciation policies to change the apparent short term financial situation. For example, using a slow depreciation policy will show more profits, helping increase the market price of the company, while using a fast depreciation policy will inflate the company's expenses to reduce the amount of tax payable to the Government. In such cases, management's aim in use of the depreciation policy is not related to the true value of the company's assets.

8. Limited quantity of cost information generated

The technique generates cost information for defined activities that are further used to calculate the cost of various products produced in a manufacturing system. Relatively accurate cost information generated about products, is used by the top management to design better pricing policies for the company's products. However, the cost information generated about activity, does not provide sufficiently detailed information about the level of resource use in each activity. This is important because the detailed information about the level of resource use for each activity, is required by production engineers to identify the areas in a production system, where they can make improvements to raise productivity.

9. The Activity Based Costing technique lacks robust structure

The Activity Based Costing technique lacks well defined objective rules for processing cost information. Subjectivity can creep in at every level of information processing, for example, in defining activities, cost pools and cost drivers. Moreover, the technique does not have a robust structure that can be fitted to the structure of a production system to calculate the cost of an operation and the cost of various resources employed in each operation. In the absence of the robust structure, the cause and effect relationships between the use of various resources and improvement in productivity, can not be ascertained. The cause and effect relationship between the use of resources and the system's productivity, is the basic requirement for improving the production process to reduce cost of production.

Turney, B.B (1991) in his book on Activity Based Costing, however, claims that the second generation of Activity Based Costing (Process View) can be helpful in improving a production system by accurately measuring the cost of activities. The process view of Activity Based Costing is designed to measure non financial performance measures, such as, efficiency, time taken to complete an activity, and the quality of work done.

According to Turney, in his process view, the cost of an activity is measured in two steps. The first step measures the efficiency of an activity to produce the activity's output volume in a certain period. For example, for activity 'a', 100 activity cycles produce 90 units of output, giving a 90% efficiency for the activity. According to Turney, the efficiency of the activity can be compared with the efficiency of similar activities either within the organization or between the organizations. The second step of his process view, employs the resources to measure the cost of the activity and the cost of the output. For example, if $1,000 worth of resources were used to produce 90 units in 100 activity cycles, then the cost per activity cycle is $10 and the cost of a unit of output, is $11.11. According to Turney, the cost of an activity can be compared with the cost of similar activities, either within the organization or outside the organization within the same industries.

However, considering Turney's process view, the comparison in the first step can only be made if the work components of the activities being compared are the same. Considering the second step of the process view, the cost of activities can only be compared if the work components of the activities in the two companies are exactly the same, and the method of cost analysis for each work component is also the same.

According to Turney, activity time is another non financial measure. More time required to complete an activity means more cost and vice versa. This measure can also be used for making comparison between activities within the company and between two companies. According to Turney, other non financial measures such as, the number of units scrapped, or the number of units reworked or recycled can also be used to compare and improve activities.

Evaluation of non-financial measures in the process view of the Activity Based Costing technique, is equivalent to the use of physical measures of productivity. The process view of the Activity Based Costing technique, appears to promote the use of standard physical productivity measures, commonly used in industrial engineering, to measure productivity. Studies showing the weakness of using physical productivity measures at various levels of an organization, are described and explained in detail in Chapter 5.

3.7 SUMMARY

The Activity Based Costing technique is developed to distribute the overhead costs over various products more accurately. It is not designed to measure the productivity of resources employed in production systems. The technique breaks the production system into activities and then measures the cost of those activities. However, it does not provide the detailed cost information of resources employed and used for performing these activities. An activity, defined as a unit of work, is a nebulous term, impossible to quantify in a way that is useful throughout the operation in a production plant. Its structure does not match the structure of operations in production systems. The technique can not provide the information about the cause and effect relationship between the employment and use of various kinds of resource in production system. Therefore, it can not be used to measure and improve the productivity of resources employed in production systems.

CHAPTER 4

COMPUTER SIMULATION MODELLING: A METHOD TO GENERATE INFORMATION FOR MEASURING PRODUCTIVITY

4.0 ABSTRACT

To measure productivity and productivity loss in terms of cost for a production system, the information about the quantity, cost, and the utilization of resources for a given production scenario, is a basic requirement. The information about the quantity of resources is generally available at the shop floor level and the information about their cost is generally traced from the accounting & finance departments.

In this research project, computer simulation modeling is used as a method to get more refined information about the utilization of shop floor resources for current production scenarios at Inco Limited Thompson, and at New Holland Canada Limited Winnipeg. Other production scenarios proposed by the plant management of these two companies were also tested using this technique.

4.1 INTRODUCTION

In manufacturing, simulation is widely used to understand and evaluate the production and time relationships under various sets of conditions. The analysis of data generated by computer simulation models of production systems, is helpful in selecting a more efficient production scenario for production purposes.

An efficient production operation is an operation that uses raw materials and other inputs efficiently, but may not be cost effective. To measure the cost effectiveness of a production system, productivity and productivity loss for the system as a whole, must be measured in terms of cost. To generate a detailed level of cost, information about physical resources, and their cost and utilization for each operation is required in detail. In this chapter, a computer simulation modeling method, used to generate accurate resource use information for measuring cost for production operations, is discussed.

In section 4.2 of this chapter, a computer simulation modeling procedure developed using Inco Limited, Thompson as a case study, is discussed. In section 4.3, the simulation process for New Holland Canada Limited is discussed. In section 4.3, the variety of questions that can be answered using this approach are also listed. In section 4.4, the process of information generation about the utilization of resources for each operation using the compter simulation method is explained. In section 4.5, the findings of the chapter are summarized.

4.2 COMPUTER SIMULATION MODELLING FOR INCO LIMITED

From 1996 to 1998, I worked on simulation projects for Inco Limited, Thompson, and used WITNESS, a discrete-event computer simulation program, to simulate the following systems:

1. The 3600 level mining & skipping system (3,600 ft below the surface)
2. The ore storage system at the surface level
3. The ore milling & grinding system

4. The ore floatation System
5. The roasting system & the smelting system

The computer simulation model of the 3600 level mining & skipping system was the first project completed for the company, and this model was used to examine the current production capability of the system under a variety of conditions.

The computer model of the 3600 level mining & skipping system was also used to project the quantity of ore and rock production for various sets of conditions in future. The success of this model encouraged the mine management to extend my modeling work to cover the ore storage system, the milling & grinding section, floatation section, and the smelting section, (roasting, melting and converting sections) at the surface level. These sections were studied in detail to analyze the interaction between resources within each section. The simulation models of these sections, together in the form of a total process model, also helped in understanding the interaction between various sections under various sets of production conditions. This modeling process made it possible to look at the total picture of the system of production.

It was discovered during computer simulation modeling exercises, that to generate useful information about a production system, the simulation model of a system should closely resemble the real system.

To create a computer simulation model with a close resemblance to the real manufacturing system, the following are required:

1. The boundary of the real system to be modeled should be clearly defined and understood by all members of the teams involved in the development of models and in the use of models.
2. All operations in the real production system should be clearly identified, named and marked, and their mechanism clearly understood by the model developers and users.
3. The boundary between any two consecutive operations should be clearly identified and marked on the system diagram.
4. Resources used for each operation should be clearly identified and marked. A list of machinery and equipment, operation space, buffers, labor, contracts and any other resource used or to be used, should be made for each operation.
5. A resource used for more than one operation, for example, an operator, should be marked separately as a resource used by more than one operation. The names of those operations using a common resource should be clearly identified.
6. The physical distances between any two operations in a system space should be measured and clearly marked.
7. The sequence of action/s of each resource used in an operation and their times of use during the operation, should be clearly defined. The set-up time and cycle time for each operation should be clearly marked.
8. The quality and quantity of material inputs, intended outputs, scrap, wastage and other by-products of an operation should be known and clearly marked.

9. A consensus diagram, i.e. a diagram drawn after building consensus among the team members about the relationship and interaction among the operations, should be used as a reference to discuss the working of a production system.

10. The computer simulation model should be created around the consensus diagram of the plant, using a suitable computer simulation language that can show visually the movement of materials and resources in the production space during operations.

11. The computer simulation model should closely represent the actual layout of the manufacturing system.

12. The computer simulation model should be tested, updated and validated under various sets of conditions until the output of the simulation model closely matches the actual output of the operations under the same set of working conditions.

4.3 COMPUTER SIMULATION MODELLING FOR NEWHOLLAND CANADA LIMITED, WINNIPEG

From 1998 to 1999, I worked on simulation projects for New Holland Canada Limited, Winnipeg, Manitoba, Canada. The company assembled wheeled and caterpiller tractors in the Winnipeg plant for the agricultural and construction industries. The company also manufactured a limited set of parts, sub-assemblies, and assemblies used in the tractors. AUTOMODE, a discrete-event simulation program, was used for simulating the plant's assembly lines.

Five different production plans and their layouts were audited for New Holland Canada Ltd., using the simulation method.

The rear axle & transmissin assembly line, the flushing system for transmissions, the over-head crane system to move transmissions in and out, for flushing, the transmission repair system, the front axle assembly lines, the power train assembly line, the paint line, the cab assembly line, and the main assembly lines were simulated and audited for each plan.

The roller bays, and inspection area spaces for testing tractors after they are taken off the main assembly line, were simulated in more detail than the other plant areas. The required quantities of roller bays and inspection spaces were also tested for each plan under a variety of production conditions. The "Touch-Up & Paint Shop Section", for paint touch ups after the testing & inspection process is over, was simulated and studied in detail to measure its productivity under various sets of production conditions.

The "Touch-Up & Paint Shop Section", was used as a detailed case study to measure and compare physical productivity measures (Partial productivity measures) with 'cost' as the most important measure of productivity.

The computer modeling experience and lessons learned at Inco Limited, Thompson, helped save modeling time for simulating the various assembly lines.

Between October 1998 and November 1999, I modeled many proposed manufacturing assembly plans and layouts for assembling different tractor models. The assembly line for mixed tractor models, was also modeled and tested. For each production plan, production bottlenecks were identified. The waiting spaces, capacity of waiting spaces, buffers, and quantity of dollies required for different production levels were shown to management for each plan. Conflicts related to time, space, distance, and defective parts entering the production system were shown visually through the computer models, to manufacturing management.

Through the use of the computer simulation models, data was generated that further helped answer the various types of questions posed by plant management.

In a broad sense, the type of questions answered using computer simulation modeling, are grouped into two sets.

A) A set of questions related to the planning stage of a production process

B) A set of questions related to the actual operations of the plan when the production plan process became relatively firm.

The variety of questions that were answered related to both stages are discussed below.

4.3.1 QUESTIONS RELATED TO THE PLANNING STAGE OF A PRODUCTION PROCESS

1. For a given quantity of output from a production process, how many machines, operators and other resources are required at a workstation?

2. How many parts, subassemblies and other direct and indirect materials and supplies are required for an operation at each workstation, at any given point of time during the production process in a production system?

3. What should be the size of the buffer space (In terms of waiting spaces for parts, subassemblies or raw materials) in front of each workstation, so that the preceding workstation is not blocked and the succeeding workstation is not starved? This assumes that the pull action of a workstation is independent of the load availability.

4. How do the distances between: buffer stores, where raw materials or parts are stored, and work stations; the distances between parking spaces for fork lift vehicles and raw material buffers; the distances between loading points at a buffer and the unloading points at the work station; the distances between the parking spaces of fork lift vehicles and delivery points of finished products; affect the functioning of a workstation?

5. How many buffer spaces at the front end and how many at the rear end of a work station are sufficient for the smooth running of a workstation, and a production line?

6. How often does a workstation in a production line become starved for a given set of production conditions?

7. How do the defective parts, defective subassemblies or defective raw materials entering the production system, affect the buffer spaces, the next dependent workstation or a production sub-system?

8. How do the defective parts, defective subassemblies or defective raw materials entering the production system, affect the quantity of output at the end of the system, the system throughput time, and the system resource utilization?

9. Under what conditions can a given workstation be used for more than one operation?

10. How should specific parts and sub assemblies be synchronized to the specific products, to specific workstations, and at specific points of time on assembly line workstations.

11. What will be the congestion level of a particular aisle of a production system at various time points under various production conditions?

12. When and how many units of raw materials or parts or subassemblies should be ordered, how many should be kept in buffer stocks to meet the production requirement during the lead time?

13. How should the cycle time of all preceding assembly lines be adjusted to have required cycle time of the following dependent assembly lines in an assembly line production system?

14. How many production machines are required at a preceding workstation to meet the input requirements of the following workstation in a production line?

15. How many persons are required to service a service area so that the waiting line does not have more than a stated number of units waiting in a queue at any given time?

16. What should be the most suitable cycle time for an assembly line?

17. How far a given assembly line is unbalanced. In other words, the cycle time of each worstation in an assembly line does not match the cycle of the line?

18. How does an added or subtracted worker or any other resource affect the system of production?

19. What is the effect of the use of different scheduling rules on the quantity of output or throughput time for any given production process?

Once a production plan becomes relatively firm the following type of questions can be answered.

4.3.2 QUESTIONS THAT CAN BE ANSWERED WHEN A PRODUCTION PLAN IS RELATIVELY FIRM

1. Questions about the general layout of the plant

2. Questions about the detailed facility layout of the plant.

3. Questions about the flow of materials in a production process.

4. Questions related to the utilization level of Equipment & Machinery, Manpower, Buffer space, and any other resource used in a production process.

5. Questions related to the production bottlenecks and their sequence for a given set of production conditions? These bottlenecks may be related to equipment & machinery, manpower, storage or buffer space or any other item.

6. Questions related to the short range planning of raw materials, parts, assemblies, sub-assemblies, supplies, contracts, equipment & machinery, manpower, buffers and storage space for a production process.

7. Questions related to the effects of machine breakdowns, machine repair, change in machine set-up time, and hiring or firing of a number of workers, on a production process.

8. Questions related to the effect of batch size variation, workers' work schedule variation, product style variation, product mix variation, percentage defectives entering the production process variation, on the output of a production process.

9. Questions related to the quantity of production that can be achieved in a given production time.

10. Questions related to the idle time of each resource of a workstation on any production or assembly line.

11. Questions related to the cost of production for a given production scenario.

12. Questions related to the cost of busy and idle resources for each workstation of a production process.

13. Questions related to the cost contribution of each resource for each workstation and for the total production process

4.4 PRODUCTIVITY RELATED INFROMATION GENERATION USING COMPUTER SIMULATION MODELING

Computer simulation modeling of the mining operations and assembly line operations, at Inco Limited, Thompson, and New Holland Canada Limited, respectively, helped me to understand the production processes in detail. It also helped in the identification of each resource involved in each operation, and the basic required information for tracing the cost of each resource from a manufacturing cost accounting department.

The running of the computer simulation models helps in the generation of data related to the utilization of each resource in each operation of a production process for a given set of production conditions. The resource utilization data generated for each resource and its related cost data, traced from accounting departments for each operation of a production process, are useful in measuring productivity in terms of cost for each resource in each operation of a production process. The data can also be used to calculate the productivity loss for each resource in each operation in terms of cost.

At Inco Limited, Thompson, the resource cost data, was not made accessible to me for this research project, therefore, the productivity and productivity loss in terms of cost could not be ascertained for the 3600 level mining system as well as the other systems. However, the production output related data were available to me and it was used to identify and measure physical productivities for the 3600 level mining system (Operating below the surface) and the ore floatation system (Operating at the surface level for separation of Nickel from rock and waste).

In New Holland Canada Limited, I was given access to the cost data for resources used in the "Touch-Up & Paint Shop Section" of the system.

The computer simulation model developed for the "Touch-Up & Paint Shop Section" was helpful in measuring the productivities of the system in physical terms.

The data generated, related to the utilization of resources for each operation of the "Touch-up & Paint Shop Section", using computer simulation modeling technique, was used along with the cost data traced for each resource, to measure productivity and productivity loss for each resource, in terms of cost.

The measure of productivity in physical terms and in terms of cost, using simulation modeling technique, paved the way for comparing physical productivity measures with productivity measures in terms of cost. The comparitive analysis of productivity measures for the same facility under the same set of production conditions, provided the evidence for the comparative effectiveness of a particular measure of productivity over the other.

The simulation technique can also help a researcher to assess how far different resources are underutilized and the reasons for their underutilization. The assessment of reasons for the underutilization of resources helps management to develop methods to use a production system in a more cost effective way.

4.5 SUMMARY

Computer simulation modeling exercises performed for Inco Limited Thompson, and New Holland Canada Limited Winnipeg, helped in finding answers to the various questions of plant management. These exercises also helped in understanding the functioning of the various sub-systems and their interactions in the total production system. It also helped in identifying the resources used at each workstation of a production process. The identification of a production resources makes it easy to trace their costs from cost accounting departments.

While working on simulation projects, it was discovered that running a computer model of a production process helped in the generation of data related to the utilization of each resource at each workstation of a production process for any given set of production conditions. The resource utilization data generated for each resource and its related cost data, traced from accounting departments for each operation of a production process, are useful in measuring productivity in terms of cost for each resource in each operation of a production process. Therefore, in this project, a computer simulation modeling technique was used to measure productivity in terms of physical units as well as in terms of cost.

CHAPTER 5

EFFECTIVENESS OF PHYSICAL PRODUCTIVITY MEASURES – A CASE STUDY OF A MINING COMPANY

5.0 ABSTRACT

The performance of functional areas in companies is measured using various types of physical productivity measures. In some cases, a company uses different physical productivity measures for different parts of the production process. The use of different physical productivity measures for different parts of the production process, most often, fails to report the impact of productivity improvement in one part of the process on the productivity of the other parts of the process.

5.1 INTRODUCTION

I worked with the mine management of Inco Limited, Thompson, Manitoba, in assessing the production capability of its mining system to meet its production requirements beyond the year 2005. In this process, I held meetings and discussions with the management of different departments, analyzed the Mining and Milling systems using computer simulation techniques, collected and analyzed the Mining and Milling data to find the answers to the various questions formulated and raised by operational managers.

One of the objectives was to identify the physical productivity measures used and their effectiveness in reporting the productivity of the Mining and Milling sections.

In section 5.2 of this chapter, an overview of the production system, its sub-sections, and the type of physical productivity measures used in Mining and Milling sections, are described in brief. In section 5.3, the cross functional effects of the use of physical productivity measures, are discussed. In section 5.4, the results of the study are summarized and concluded.

5.2 BRIEF OVERVIEW OF THE PRODUCTION SYSTEM

The company produces Nickel as its main product.

The overall system of Nickel production at the company's manufacturing site consists of the following sections:

1. Mining Section (Drilling, blasting, mucking, crushing and hoisting processes)
2. Milling Section (Crushing, grinding and floatation processes)
3. Smelting Section (Roasting, melting and converting processes) and
4. Refining Section (Electrolysis process)

A concise diagram of the system of Nickel ingot production is shown in Figure 5-1.

The Mining section produces ore as an input for the Milling section, Milling section produces Nickel concentrate as an input for the Smelting section and Smelting section produces Nickel ingots as input for the Refining section.

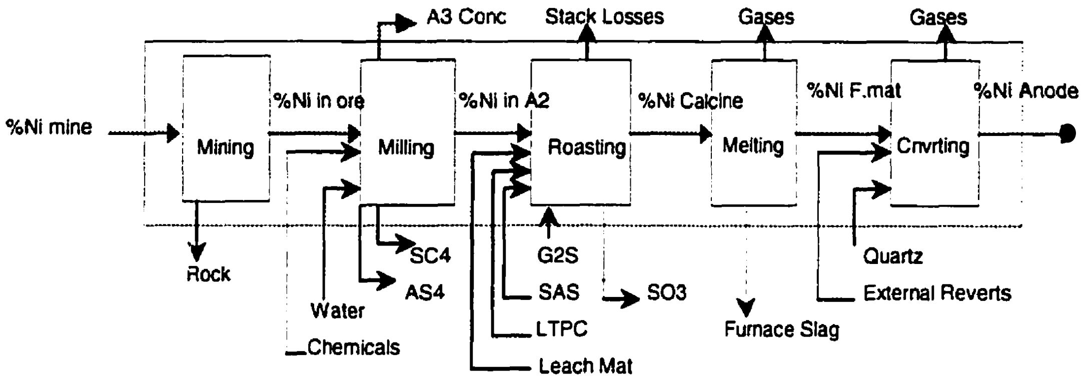

Figure 5-1. Diagrammatic representation of Nickel anode production process

In the Mining section, ore is blasted and mucked at various underground mining sites, moved to the 3600 ft level by Trucks and through Ore passes, transported by train to a crusher, crushed into small pieces, then hoisted to the surface level by the skip. A diagrammatic representation of the 3600 ft mining section is shown in Figure 5-2.

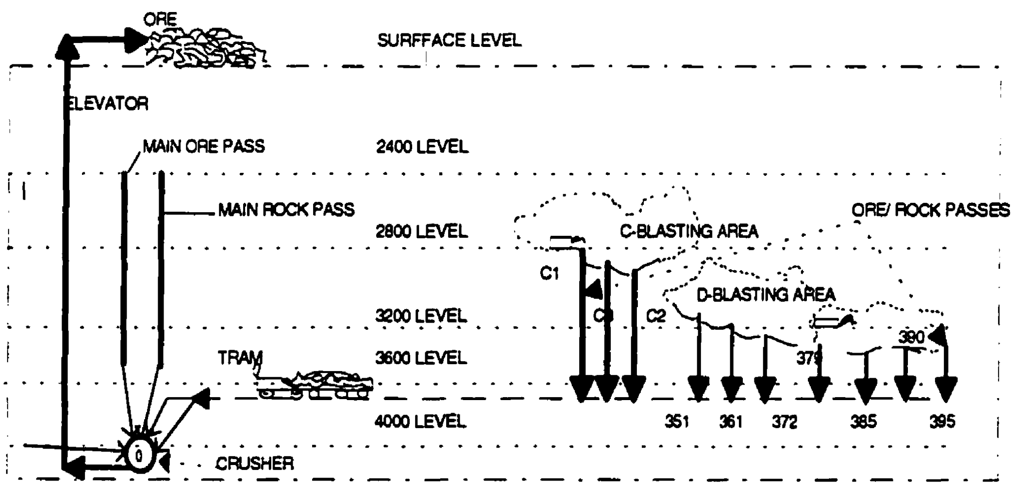

Figure 5-2. Diagrammatic representation of 3600 level mining system

In the Milling section, the ore is crushed, ground into very small particles and then fed to floatation tanks, and mixed with water and chemicals to separate the Nickel concentrate (A2), and Copper concentrate (A3), from rock and other wastes (SC4 and AS4).

In the Smelting section, the Nickel concentrate is mixed with chemicals and additives, (G2S, SAS, LTPC and Leach Mat) and then dried and roasted, by burning the excess quantity of Sulfur available in the Nickel concentrate. The burning of Sulfur in the Nickel concentrate saves fuel required to dry and roast the Nickel concentrate and it also raises the percentage of Nickel to about 25 percent by burning impurities.

The resulting material, called Calcine, is melted in furnaces and then more additives are added to bring impurities, called furnace slag, to the surface of the melted material. The furnace slag is skimmed off the melted material and the Nickel content of the remaining material called furnace matte increases to about 30 percent. The furnace matte is further poured into converters where hot air is passed through it, to bring oxidized impurities called converter slag to the surface for skimming. After skimming, the remaining material in the converter called converter matte contains about 75 percent Nickel in it. The converter matte is poured and cooled to make Nickel ingots that are used later in the Nickel refining process.

The Nickel from the Nickel ingots is refined through an Electrolysis process, in which Nickel ingots are used as anodes to get pure Nickel at cathodes.

In this chapter, the productivity related analysis and discussion is focussed on to the Mining and Milling sections. The daily production reports of Mining and the Milling sections, for a period of three months in the year 1997, are the main source of data used for analysis.

5.2.1 MEASURE OF PRODUCTIVITY IN THE MINING SECTION - PRODUCTION OF ORE PER DAY

In the Mining section, the goal is to hoist about 9K tons of ore per day. All sub-sections of the Mining section are coordinated to achieve this goal.

The ore is hoisted for five days a week and at the weekend, the hoisting system is closely inspected for maintenance and repair along with other systems in the mining area.

The daily production report, for a three months period in 1997, showed an average production of about 8.5 K tons of ore per day. However, the percentage of Nickel in the ore over the three months period varied from 1.8 percent to 3.00 percent with an average of about 2.30 percent

The use of physical productivity measure i.e. production of ore per day, does not report the productivity of the department correctly. The main product of the company is Nickel and the measure of productivity used does not report the quantity of Nickel hoisted. The measure of productivity used encourages mine management to hoist more quantity of ore without inspecting the Nickel content in it. Hoisting more quantity of diluted ore may cause an increase in the cost of Nickel production. Moreover, processing of diluted ore in the Milling section also increases loss of Nickel in waste, described later in this chapter. This measure of productivity does not provide any encouragement to check dilution of ore during blasting, mucking, orepassing, transporting, crushing and hoisting processes.

Improvement in the measure of productivity may lead to increase in the cost of Nickel production.

5.2.2 MEASURE OF PRODUCTIVITY IN THE MILLING SECTION – PRODUCTION OF NICKEL CONCENTRATE PER DAY

The quantity of Nickel concentrate produced in the Milling section depends upon the quantity of ore produced, and concentration Nickel in the ore.

Figure 5-3 shows the relationship between Nickel concentrate as a percentage of the ore to the percentage of Nickel in the ore. There is no direct relationship between the measure of productivity in the Mine, i.e. quantity of ore per day, and the measure of productivity in the Mill, i.e. quantity of Nickel concentrate (A2) per day.

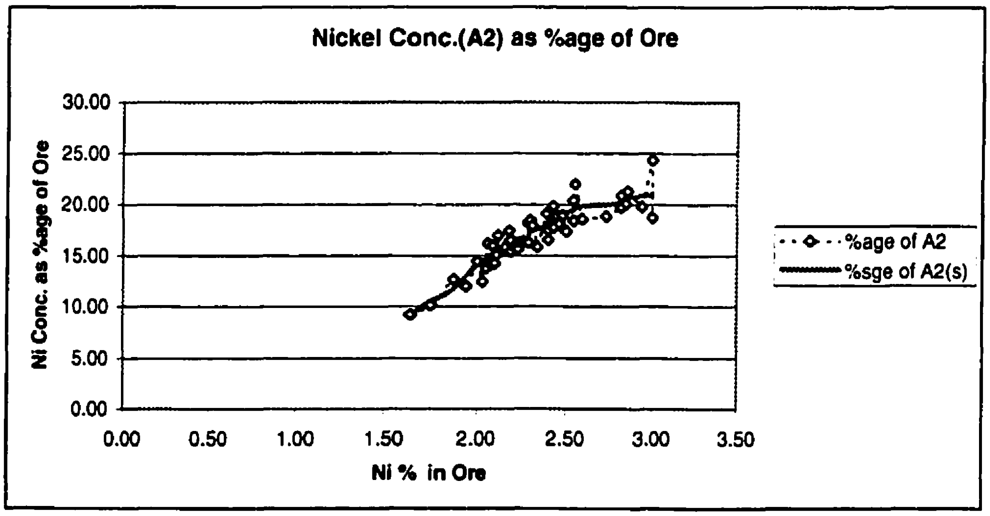

Figure 5-3. Showing the relationship between percentage Nickel in the ore to percentage Nickel concentrate produced from the ore

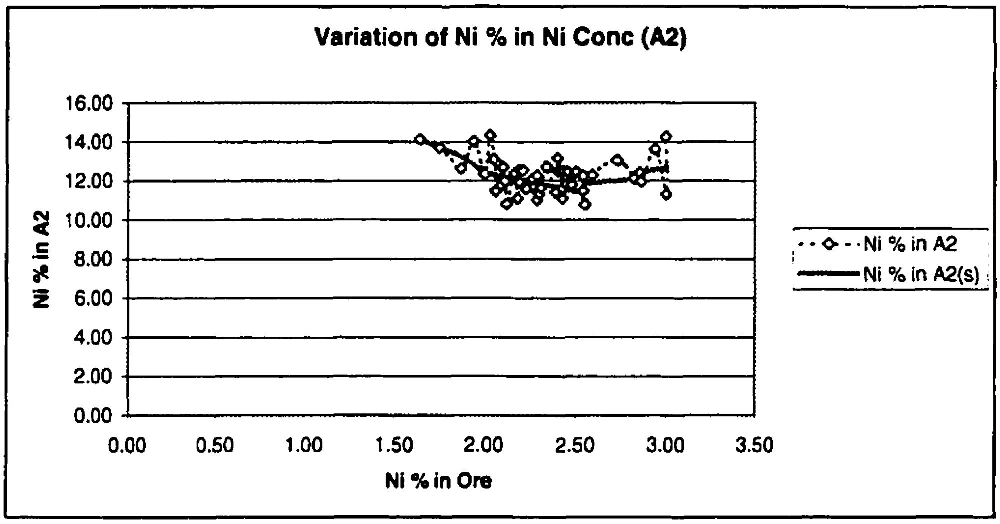

Figure 5-4. Showing relationship between percentage of Nickel in ore to percentage of Nickel in Nickel concentrate

The data collected from the Milling section indicates that the Nickel separation process in the Milling section produces relatively more Nickel concentrate as the Nickel content in the ore increases from 1.6% to about 2.5%. Over 2.5% Nickel content in the ore, the rate of increase of Nickel concentrate slows down.

Figure 5-4 shows that the percentage of Nickel in the Nickel concentrate produced is also not stable. The analysis of data related to the Nickel content in the Nickel concentrate shows the variation of Nickel from 10.8 percent to 14.3 percent. Thus, the quantity of Nickel concentrate produced per day does not really indicate the quantity of Nickel separated from waste in the floatation process.

Figure 5-5 shows the in-depth analysis of the Nickel content in the Nickel concentrate. It indicates that Nickel content in the Nickel concentrate is lowest, i.e. 10.8 percent when ore fed to the milling section has about 2.5 percent Nickel in it.

Figure 5-5 indicates that relative production of Nickel concentrate also tapers off at about 2.5 percent Nickel in ore.

It shows that when the quantity of Nickel concentrate produced per unit of ore used is high, then the Nickel per unit of Nickel concentrate produced is less. Thus, the quantity of Nickel concentrate, which is used as the productivity measure for the Milling section, does not indicate the real quantity of Nickel separated.

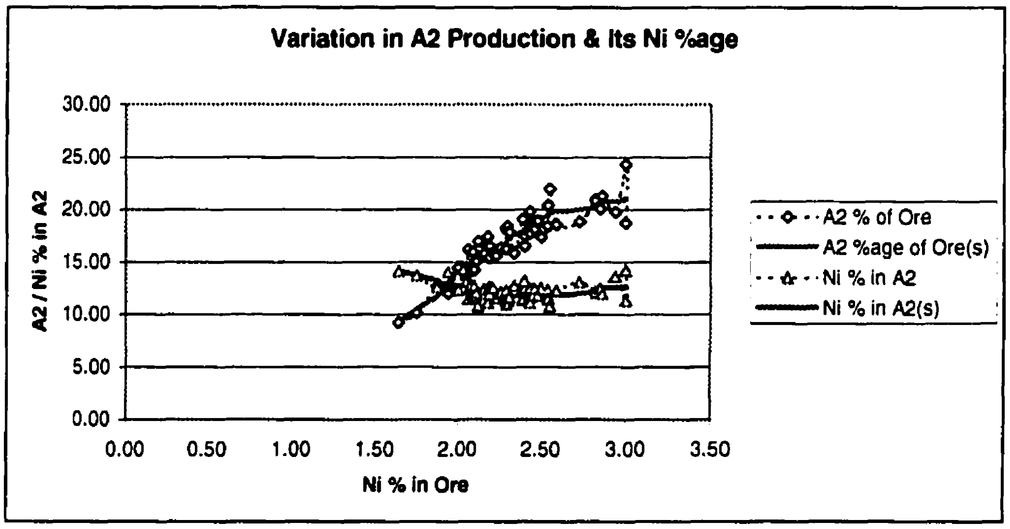

Figure 5-5. Showing lowest level of Nickel in the Nickel concentrate

Finally, analysis of production data related to the Milling and Mining sections, indicate that the productivity measurements used do not provide the real quantity of Nickel separated in the Milling section and the real quantity of Nickel hoisted in the Mining section.

5.3 CROSS FUNCTIONAL EFFECTS OF USING PHYSICAL PRODUCTIVITY MEASURES

The ore stockpile build up in front of the Milling section, loss of Nickel in the floatation process, and the utilization of the smelter at the rear end of the Milling section, are dependent upon the quality and quantity of the ore fed to the floatation process. The causes of ore stockpile build up, loss of Nickel in floatation process, and the low level of smelter utilization are discussed in detail by discussing the interaction between departments.

The following 4 sub-sections are devoted to the discussion of interactions between departments. In sub-section 5.3.1, the Milling and Smelting section interface is discussed. In sub-section 5.3.2, the ore dilution in the Mine and its effect on the Nickel loss in the floatation process is discussed. In sub-section 5.3.3, the Milling and the Mining section interface is discussed. In sub-section 5.3.4, cross functional effects are summarized.

5.3.1 CROSS FUNCTIONAL EFFECTS AT THE MILLING AND SMELTING SECTION INTERFACE

Nickel concentrate produced in the Milling section is used in the Smelting section. The Milling section operates 24 hours a day, five days a week. During the weekend, maintenance and repairs are done.

The Smelting section operates 24 hours a day, seven days a week, which means that the Milling section is required to produce enough Nickel concentrate in five working days for the Smelter's use over seven days.

The Smelting section's extra two days' requirement of feed, is stored in buffer tanks, which the Mill fills over five working days while feeding the Smelting section directly. This type of ideal production situation for the Milling and Smelting sections is represented in Figure 5-6. The productivity of the Milling section is measured in terms of tons of Nickel concentrate produced per day. The quantity of Nickel concentrate production is dependent upon the percent of Nickel in the ore consumed.

If the percentage of Nickel in the ore consumed in a week is more than the average, then the quantity of Nickel concentrate produced per ton of ore consumed in the Milling section increases. Increased Nickel concentrate production fills the buffer tanks in less than five days, (Say four days) thus forcing the early shut down of the Milling section.

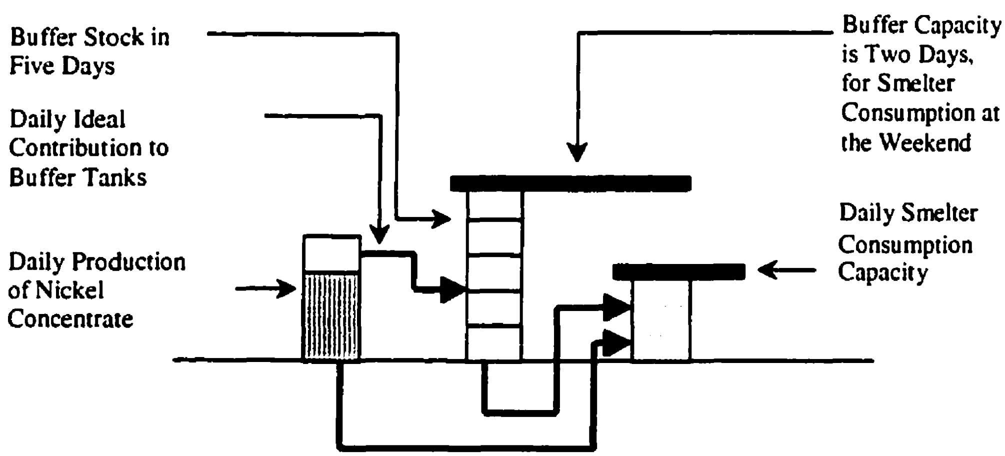

Figure 5-6. Diagrammatic representation of ideal production situation for the Milling and Smelting sections

The Nickel concentrate from the buffer tanks (Which can only hold two days Smelter's consumption of Nickel concentrate) leads to the starvation of the Smelting section near the end of the weekend due to early consumption of Nickel concentrate from the limited capacity buffers; thus reducing the productivity of the Smelting section. This type of production situation is shown in Figure 5-7.

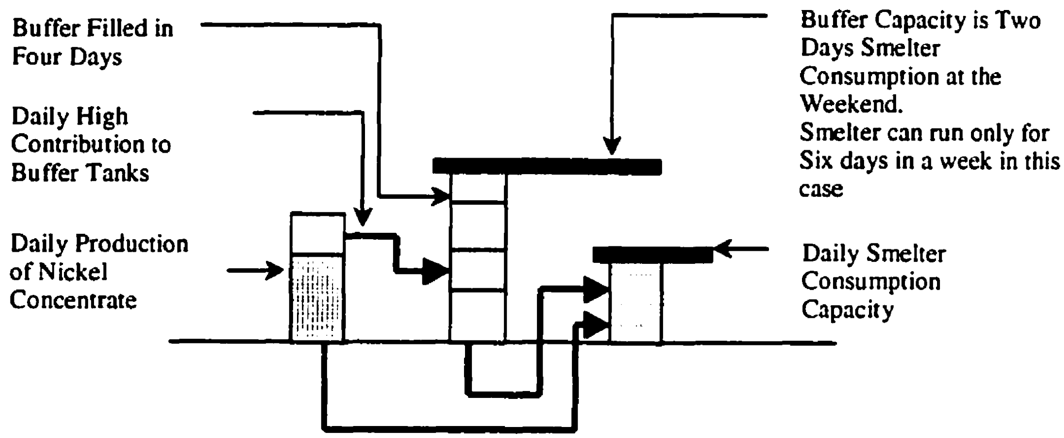

Figure 5-7. Diagrammatic representation of the production situation, when the Milling section produces more than the average quantity of Nickel concentrate

This problem can be solved by reducing the mill production rate or by increasing the capacity of buffer tanks or by reducing the smelter production rate so that it still could be run for seven days. Shutting the smelter off for some time but keeping it hot is an other possible solution. However, for all these possibilities, the cost will increase.

If the percentage of Nickel in the ore used in a week is less than the average, then the quantity of Nickel concentrate produced per ton of ore reduces and it leaves some buffer tanks either empty or not filled to their capacity, thus starving the Smelting section on the weekend. This type of production situation is shown in Figure 5-8.

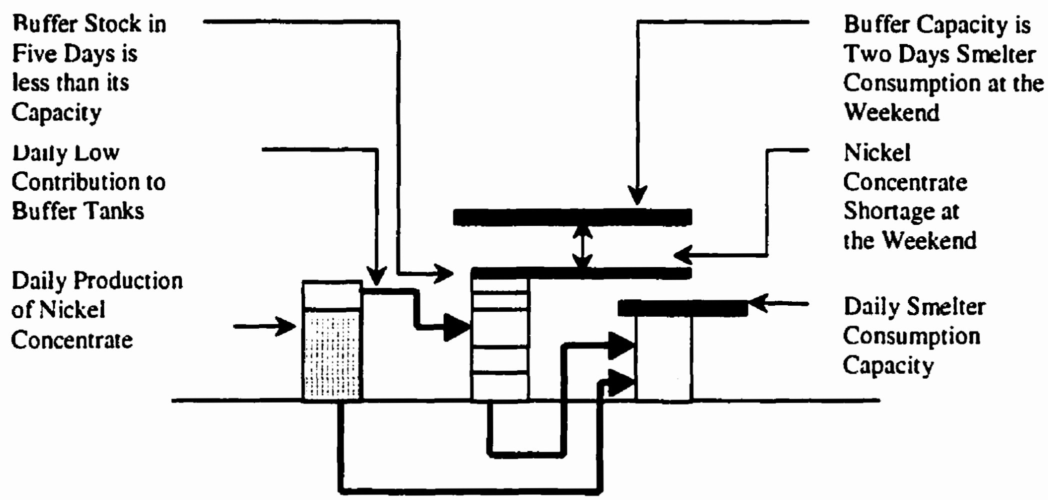

Figure 5-8. Diagrammatic representation of production situation when the Milling section produces less than the average quantity of Nickel concentrate

This problem can be solved by expanding the milling capacity of the mill, at an increased cost, so that a large quantity of diluted ore is crushed, ground and floated in less time, to make up the required production quantity of Nickel concentrate.

5.3.2 THE ORE DILUTION IN THE MINE AND ITS EFFECT ON NICKEL LOSS IN THE FLOATATION PROCESS

Figure 5-9 shows the analysis of data related to the Nickel loss in the Milling process. It shows that some quantity of the total Nickel hoisted in the ore is lost to the waste. The Nickel loss in the Floatation process of the Milling section is much higher when the percentage of Nickel in the ore consumed in the Milling process is less.

The use of a productivity measure such as tons of ore in the Mining section provides an incentive for the dilution of ore at various stages in the mine and it leads to the increase in the loss of Nickel to waste in the floatation process.

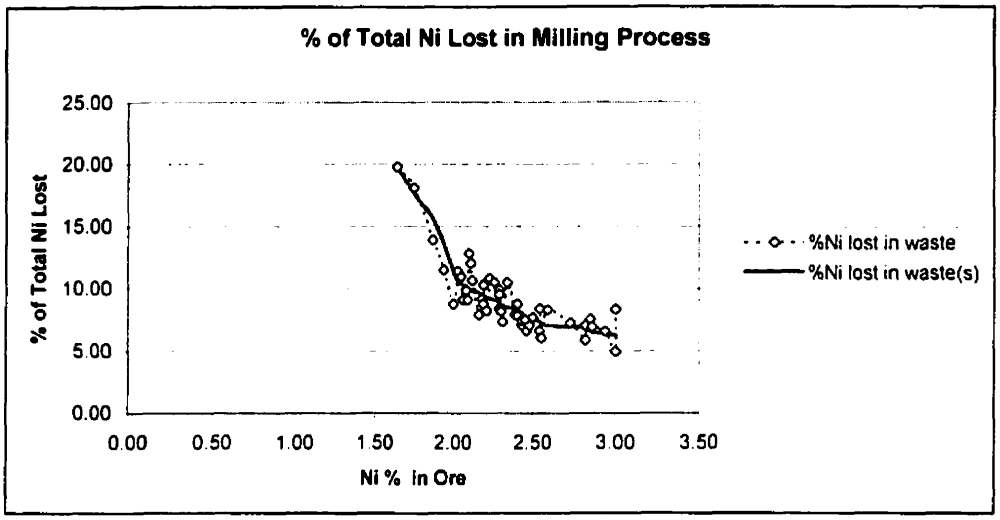

Figure 5-9. Showing loss of Nickel in floatation process as a function Nickel in ore

5.3.3 THE CROSS FUNCTIONAL EFFECTS AT THE MINING AND MILLING SECTION INTERFACE

The Mining section operates 24 hours a day, five days a week. The Milling section also operates 24 hours a day, five days a week. The ideal production situation for the Milling Section is to consume whatever quantity of ore is hoisted from the mine every day. This type of production situation is represented in Figure 5-10. If the quality of ore used in floatation process is better than the average, then the quantity of Nickel concentrate production in floatation process depends upon the quality of ore used. Less quantity of high quality ore intake into the mill produces the maximum quantity of Nickel concentrate that the floatation tanks in the mill can handle. In this situation, the surplus ore that is not picked up by the mill is dumped to the ore stockpile.

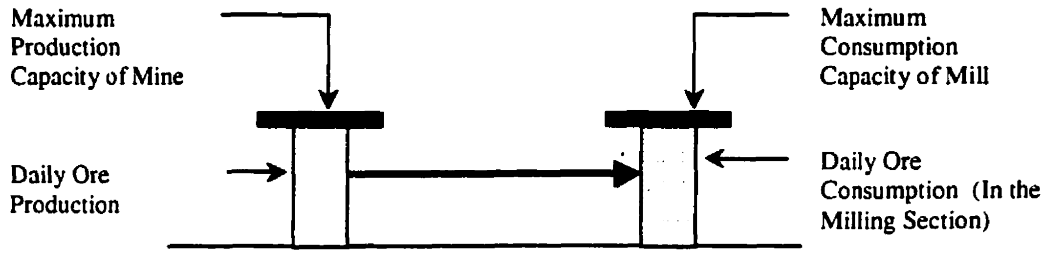

Figure 5-10. Diagrammatic representation of production situation wherein the Milling section consumes whatever quantity of ore the Mining section produces.

On the other hand, a greater quantity of Nickel concentrate production per day, fills the buffer tanks in less than five days, forcing the early shut down of the Milling section. However, the Mining section keeps its production going to achieve its weekly production target and the quantity of ore produced in this case is directed totally to the stockpile.

If the Nickel in the ore is much less than the average, then quantity of Nickel concentrate production in the floatation process is dependent upon the quantity of the ore used. More quantity of low quality ore is required to fill the floatation capacity of the floatation tanks. In this situation, to meet the milling requirement, additional ore is trucked from the ore stockpile to meet the capacity requirement of the floatation tanks. The trucking of ore from the ore stockpile and feeding it to the Milling section costs extra dollars to the Milling section for ore transport, thus adding to the total cost. This type of production situation is represented in Figure 5-11.

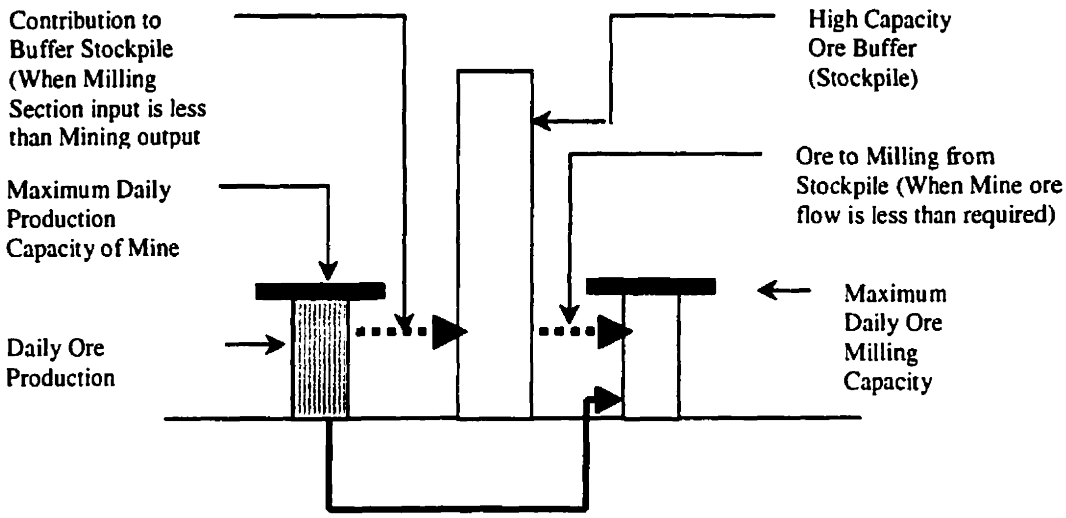

Figure 5-11. Diagrammatic representation of production situation wherein the Mining section directs the ore to the Stockpile & from Stockpile to the Milling section

5.3.4 SUMMARY

The critical evaluation of cross functional effects in the Mining and the Milling sections has shown that the variation of Nickel percentage in the ore fed to the Milling section keeps:

1. Ore going in and out of ore dump or stockpile at the end of the Mining operation.
2. The smelters starving close to the week ends at the end of the Milling operation.
3. In addition to that the diluted ore (From the Mining section) fed to the Milling process also increases the loss of Nickel to the waste thus reducing the availability of total Nickel at the end of the Milling process

5.4 CONCLUSIONS

Production of ore per day, and the production of Nickel concentrate per day, are the physical productivity measures used in the Mining and the Milling sections respectively.

Due to the use of the physical measure of productivity i.e. production of ore per day, in mining, there is no incentive to try and reduce the dilution of ore during the mining process, or balance the output of the mine to fit the requirements of the mill and smelter. Due to the use of the physical measure of productivity in the milling section i.e. production of Nickel concentrate per day, there is no incentive to balance the mill output to the requirements of the smelter. To reduce the cost of production at the firm level, the 'Cost' itself should be used as a measure of productivity instead of other physical productivity measures. Cost should be measured in detailed form for all operations at each functional level and at the firm level.

When the percentage of Nickel in the ore is less and the Mining section keeps up production of ore to achieve its goal of daily production, then, the company is incurring an extra cost due to:

1. Mining and hoisting more quantity of low quality ore to the surface
2. Paying an incentive to the employees for low quality but high quantity production
3. Crushing and grinding an extra quantity of low quality ore
4. Use of more additives to float separate the greater quantity of ground ore
5. An increase in the loss of Nickel, in the Nickel concentration process in the Milling section

6. The extra cost of carrying ore to the large stockpile at the surface level
7. The extra cost of transporting the ore from the stockpile to the Milling section without adding any value.

When the percentage of Nickel in the ore is higher than the average, the quantity of the Nickel concentrate produced per day, increases and fills the buffer tanks earlier than the five days week period. The stored Nickel concentrate that is used at the weekend when the Milling section is off for repair and maintenance, is used before the weekend is over.

The higher quantity of Nickel concentrate production per day leads to:

1. Starvation of the Smelter close to end of the two days weekend period, before the beginning of next week on Monday, due to early usage of Nickel concentrate stored in buffer tanks.
2. Building up of the ore stockpile at the front end (Input end) of the mill, due to less quantity of high quality ore consumption by the Milling section causing early shut off, of the Milling section before the beginning of the two days weekend period at the end of the week.

In this study it has been observed that the use of the limited set of physical productivity measures do not provide true information to management within the functional areas and the use of these type of measures, most often, also send wrong signals across the functional areas.

Later, in Chapter 7, it has also been shown that the use of physical productivity measure does not always provide true cost information about functional areas to the management.

Expanding on the Mining and the Milling section's results, it can be concluded that the aim of improving physical productivity measures, at functional levels in any firm, may lead to an extra cost within respective functional areas as well as in other related areas of a firm. The efforts made to improve physical productivity measures at functional levels, with the goal of reducing the cost at the firm level, may actually add extra cost to the cost of production at the functional and at the firm level.

CHAPTER 6

OPERATION BASED COSTING – A COST MEASUREMENT SYSTEM FOR PRODUCTION SYSTEMS

6.0 ABSTRACT

In this chapter, an Operation is considered to be the basic unit of a production system. Operations use and consume resources that cause costs in production systems. Operation Based Costing is based on the concept of adding the cost contribution of each resource employed in an Operation, to the material undergoing an Operation in a production system.

In this chapter, all the resources employed in production operations are classified within 8 resources categories of, Machinery, Fixture, Operator, Space, Contracts, Incentives, Materials, and resources "Tied Up" in inventories. The cost for each resource in each category in each Operation can be separately calculated.

NEW TERMS USED:

To explain the Operation Based Costing system, 3 terms related to operation, operation time, and operation resources are defined in Appendix (1).

6.1 INTRODUCTION

A typical manufacturing Operation is performed in a certain fixed physical Space called a workstation, designed for the Operation. Some buffer Space is required to store raw material or parts, brought in as material inputs, for the Operation. Some buffer Space may also be required to store the product of the Operation if it is not immediately delivered to or picked up for the next Operation.

Operators perform operations on Materials with the help of Machines, or mechanical tools. In other cases, the Machines perform operations without involving any operators during the Operation time. Sometimes Fixtures are also required to hold or help shape parts during the Operation.

In some manufacturing systems, some operations are contracted out; for example, the nickel plating of parts, and transportation of finished product. In other cases, outside contractors are brought into the production system to provide certain operating services during the Operation time. For example, workers may be hired on Contract to stock the raw materials in buffer spaces in front of workstations.

The Incentive system is provided for suppliers of inputs and customers of outputs for quality of materials and on time shipment. Incentives that are paid to operators to encourage them to produce quantity and quality of goods and services are considered part of the Operator resource cost, not part of Incentives.

Strong (1996), in his manuscript on Manufacturing Cost Analysis, identified 6 cost elements, i.e. Machine, Fixture, Operator, Space, Contract, and Incentives, that cause costs to the manufacturing system. He called them the basic cost elements. However, in the course of this research, 2 other cost elements are identified that also add costs to operations. One element is found to be in the form of loss of Materials in waste and scrap during the Operation, and the other element is in the form of cost "Tied Up" in inventories in and around operations. These 8 cost elements represent the 8 general resource categories employed in operations.

In this study, the 8 cost elements are called the 8 resource categories. The Operation Based Costing technique is based on these 8 resource categories employed in operations. The resources employed in operations can be identified with these 8 resource categories for production cost analysis purpose.

In this chapter, in section 6.2, the structure of a typical manufacturing Operation is discussed in terms of the 8 resource categories. In section 6.3, the contribution of resources to the cost of operations and transfer of Operation cost to the material undergoing an Operation is explained. In section 6.4, the results of the application of the Operation Based Costing technique in Inco Limited, Thompson and New Holland Canada Limited, Winnipeg, are discussed.

Findings of the chapter are concluded at the end, in section 6.5.

6.2 STRUCTURE OF A TYPICAL MANUFACTURING OPERATION

The structural components of a typical manufacturing operation are:

1. Machinery for the Operation
2. Fixture to hold material or help shape the material undergoing an Operation
3. Operator to operate the machine or work with other tools, on materials undergoing an Operation
4. Work Space for a workstation to conduct an Operation, and a small buffer Space for inputs and outputs of the Operation

5. Contract with outside parties for some operations or for support functions and services required in production
6. Incentive quality and timely delivery of materials
7. Materials to make the products required by customers
8. The resources "Tied Up" in inventories in and around each Operation.

The 8 components of a typical Operation structure are shown in Figure 6-1. Operations operate upon input Materials, to produce a required item. In this process, some Materials are consumed in the operations, others are added to the Material undergoing an Operation. In some cases, some portion of the Material undergoing an Operation may be removed as scrap or waste. The front-end raw Material inventory and work-in-process inventory ties up capital that adds cost to the Operation in the form of interest on the capital "Tied Up".

These Operation components need a variety of functional support, help or costs for keeping them operational. As examples, Machinery may require power, gas and water, and may eventually wear out and require repair or need replacement. Interest is also paid on the capital invested in Machinery. Wages are paid to Operators for maintenance. Workstation Space is cleaned regularly and maintained for efficient conduct of operations. Contractors are paid regularly for Material inputs and services. Incentives are regularly provided to insure quality and timely delivery of Materials.

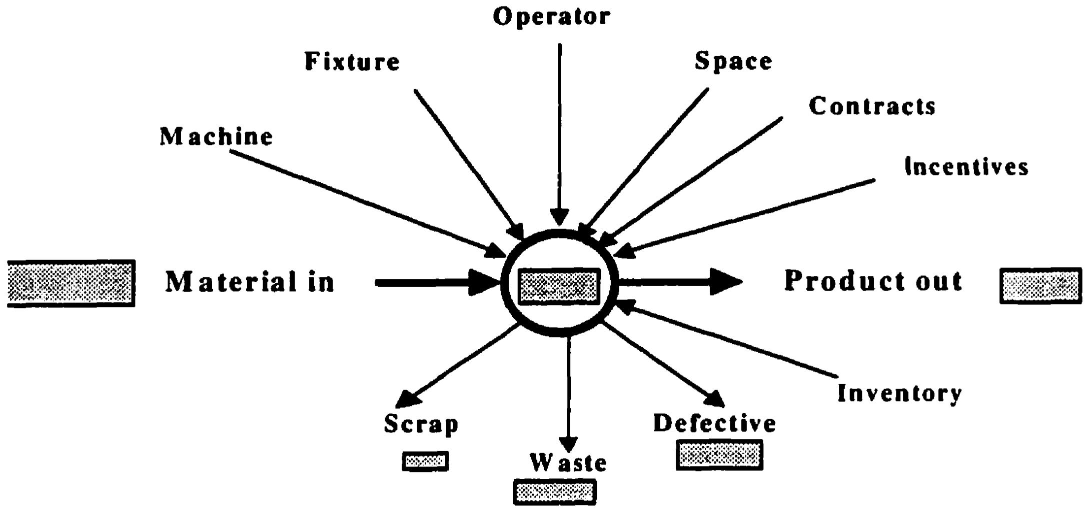

Figure 6-1. Structure of a typical manufacturing Operation

6.3 CONTRIBUTION OF RESOURCES TO THE COST OF OPERATIONS

The structural components of a typical manufacturing Operation illustrate the employment of 8 categories of resources in a manufacturing system. The employment of these resources cost money to the organization. The cost is in the form of loss in value of Machinery and Fixtures plus the use of utilities related to Machinery and Fixtures. The cost is in the form of salary and other benefits being paid to Operator or worker. The cost is in the form of rent for workstation Space plus space related utilities, Contract fees paid to contractors, and Incentives to suppliers of inputs and customers of products. The cost is in from of paid price of the quantity of Material lost, scrapped, and wasted during Operation. The cost is in the form of interest paid on the capital "Tied Up" in stocks of Materials in front of operations, and capital "Tied Up" in work-in-process inventories in operations.

6.3.1 CONTRIBUTION OF RESOURCES TO OPERATION COST

The cost of an Operation is the total of the cost of all the resources made available for the Operation.

1. Contribution of Machinery to the Operation Cost

A Machine is not consumable in one Operation. It lasts for a long period of time, and performs numerous operations. However, it loses value over time and wears with use. At one point in the production process the Machine wears out to the extent that it becomes unsuitable for further use in operations and at that point, the Machine has no productive value. However, this worn out machinery may have scrap value or may be rebuilt.

The Machine, as it wears out, loses value. The Machine also loses value over time due to the reduction in its productive life, even if it is not used in operations. The total loss in value of the Machine is the combined effect of its use in operations and the time elapsed after its purchase. The loss in value of the Machine plus Machine related utilities, such as power and / or gas used to run the Machine in a given time period, is the cost contribution of the Machine toward the total number of operations performed in that time period. The division of the total Machine cost over the number of operations performed in that period, is the cost contribution of the Machine to the cost of the Operation.

The purchase price, transportation cost, tax and duty, installation cost, Operator training cost and interest are identified as the cost components of the Machine.

2. Contribution of the Fixture to the Operation Cost

The Fixture contributes its cost to the Operation, as does the Machine. The Fixture has less wear and requires no service. It has less resale value as compared to a Machine, because it is designed and built for a specific process and purpose, whereas the Machine is designed and built for generic processes and purposes.

3. Contribution of Operator or Labor to the Operation Cost

In a manufacturing Operation the cost of the Operator or labor is often the most visible cost, and in some manufacturing systems, it is the dominant cost. The Operator related costs include wages or salary along with cost of living allowance, fringe benefits and costs of support services for the Operator at the work place.

Wages may be paid on a per hour or piecework basis. Fringe benefits may include paid holidays and absences, bonus, unemployment insurance contribution, payroll taxes, workman's compensation, contribution to pensions, and medical and dental care. Support services may include cafeteria, wash rooms, parking lot, counseling and medical aid facilities and services at the work place for workers' use. The services of the supervisor are also part of the support services.

The total cost of the Operator, in a given period of time, is divided by the number of operations performed in that period, provides the cost contribution of the Operator to the cost of the Operation.

4. Contribution of Work Space to the Operation Cost

The workstation Space is designed to perform the Operation effectively. The workstation Space with work facilities provided in it, cause costs to the company. Its cost is measured in terms of market rent rate for a similar area on a cost per square area per time basis. The cost of utilities such as electricity for lighting, gas for heating and the cost of a security system, maintenance and general cleaning of the work area, are part of the costs related to the workstation Space. The division of the total workstation space cost over the quantity of operations performed in the given time period is the contribution of workstation Space to the cost of Operation.

5. Contribution of Contract Services to the Operation Cost

In some operations, some services may be provided by outside contractors. These services may be the delivery of raw Materials to a workstation. In the cost of Contract services, the detailed cost components are not transparent to the Contract customers. Moreover, the control of job or service in most Contracts is in the hand of the contractors.

In cases where, the Operators, Machinery, Fixture or workstation Space are hired on a Contract basis to perform Operations, the customer of the Contract services controls the resources, and the cost of the contracted services are considered as part of the normal resource cost categories. Reid (1986), has reported the use of contractor operated, in-plant storage of inventories required for production operations, to reduce the investment in inventory, administrative expenses, costs of purchasing, expediting, receiving, inspecting, storing and issuing stored inventory items

The Contract fees for services are usually paid in some combination of a time basis and a per piece basis.

The Contract cost includes the initial Contract expenses, annual or monthly fees and regular time based or piece based expenses. The total of initial expenses, annual fees and regular costs for a given period make up the cost of the Contract for that period. The division of this cost over the total quantity of Operations performed in that period, is the cost contribution of the Contract services to the cost of an Operation.

6. Contribution of Incentives to the Operation Cost

In most companies, Incentives are provided to suppliers to insure the on time arrival of Material of sufficient quality. A delay in Material delivery, delays the manufacturing Operations, and causes cost in terms of all other resources waiting to be used for the Operation and subsequent delivery to customers. Defective material will produce a defective output, or cause Operation delays, waiting for new material to be delivered. The Incentive structure, i.e. reward and penalty, reduces the chance of delay and percentage of defective parts entering the system. It is commonly used in the automobile manufacturing and vegetable oil refining industries. This process works in reverse for the relationship between the manufacturer and its customers.

The cost of incentives is the total of Incentive fees paid to the suppliers for a given time period. The division of the total Incentive cost over the number of operations performed in that period of time is the cost contribution of the Incentives.

7. Contribution of Materials to the Operation Cost

The Materials contribute to the cost of the Operation, in terms of waste and scrap creation. In some operations, a part of the Material undergoing an Operation may be scrapes as part of the Operation, e.g. cutting a hole in a piece of Material creates scrap material. In other cases a part undergoing an Operation may become damaged and may have to be scrapped. The cost of original Material that is scrapped becomes part of the Operation cost.

In some cases, the Material becomes obsolete, gets damaged and spoiled, and may be stolen during storage. In these cases, loss in the value of Material and loss of Material become part of storage Operation costs.

In some cases there is a loss of Materials during purification. For example, in the Nickel ore floatation process, a large quantity of water and chemicals are required to float separate Nickel components, in the form of a Nickel concentrate. In this process some quantity of Nickel goes out with the waste rock.

In some cases there is material loss during joining operations. For example, parts and sub assemblies are joined to the main assembly in various operations of an assembly line. In some cases materials, such as, welding rods and nuts and bolts are considered to be consumed in the operations as they join sections together. In such operations, the joining materials add to the material cost of the Operation.

The total material cost contribution to an Operation is measured as the total cost created, due to the creation of Material waste, Material scrap, Material loss and joining Material used, over a given time period. The division of the total Material cost over the number of Operations performed in that time period is the cost contribution of Material resource to the cost of the Operation.

8. Contribution of Cost "Tied Up" in Inventory to the Operation Cost

Carrying front-end and work-in-process inventory, cause cost to the Operation. In some cases, a Material item that undergoes an Operation is very expensive. Carrying a few pieces in inventory, cause a significant cost contribution to the Operations. For example, carrying an inventory of assembled tractors, trucks, and cars in front of a Paint and Touch-Up Operation.

The Cost related to inventory is the cost of interest on the capital Tied Up in the inventory. The interest cost for a given time period is one of the costs of carrying inventory. The division of this cost over the number of operations in that time period is the cost contribution of inventory "Tied Up", to the cost of an Operation.

In some cases, special extra Space is kept for carrying inventory for the Operation. In such cases, the special extra Space should be treated as part of workstation Space.

6.3.2 TRANSFER OF RESOURCE COST TO THE MATERIAL UNDERGOING AN OPERATION

In production Operations, resources operate on the Material undergoing an Operation, to convert it into the required output.

The conversion of input into an output is the result of the combined effort of all the resources employed for the Operation time. The combined cost contribution of all resources for the time of an Operation is the cost of an Operation.

The mechanism of resource cost transfer to the Material undergoing an Operation is shown in Figure 6-2.

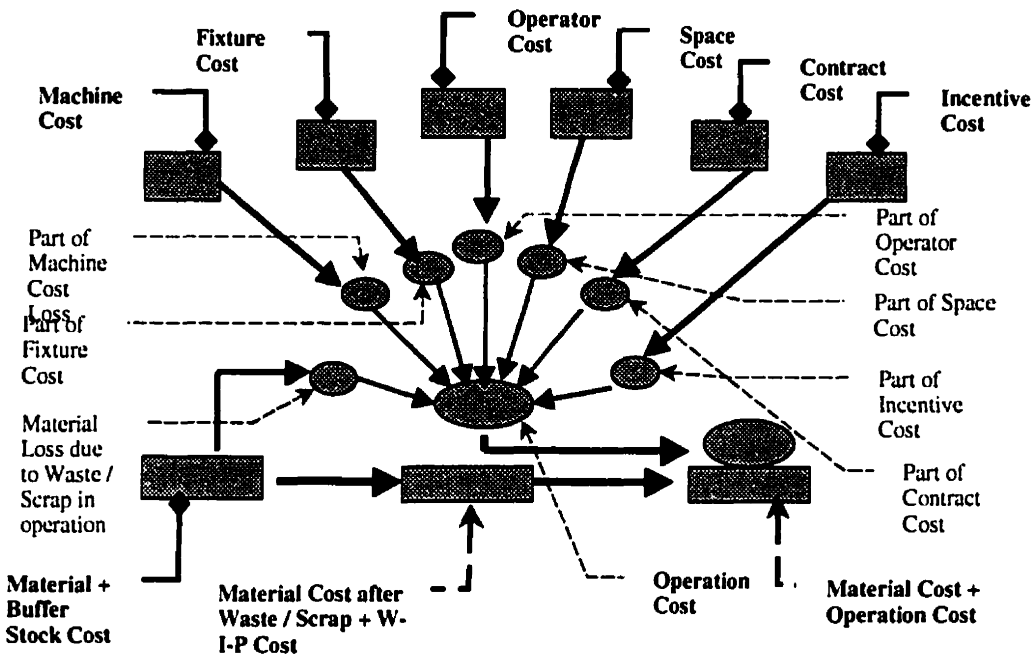

Figure 6-2. Mechanism of resource cost transfer to material undergoing an operation

In a successful Operation, the cost of the Material undergoing an Operation increases. The increase is equal to the cost of the Operation performed on the Material. It implies that the cost of a successful Operation is transferred to the Material undergoing the Operation.

In an unsuccessful Operation, if the Material undergoing an Operation is not scrapped or wasted, but is redone in the Operation, then the cost of Operation is the total of the cost of unsuccessful Operation plus the cost of a successful Operation. In this case, the cost of the unsuccessful Operation plus the cost of the successful Operation gets transferred to the cost of Material brought under the Operation.

In an unsuccessful Operation, if the material undergoing the Operation is scrapped or wasted, then, the cost of the Operation is the cost of a unit of Material taken in for Operation, plus the cost of the unsuccessful Operation. Note that the cost of a unit of output requires that the costs of the unsuccessful operations spread across the successful operations for the time that there were no changes in the Operation.

6.4 APPLICATION OF OPERATION BASED COSTING

Operation Based Costing technique is applied at the Nickel Ore Processing System of a Nickel Producing company, and at the "Touch Up & Paint Shop" System of a tractor manufacturing company. In these two very different case studies, it is found that the system is applicable without modification, if the information about the quantity and quality of inputs and outputs is available at the beginning and at the end of each Operation.

6.4.1 A CASE STUDY OF THE SYSTEM OF NICKEL PRODUCTION

The overall system of Nickel production, described in Chapter 3, consists of the following sections:

1. Mining Section (Drilling, blasting, mucking, transporting, crushing and hoisting processes)
2. Milling Section (Crushing, grinding and floatation processes)
3. Smelting Section (Roasting, melting and converting processes) and
4. Refining Section (Electrolysis process)

The drilling and blasting process of the Mining section and the whole Refining section were not part of this research study.

In the mucking, transporting, crushing and hoisting processes of the Mining section, and the crushing and grinding processes of the Milling section, the information about the quantity of ore is collected regularly, at both ends of each process. The information about the ore quality in terms of Nickel percentage in the ore, in these processes, is collected only at few time intervals in a year to save costs. The Nickel percentage in the ore is not measured regularly as a processing parameter until the ore enters the floatation process of the Milling section.

The quantity of materials along with the Nickel percentage in these materials is measured regularly as processing parameters in the floatation process in the Milling section, and in the melting and the converting processes of the Smelting section.

In the Mining and Milling sections, up to the floatation process, the system can be analyzed as a combination of operations in the form of black boxes. In these black boxes, the information about the Nickel percentage in materials is collected from time to time, but the information about the input and output quantities of materials, is collected on a regular basis. In these cases, the Operation Based Costing system can be applied to give an overview cost information for the black boxes. However, the effect of the variation of Nickel percentage on the cost of black box operations can also be measured using Operation Based Costing. This type of exercise can provide information about the savings in cost that can be made by measuring and controlling the Nickel percentage in the ore on regular basis

1. Production Segment, Production Segment Window and Capsule of Operations

A production segment is a combination of two or more operations, shown in Figure 6.3.

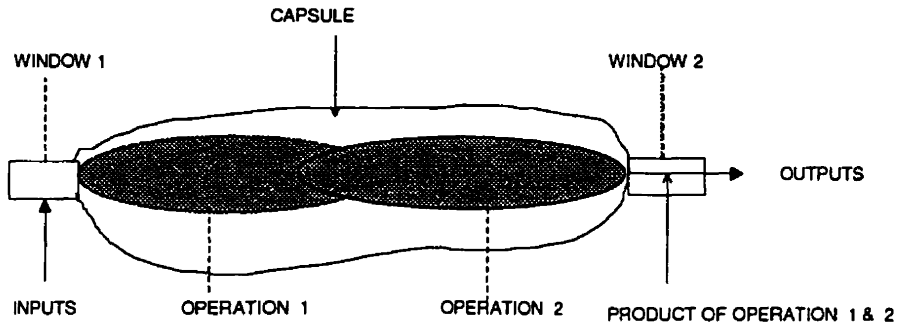

Figure 6-3. Showing a capsule of two operations

An end of a production segment, where complete information about the quality and quantity of inputs and outputs is available, is called a window of a production segment. The production segment between two consecutive windows is called a capsule of operations.

2. Operations and the Capsule of Operations in the System of Nickel Production

In the system of Nickel production, if the quality of ore mucked and poured into the ore pass is available, then the mucking, transporting, crushing and hoisting operations of the Mining section, plus the crushing and grinding processes of the Milling section, make up a capsule of operations. In this capsule, the list of resources for each Operation was identified. For example, in the 3600 level train transportation Operation, the resources, such as, train engines, train drivers, train wagons, ore loading and unloading workers, train tracks, and tunnels are the identified resources that can be categorized into 8 basic Operation resource categories. The train engines and wagons fall in the Machine category. The train drivers and ore loading and unloading workers fall in Operator category. The train track falls in Fixture, and the track tunnel in the Space category. These 4 resource categories make up almost all the cost of the 3600 level transportation Operation of the capsule.

At the 3600 level ore transport Operation, the Machine category consists of 2 engines and 21 wagons employed to transport ore from 7 ore passes to the ore dump. One driver to drive the train and 3 other workers to load and unload the ore, are required per shift to smoothly run the Operation. The total length of the track and tunnel used for transportation Operation is about 8 kilometers. The electric lights are used to light the ore loading and ore dumping area. However, the information related to the cost of machinery, energy, track, tunnel and their maintenance, were not available to us to calculate the cost of Operation per ton of ore transported. If the Nickel percentage in the ore transported is checked regularly, then the transportation cost per ton of Nickel, the true measure of productivity per Operation can also be calculated.

The quantities of resources employed in other operations of the capsule are also available in detailed form to measure the cost of operations, but the information related to the cost of resources employed in each Operation of the capsule is not available. If the cost information for all resource categories for all operations is available then the cost of the capsule of operations as a whole can be calculated on per ton of Nickel basis.

In the floatation, melting and converting operations, the basic flow of materials and their Nickel content is available, and it has been analyzed and discussed in detail in Chapter 5. The quantitative information about the resources employed in each Operation is also available for these operations. However, the cost information for all resource categories employed in these operations is not available. In the absence of this information the cost of the Operation and the cost of resources for each Operation per ton of Nickel, can not be calculated.

The sharp decline of price of Nickel in 1997 and 1998 led to the cut in research funding for this project. In addition, many workers, including some key persons involved in supplying information for this study, were also terminated. In this process, some key parameters required to measure productivity and productivity variations, for each Operation, for each capsule of the operations, and for the total system of production, became unavailable. This lack of information availability prematurely ended this project.

6.4.2 A CASE STUDY OF THE "TOUCH UP & PAINT SHOP" SYSTEM OF A TRACTOR MANUFACTURING COMPANY

Deo (1999), and Deo and Strong (2000), used the Operation Based Costing technique to measure the cost of each resource and each Operation in the "Touch Up & Paint Shop" System of a tractor manufacturing plant. The results of the study were shared with the manufacturing manager, to his satisfaction.

In this chapter, the results of the study are discussed to show the depth and details of cost analysis achieved, using the Operation Based Costing technique. However, the absolute numbers shown in terms of dollars in the various tables, are not exactly real, to maintain company's financial confidentiality.

In the "Touch Up & Paint Shop" system, three operations are performed. These are:

1. Decal & Paint Touch-up Operation
2. Standard Paint Shop Operation

3. Rust Resistant Paint Shop Operation

1. Cost of the "Touch Up & Paint Shop" System

This is the total of the cost of the Paint Touch-up Operation, the Standard Paint Shop Operation and the Rust Resistant Paint Shop Operation. In these operations, 4 resource categories, i.e. Operators (Manpower), Space, Materials and resources "Tied In" in inventories, account for almost all of the costs of the operations. The cost of Machines in the form of paint spray guns was insignificant. The other 3 resource categories, i.e. Fixtures, Contract and Incentives were not involved in these operations.

The total cost of the system is shown in Table 6-1 for 4 simulated production scenarios. The costs for production scenario #'s 1-4 are $ 142.29, $ 150.25, $ 149.75 and $ 170.73 respectively.

TABLE 6-1
COST OF TOUCH-UP & PAINT SHOP SYSTEM PER UNIT OF OUTPUT

Prodn. Scen. #	Manpower Cost/unit	Space Cost/unit	Mtl.& Sup Cost/Unit	Tied Up Cost/Unit	Operation Cost/Unit
1	95.06	7.13	23.74	16.36	**142.29**
2	105.79	6.06	23.76	14.63	**150.25**
3	103.66	6.05	23.73	16.30	**149.75**
4	124.03	6.06	23.78	16.86	**170.73**

Table 6-1. Cost of "Touch Up & Paint Shop" system per unit of output

The scenario # 1 is the original production situation with total 9 touch-up booths, one standard paint shop, and one rust resistant overcoat paint shop. 6 workers are employed in the 9 touch-up booths, one worker in the standard paint shop, and one worker in the rust resistant overcoat paint shop. The 900 square meter area is used for 9 touch-up booths, and 150 square meter area for each paint shop. The tractors waiting for any service are stored in the vacant touch-up booths and in the parking lot outside the building.

The quantity of tractors waiting outside in the parking lot keep increasing over time, because, sometimes, the total quantity of tractors serviced in the "Touch Up and Paint Shop" system is less than the quantity of tractors coming off the assembly lines. When the inventory size of waiting tractors in the parking lot equals to a day's extra workload of the "Touch Up and Paint Shop" system, the management allows the supervisor to run the system at the weekend. The extra workday at the weekend reduces the quantity of waiting tractors in the parking lot to a great extent. The outside parking lot space is very inexpensive as compared to the covered space in side the manufacturing plant.

In scenario # 2, the plant management intended to take out 2 touch-up booths and use the Space for some other Operation. The number of touch-up booths reduced from 9 to 7, reducing the touch-up space by about 200 square meters. The reduction in the quantity of touch-up booths resulted in the reduction of tractor storage Space in the touch-up Operation area.

The Operation Based Cost analysis of the computer simulated scenario # 2, showed that the productivity of space, and tied up capital resources in inventories increased and the productivity of the manpower resource in the system declined.

The reduction in the Space cost is the result of a reduction of the 2 touch-up booth spaces in the touch-up area. The reduction in the tied-up cost in inventories is the result of increase in the frequency of extra workdays at weekends to reduce the quantity of waiting tractors in the parking lot. The reduction in the manpower resource productivity is caused by the increase in the workers' waiting time due to the reduction in the quantity of tractors waiting for the service in the touch-up area, that further increased the frequency of having no tractor available in the touch-up area. The increase in the waiting time of the workers required them to work more overtime to service all tractors coming off the assembly line. However, the reduction of the manpower resource productivity was greater than the gain in productivity due to the Space and "Tied Up" capital resources in inventory.

In scenario # 3, management added one worker to reduce the waiting time of the touch-up workers, and used him to drive the tractors waiting outside, into the touch-up area, as soon as a vacant touch-up booth space became available. The simulation of this scenario showed that the addition of one driver in the area helped increase the manpower productivity, but reduced the productivity of "Tied-Up" capital resources in tractors inventory. The increase in manpower productivity was due to the reduction in the waiting time of the workers that in turn caused reduction in the overtime required to service all the tractors coming off the assembly line. The addition of a driver helped keep the touch-up booths busy by driving the tractors waiting outside, in, as soon as a vacancy occurred. The increase in productivity of the workers in the touch-up area reduced the rate of tractor inventory increase that led to the increase in the time duration between two consecutive extra workdays which in turn increased the average size of tractor inventory in the parking lot and the touch-up area. The increase in the quantity of tractors waiting for service in the touch-up area, caused an increase in the cost of "Tied Up" capital resources in tractor inventory.

In scenario # 4, to reduce the quantity of waiting tractors in the touch-up area, the management employed an additional group of 3 workers in the touch-up area, for the touch-up Operation. The simulation of this scenario showed that the addition of 3 workers in the touch-up area expanded the production capability of the touch-up Operation, but reduced the manpower productivity in the system by increasing the idle time of workers in the touch-up area. The expanded production capability of the touch-up area helped reduce the overflow of tractors to the parking lot to a minimum level that in turn increased the time duration between two consecutive extra workdays to a great extent. The increase in the time duration between two consecutive extra workdays caused the increase in the average size of tractor inventory in the parking lot. The increase in the production capability of the touch-up area also helped in the increase of the serviced quantity of tractors, waiting in their respective touch-up booths, for the service of the next Operation i.e. the standard paint shop Operation. The standard paint shop with one worker employed in it became the subsequent bottleneck of the system. The increase in the quantity of tractors waiting for service in the touch-up area and in the parking lot, caused an increase in the cost of "Tied Up" capital resources in tractor inventory.

2. Identification of the Potential Cost Saving Resources in the System

The conversion of cost figures in Table 6-1 into percentage figures in Table 6-2, indicates that manpower cost per unit of output is the highest cost in the system, followed by the cost of Materials and supplies, the cost "Tied Up" in inventories, and finally, the cost of Space. The share of Space cost is less than 5 % in the total cost of the system.

The manpower resource contributes more than $2/3^{rds}$ of the total cost in each production scenario and it is not always intuitively obvious to management. It suggests that management should examine ways to make more savings in manpower resource cost as compared to the Space cost.

TABLE 6-2
SHARE OF COST ELEMENTS IN TOUCH-UP & PAINT SHOP SYSTEM

Prodn. Scen. #	Share of Manpower Cost/unit	Share of Space Cost/unit	Share of Mtl.& Sup Cost/Unit	Share of Tied Up Cost/Unit	Total
1	0.67	0.05	0.17	0.11	**1.00**
2	0.70	0.04	0.16	0.10	**1.00**
3	0.69	0.04	0.16	0.11	**1.00**
4	0.73	0.04	0.14	0.10	**1.00**

Table 6-2. Share of cost elements in "Touch Up & Paint Shop" system

3. Identification of the Operation with the Most Cost Saving Potential

The detailed analysis of cost in terms of Operation cost in Table 6-3 shows that the Touch-up Operation contributes the most i.e. 65 %, to the cost of the system. The contribution of Paint shop Operation is about 20 %, and the contribution of Rust resistant overcoat paint Operation is about 15 % to the total cost of the system.

TABLE 6-3
COST CONTRIBUTION OF EACH OPERATION TO THE TOUCH UP & PAINT SHOP SYSTEM

Prodn. Scen. #	Touch up Opn.Cost/Unit	Paint shop Opn.Cost/Unit	R.R. Paint Opn. Cost/Unit	System's Cost/Unit	Share Opn. Touch Up	Share Opn. Paint Shop	Share Opn. RRPaint Shop
1	93.58	28.41	20.30	142.29	65.77%	19.96%	14.27%
2	98.86	29.73	21.65	150.25	65.80%	19.79%	14.41%
3	90.26	33.78	25.72	149.75	60.27%	22.56%	17.17%
4	114.72	32.04	23.97	170.73	67.19%	18.77%	14.04%

Table 6-3. Cost contribution of operations to the "Touch Up & Paint Shop" system

The detailed cost analysis of the system indicates that if the plant management intends to increase productivity in the production system, it should give first priority to the touch-up Operation, and its manpower resource, to make the greatest gains in productivity improvement.

6.5 CONCLUSIONS

In this chapter, 8 resource categories that cause costs to the production Operation are identified. These categories are Machinery, Fixture, Operator, Space, Contracts, Incentives, Materials, and "Tied-up" cost in inventories. These 8 resource categories employed in operations make up the basic structure of the Operation Based Costing technique.

The Nickel production system case study demonstrated that the Operation Based Costing system is applicable, if qualitative and quantitative information about, inputs of the Operation, outputs of the Operation, and the cost of resources employed in each Operation are available. If the information is not available for every Operation, but for a capsule or group of operations, then the overview cost calculations can be made for a capsule of operations instead of an individual Operation. However, since the information about many of the resource categories is not available, the final cost per unit of output can not be calculated for the system as a whole.

The productivity analysis of the "Touch Up & Paint Shop" area, using the Operation Based Costing system, has shown that the system is also helpful in the identification of the priority areas, i.e. resource categories and/or operations, for cost reduction, for management. The system has shown that the manpower resource is the dominant cost among the resource categories, and the touch-up Operation is the dominant cost contributing Operation to the total cost of the "Touch-up & Paint Shop" area. The Operation Based Cost analysis technique has shown that the reduction in the touch-up booths from 9 to 7 is not the right scenario for improving productivity.

In this chapter it has been demonstrated that the Operation Based Costing technique provides cost information for every resource employed in each Operation and in the total system of production in such a way that the productivity or cost tradeoffs between resources and production operations can be understood. It has also been demonstrated that all operations may not employ all the 8 resource categories described, nor do any other cost categories need to be added beyond these 8 resource categories.

CHAPTER 7

COMPARISON OF PRODUCTIVITY MEASURED IN TERMS OF PHYSICAL PARAMETERS WITH PRODUCTIVITY MEASURED IN TERMS OF COST

7.0 ABSTRACT

In this chapter, physical productivity measures that are generally used by industrial engineers, are compared with productivity measures in terms of cost. Physical productivity measures, used for a resource in an operation, are shown to not reflect the cost behavior of that resource.

7.1 INTRODUCTION

It is a common observation that engineers do not think about cost measurement, and the management of companies agree that they should not think about cost measurement, because they are hired only to think about making improvements to the production processes. It is also a common misconception among engineers that any improvement in the production process that reduces the quantity of a physical resource employed or consumed, improves the productivity of the resource employed in terms of the cost of production. Therefore, they tend to measure improvements in production systems, using physical measures of productivity that may report efficient employment of resources, but may not cause the efficient employment of the cost of resources.

This chapter is based on the "Touch Up & Paint Shop" section of the New Holland Canada Limited, Winnipeg, a tractor manufacturing company.

The plant management of New Holland Canada Limited, a tractor manufacturing company located at Winnipeg, hired me to audit a few proposed production plans, and to study the cost of operations for different production scenarios in each production plan. In the course of this study, I found evidence to prove that physical productivity measures do not reflect the cost behavior of the resources employed in the production systems.

The cost behavior of different resources under different production scenarios in the "Touch Up & Paint Shop" production process, has been discussed in detail in Chapter 4. In this chapter physical productivity measures related only to manpower resources, are compared with the ultimate measure of the manpower resource productivity i.e. the cost of manpower resource per unit of an output.

7.2 CASE STUDY OF "TOUCH UP & PAINT SHOP" PROCESS

Every tractor, coming off the assembly line, passes through the "Touch Up & Paint Shop" section for paint touch-up and other paint services. Three operations i.e. decal & touch-up, standard paint shop, and rust resistant overcoat paint operation, are performed in the section.

The "Touch Up & Paint Shop" process of the plant is represented in Figure 7-1.

The decal & touch-up operation is performed in 9 touch-up booths specially designed for the purpose. The standard paint shop operation is performed in a standard paint shop, and the rust resistant overcoat paint operation is performed in a specific rust resistant overcoat paint shop.

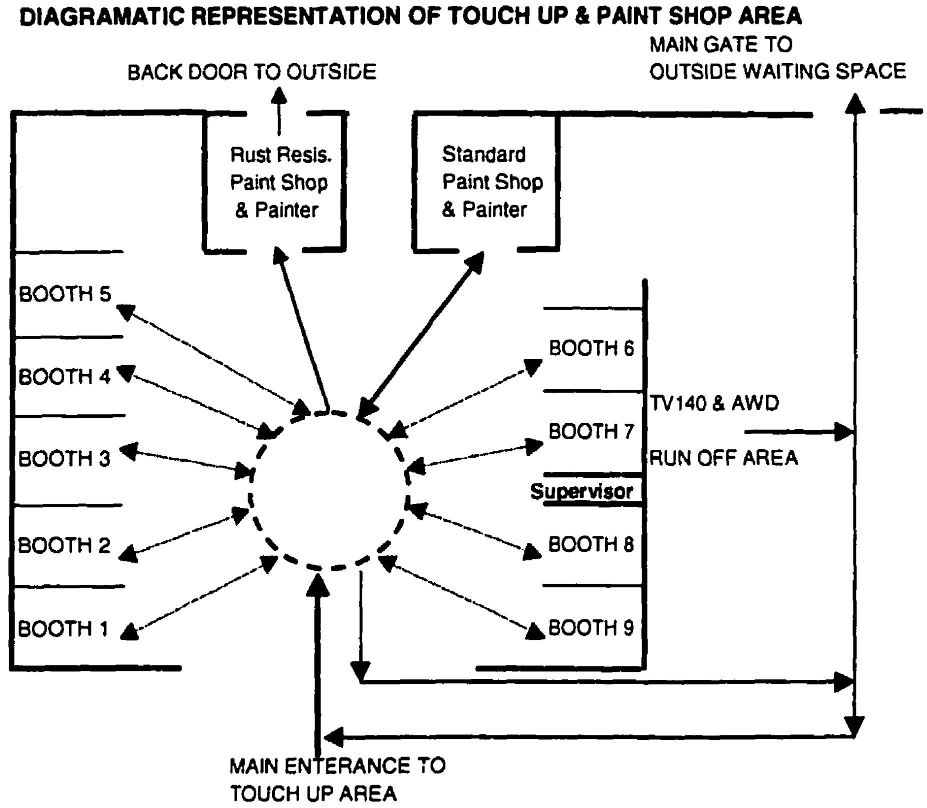

Figure 7-1. Showing the "Touch Up & Paint Shop" process of the tractor manufacturing company

Tractors assembled for sale in North America are not painted with the rust resistant overcoat. For all other markets in the world, tractors are over-coated to avoid rusting during shipping.

1. The Operation Decal & Touch-Up

In this operation, a tractor is cleaned, decaled and touched-up. The operation is performed in 9 touch-up booths represented in Figure 7-1. Six workers, in 2 groups with 3 workers in each group, are employed for the operation. The tractors are driven to vacant booths from the run off areas, and if all booths are busy, the tractors are driven to a parking area outside the plant building.

2. The Operation Standard Paint

In this operation the underside of the tractor is spray painted. This operation is performed in the standard paint shop shown in Figure 7-1. A worker is exclusively employed for spray painting in the paint shop.

3. The Operation Rust Resistant Paint

It is a special operation performed on tractors to prevent rust and corrosion. The operation is performed in a special rust resistant overcoat paint shop shown in Figure 7-1. One worker is employed for this job in the shop.

7.3 PRODUCTION SCENARIOS

For the "Touch Up & Paint Shop" system, 4 production scenarios, described in Chapter 6, were evaluated using computer simulation. The summary of variables for each scenario is shown in Table 7-1.

The time and resource related data used for simulating the production scenarios was collected during a two week production period in July 1999.

Before running production scenarios, the model and its results were validated with the actual production results.

TABLE 7-1
VARIABLES FOR PRODUCTION SCENARIOS

Prodn.	Touch Up Area		Std.Paint shop area		RR Paint shop area		Total # of
Scen. #	# Booths	# Workers	# Shops	# Workers	# Shops	# Workers	Workers
1	9	6	1	1	1	1	8
2	7	6	1	1	1	1	8
3	7	6	1	1	1	1 + 1* = 2	9
4	7	9	1	1	1	1 + 1* = 2	12

* Addition of Tractor Driver in Paint shop area

Table 7-1. Variables for production scenarios

The model and its results were discussed with the manufacturing manager and the department supervisor for their inputs. The details related to each production scenario are given in Appendix (2).

7.4 SIMULATION EXERCISE

For each production scenario, the simulation model was run for 60 work days after the warming up period. Two shifts a day and 8 hours a shift were simulated.

Three assembly lines are simulated. One assembly line works 2 shifts a day and produces 18 tractors per shift. The other 2 assembly lines, work one shift a day. One assembly line produces 10 tractors, and the other produces 4 tractors per shift. From each assembly line, tractors are sent to roller bays for running and then sent to run off areas for inspection, and repair if required. From the run off areas, tractors are sent to the "Touch Up & Paint Shop" section.

Total 50 tractors arrive each day for touch-up and paint services.

1. Simulation Results for 60 Days Run Time

The outcome of the 4 production scenarios is given in Table 7-2. With the reduction of 2 touch-up booths, from 9 to 7, in scenario # 2, the quantity of tractor production drops to 2528 units from 2728 units in scenario # 1. However, the quantity of units waiting for touch-up services increases to 480 units from 283 units in scenario # 1. In scenario # 3 & 4 the production increases and the quantity of outside waiting tractors reduces. In scenario # 4, only 7 tractors wait outside the building, at the end of the period.

TABLE 7-2
AN OVERVIEW OF SIMULATED PRODUCTION RESULTS FOR 60 DAYS

Prodn. Scen. #	Number of Workers	Number of Booths	Run time in Days	Shifts per Day	Total Production	Tractors Waiting
1	8	9	60	2	2728	283
2	8	7	60	2	2528	480
3	9	7	60	2	2788	224
4	12	7	60	2	2999	7

Table 7-2. An overview of simulated production results for 60 days

TABLE 7-3
CALCULATED PRODUCTION & TRACTOR WAITING QUANTITY PER YEAR

Prodn. Scen. #	Number of Workers	Number of Booths	Run time in Days	Shifts per Day	Total Production	Tractors Waiting
1	8	9	260	2	11821	1226
2	8	7	260	2	10955	2080
3	9	7	260	2	12081	971
4	12	7	260	2	12996	30

Table 7-3. Calculated tractor production & tractor waiting quantity per year

Generally the manufacturing organizations work for 260 days a year. Therefore, from the simulated results, the production and waiting quantity of tractors for 260 days is ascertained. The results are shown in Table 7-3.

2. Extra Work Days Required to Service all the Waiting Units

In actual practice, the waiting tractors are serviced in the "Touch Up & Paint Shop" process by putting extra work days at weekends.

TABLE 7-4
YEARLY PRODUCTION WITH EXTRA WORK DAYS FOR EACH SCENARIO

Prodn. Scen. #	Run time in Days	Shifts per Day	Regular Production	Over Time Production	Over time in Days	Total Production
1	260	2	11821	1226	26.97	13048
2	260	2	10955	2080	49.37	13035
3	260	2	12081	971	20.89	13052
4	260	2	12996	30	0.61	13026

Table 7-4. Yearly tractor production with extra work days for each scenario

The extra work days required to service all waiting tractors in each scenario, is shown in Table 7-4. In production scenario # 2, the number of extra work days required were maximum i.e. about 49, among all the production scenarios. The extra work days required were reduced in scenario # 3 and 4.

7.5 COMPARISON OF MANPOWER PRODUCTIVITY MEASURES WITH THE MEASURE OF MANPOWER COST

The productivity of the manpower resource is measured in terms of two physical productivity measures. These are:

1. Production of tractors / man / year, is called Manpower productivity. In this case the number of workers is the number of positions, and does not consider the number of hours worked in each position.

2. Production of tractors / man-hour, is called Man-hour Productivity. This includes the number of workers and the hours worked by each worker.

The manpower cost per unit of output, calculated and discussed in Chapter 6, is used as measure of productivity in terms of cost.

Table 7-4, discussed above, shows the total quantity of tractor production by using extra work days in addition to regular work days.

Table 7-5, shows the production of tractors per man per year i.e. Manpower productivity.

TABLE 7-5
MANPOWER PRODUCTIVITY PER YEAR

Prodn. Scen. #	Workers Per Day	Work Time in Days	Total Production	Production / man / Year
1	16	286.97	13048	815
2	16	309.37	13035	815
3	18	280.89	13052	725
4	24	260.61	13026	543

Table 7-5. Manpower productivity per year

The Table 7-6, shows the production of tractors per man-hour i.e. Man-hour productivity.

TABLE 7-6
MANHOUR PRODUCTIVITY PER YEAR

Prodn. Scen. #	Workers Per Day	Work Time in Days	Work Hours per Shift	Total Production	Production / Manhour
1	16	286.97	8	13048	0.3552
2	16	309.37	8	13035	0.3292
3	18	280.89	8	13052	0.3227
4	24	260.61	8	13026	0.2603

Table 7-6. Man-hour productivity per year

The Table 7-7, shows the manpower cost per tractor. The overtime costs 1.5 times the regular cost per hour.

TABLE 7-7
MANPOWER COST PER UNIT OF OUTPUT

Prodn. Scen. #	Workers Per Day	Regular Work Days	Cost Per Manhour $	Regular Mpwr cost $	Over time in Days	Over Time Cost $	T.Manpowr Cost $	Man Power Cost $ / unit
1	16	260	32.25	1,073,280.00	26.97	167,011.50	1,240,291.50	95.06
2	16	260	32.25	1,073,280.00	49.37	305,681.01	1,378,961.01	105.79
3	18	260	32.25	1,207,440.00	20.89	145,516.44	1,352,956.44	103.66
4	24	260	32.25	1,609,920.00	0.61	5,636.60	1,615,556.60	124.03

Table 7-7. Manpower cost per unit of output

In Table 7-8, the measure of manpower cost / unit, is inverted so that three measures of productivity show the same direction during comparative analysis.

TABLE 7-8
COMPARISON OF PHYSICAL PRODUCTIVITY MEASURES WITH INVERSE OF COST

Prodn. Scen. #	Production per man	Production per Manhour	Man Power Cost / unit	Inverse of Man power cost/unit
1	815	0.3552	95.06	0.010519839
2	815	0.3292	105.79	0.009452527
3	725	0.3227	103.66	0.009647022
4	543	0.2603	124.03	0.008062856

Table 7-8. Comparison of physical productivity measures with inverse of cost

The physical measures of productivity and the inverse of cost per unit are converted to respective coefficients of productivity for stressing their differences, by multiplying each measure with some constant number in such a way that three measures have the same value in scenario # 1.

TABLE 7-9
COMPARISON OF COEFFICIENTS OF PHYSICAL PRODUCTIVITY MEASURES WITH THE COEFFICIENT OF INVERSE OF COST

Prodn. Scen. #	Coeff. Of MpwrProdtvt	Coeff. Of Mhr.Prodtvt	Coeff. Of Inverse of Cost / unit
1	105.20	105.20	105.20
2	105.09	97.49	94.53
3	93.54	95.57	96.47
4	70.02	77.10	80.63

Table 7-9. Comparison of coefficients of physical productivity measures with the coefficient of inverse of cost

The comparison of the coefficient of manpower productivity and the coefficient of man-hour productivity, with the coefficient of inverse of manpower cost per unit is shown in Figure 7-2.

The comparison of coefficients of productivity measures, indicates that the coefficient of manpower, and man-hour productivity do not mimic the behavior of the coefficient of inverse of manpower cost per unit.

Moving from production scenario # 3 to production scenario # 4: the 3 productivity measures show a general direction of decline, but the coefficients of manpower and man-hour productivity do not match with the coefficient of inverse of cost.

Moving from scenario # 2 to scenario # 3: the coefficients of manpower and man-hour productivity indicate that the coefficient of the inverse of the cost per unit of output in scenario # 3 should be less than production scenario # 2. However, in scenario # 3, the coefficient of the inverse of manpower cost per unit of output is found to be higher than the scenario # 2. In this change the coefficients of manpower and man-hour productivity failed to mimic the behavior of cost.

Moving from scenario # 1 to scenario # 2: the coefficient of inverse of manpower cost per unit of output reduced. However, the coefficient of manpower productivity did not show this change and it failed to mimic the behavior of the coefficient of the inverse of cost / unit in production scenario # 2. The actual manpower cost per unit of output in scenario # 2 increased to $ 105.79 from about $ 95.08 in scenario # 1. This significant change of $ 10.70 per unit of output was not shown by the measure of manpower productivity.

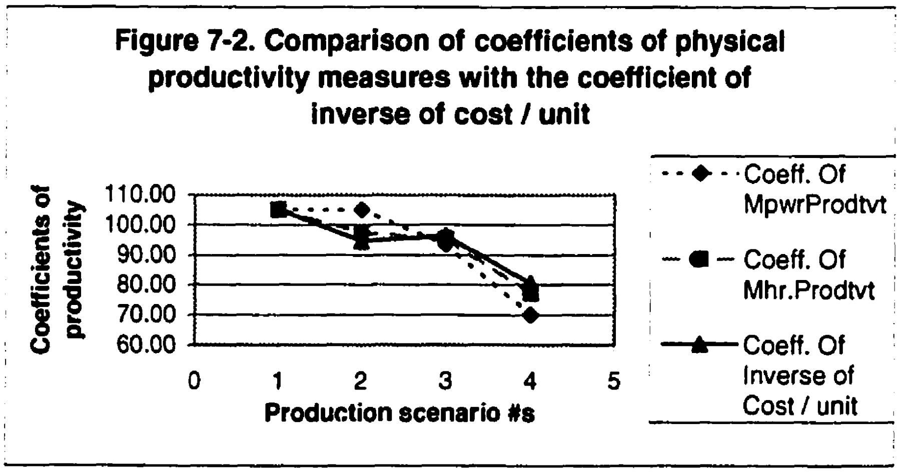

Figure 7-2. Comparison of coefficients of physical productivity measures with the coefficient of inverse of cost / unit

The coefficient of man-hour productivity shows a general decline from scenario # 1 to scenario # 4 and it also does not mimic the behavior of the coefficient of the inverse of manpower cost / unit over four production scenarios.

The detailed analysis of cost data used in the calculations, shows that the measure of Manpower productivity i.e. production / man / year, does not consider the quantity of over-time in addition to the regular work time worked by workers to meet the production requirement.

The measure of Man-hour productivity i.e. production / man-hour, does not consider the difference in the cost of the regular work hour and the extra work hour. The extra work hour i.e. overtime, costs about 1.5 times more than the regular work hour.

The manpower cost per unit of output, the real measure of manpower productivity, includes all the cost variations related to regular work hours and its regular cost per man-hour, overtime hours and its cost per hour, for cost calculations.

7.6 CONCLUSIONS

The evidence related to the measures of productivity, shows that physical measures of productivity do not mimic the behavior of cost per unit of output i.e. the real measure of productivity. If the cost per unit of output reduces by making improvements in the system, then the productivity of the system increases and if the cost increases, then the productivity of the system decreases.

CHAPTER 8

RESOURCE COST PRODUCTIVITY – A TOOL TO MEASURE POSSIBLE COST SAVINGS IN A MANUFACTURING SYSTEM

8.0 ABSTRACT

The productivity for a balanced production system is measured as 1.00 or 100%. In this chapter, the Resource Cost Productivity concept, is developed and used to measure the actual productivity for a system of production. The actual productivity for a system, is further used to measure the difference in productivity i.e. productivity deficit, from the productivity of the balanced system. The productivity deficit is helpful to measure the possible cost savings that can be made in the employment of resources in a production system

Six main causes of productivity deficit are identified, in this chapter. They are: synchronization problem between the production system and suppliers, synchronization problems within operations, synchronization problem between operations, synchronization problem between production and market demand, idle plant capacity, and miscellaneous production problems that further increase the synchronization problems in production systems. The Resource Cost Productivity concept is also useful to identify the share of each cause of productivity deficit in manufacturing system, that can guide industrial engineers to develop improvement projects for reducing the cost of production.

8.1 INTRODUCTION

In Chapter 7, cost per unit of output, is shown as the basic reliable measure of productivity, that can be used to evaluate the improvements made in production systems. If the cost per unit of output reduces, then the improvements made in the system increase the productivity of the system and vice-versa.

To increase the productivity of a production system, it is necessary to measure the costs of resources per unit of output, and the efficiency of cost dollars spent, i.e. the dollars spent on the actual producing function, in producing that unit of output. The measurement of the costs of resources per unit of output is discussed in Chapter 6, and the measurement of the efficiency of cost dollars spent, is discussed in this chapter.

A machine may be available for production for 24 hours per day, but it may only be used for two, 8 hour long shifts per day. The percent use of a resource available for production in a system indicates the efficiency of the resource use. For example, a worker hired for a day, was occupied with work for $2/3^{rds}$ of the day, and was waiting for the work, to be given to him, for $1/3^{rds}$ of the day. It means, the worker use in the production process is 67%. 33% of his paid time was lost, because he was not given enough work to do. If the worker costs \$30.00 per unit of output then the worker cost productivity is 67% of the \$30.00, i.e. \$20.00 per unit, and 33% is the worker's cost productivity deficit, i.e. \$10.00 per unit. It means, a unit of output has \$10.00 worth of the worker's non-utilization cost in it.

The non-utilization cost of available resources in operations may occur for many reasons. It may be caused by the delay in the input material arrival. It may be due to the handling of operation problems during an operation. It may be due to the imbalance of the resource use within the operation. It may be due to the blockage of the operation caused by the lack of adequate storage space between operations or due to the presence of a bottleneck operation in the system. The non-utilization cost may also be the result of large production capacity built into the system to meet the variations in demand of products that have short shelf life. In some cases, the extra production capacity built into the system to meet the future expanded demand, also adds to the non-utilization cost of resources.

The Resource Cost Productivity, and Resource Cost Productivity Deficit, can be measured for all available resources in each operation and in the total production system. These measures indicate the extent of resource utilization, and non-utilization in terms of the dollars spent.

In section 8.2, the concept of Resource Cost Productivity is described and explained. In section 8.3, characteristics of a balanced system are listed. In section 8.4, the concept of Resource Cost Productivity Deficit, its causes and cost related terms are defined and explained. In section 8.5, the application of these concepts in the "Touch Up & Paint Shop" system of New Holland Canada Limited, Winnipeg, is described to show the share of productivity deficit due to various causes. At the end, in section 8.6, the findings of the chapter are concluded.

8.2 RESOURCE COST PRODUCTIVITY

The Resource Cost Productivity for a resource is measured as the ratio of its cost per unit of output at the designed production capacity level, to its cost per unit of output at the actual production level. The designed production capacity for a balanced production system, is the maximum production capacity that the system can achieve with 100% use of available resources in production. If a balanced production system is actually run at its designed production capacity level, the Resource Cost Productivity will be equal to 1.00.

A balanced production system is the ideal system, for which the resource cost per unit of output at its designed capacity level, is the lowest. Any further improvement in productivity in such cases, requires investments in technological improvements, rather than improvements in the organization of resources in production processes. The characteristics of a balanced system are discussed in section 8.3.

However, if the balanced system is not run at its designed capacity level, due to lack of demand, then the system has an idle capacity that increases the unit cost of production and in this case, the Resource Cost Productivity for a resource will be less than 1.00. The other possible reasons of Resource Cost Productivity to be less than 1.00, are explained below with help of examples.

Surplus Resource Capacity within the Operation

In an operation, if the time of use of any resource within the operation, is less than the operation time, then that operation has a built in surplus resource capacity. The non-use of surplus resource capacity in operation increases the actual cost of operation, thus reducing the Resource Cost Productivity for the resource. For example, in a 10 minutes operation, the operator finishes his part of the job in 5 minutes and for the other 5 minutes he does not have any other job to do, and waits for the machine to complete the operation. In this case, for every operation the operator's service is utilized only for 5 minutes. In an ideal situation the operator's service could be used for the whole 10 minutes by allocating his work time on 2 machines instead of one.

Different Operation Times of Two Consecutive Operations

In a production system, if the operation time of two consecutive operations is not balanced, then the output time of the upstream operation will not synchronize with the input time requirement of the downstream operation. This synchronization problem between two operations will keep the available resources in the downstream operation unutilized for some time. The unutilized time of available resources, is the time lost from production that reduces the production quantity of output per period, for that operation. The reduction in the production quantity per period increases the actual cost of production that in turn leads to the reduction in the Resource Cost Productivity. The synchronization problem between operations can be reduced by providing the storage space for storing the output of the upstream operation to be used as input for the downstream operation. However, the stored material and the storage space add their share of cost to the unit of output produced.

Other Miscellaneous Reasons

The synchronization problem between operations may get worse if production problems occur anywhere in the production system. It may be due to the arrival of defective input materials and parts that either can not be used in production or have to be corrected before sending out for the next operation. The problem may be due to the breakdown and repair of a machine or fixture in operation. It may be due to the non-availability of the operator at the operation site, due to any reason when he is supposed to be there for conducting and overseeing the operation. The problem may be due to the lack of proper working tools, or lack of vital supplies and utilities required for the operation.

8.3 CHARACTERISTICS OF A BALANCED SYSTEM

A balanced system has seven characteristics. They are:

1. No synchronization problem between the suppliers of resources and production operations
2. No surplus resource capacity within the structure of the operation
3. No synchronization problem between any two consecutive operations of the system
4. No storage used between two consecutive operations to store incoming and outgoing parts.
5. No synchronization problem between the production system and the customer demand
6. The absence of production problems that upset the synchronization in the production system
7. The system operates full time i.e. 24 hrs/day, 7days/wk.

A system having these characteristics, is an ideal system that may not necessarily be achievable in the real world. However, it is useful to use the balanced system as a benchmark for comparison and for making improvements in a real system, to raise productivity.

In actual practice, most production systems are not balanced. In such cases, Resource Cost Productivity will always be less than 1.00. It means the available resources are not as productively used as theoretically possible, and there may be a window of opportunity to reduce the cost of production by increasing the productivity of the system, using industrial engineering techniques.

8.4 RESOURCE COST PRODUCTIVITY DEFICIT

The difference between the values of the Resource Cost Productivity for the balanced system, the 7 characteristics of which have been described above, and the real system operating at the actual production capacity level, is the Resource Cost Productivity Deficit for that system. For example, if the actual value of the Resource Cost Productivity is 0.7, then the Resource Cost Productivity Deficit for that system will be 0.3, i.e. 1 – 0.7 = 0.3. As stated above, 1.00 is the value of Resource Cost Productivity for an ideal system.

The size of the Resource Cost Productivity Deficit determines the category of productivity improvement projects to be undertaken. If the value of the resource productivity deficit is zero or close to zero, then the productivity of the system can only be improved by upgrading the technology of the system, e.g. taking a mechanical, or electrical or computer engineering approach to productivity improvement. If there is sufficient room for improvement of a production system then the value of the Resource Cost Productivity Deficit will be significantly greater than zero. The greater than zero value of Resource Cost Productivity Deficit, is an indicator that the system may further be improved by organizing the resources in the production processes.

The various causes of resource productivity deficit are expanded in detail below.

8.4.1 CAUSES OF RESOURCE COST PRODUCTIVITY DEFICIT

In this research project, six main causes of Resource Cost Productivity Deficit have been identified. They are:

1. Synchronization Problems between Resource Suppliers & Production Operations

The problem occurs when production operations are stopped or delayed due to the non-arrival of input materials and parts from suppliers at the agreed time due to any reason. The time for which the production is stopped or delayed is the time for which all the available resources in the affected operations remain unused. It is the cost of delayed supplies to the customer. In actual practice, this problem is solved to some extent by keeping buffer stocks of raw materials and parts at factory sites. However, the buffer stocks of raw materials and parts carried as inventories also cause increase in cost of tied-up capital resource, and cost of space used for carrying inventories. In addition, the buffer stocks of raw materials and parts, also cause increase in the materials and parts handling expenses and the risk of obsolescence and theft over the storage period.

2. Surplus Resource Capacity within the Structure of Production Operations

In some production operations, the resource utilization time in each operation may be less than the actual operation time, and in such cases some resources may have surplus capacity within each operation. For example, in a 5 minutes manufacturing operation, an operator may be occupied for 3 minutes, and for the other 2 minutes he may be waiting for the machine to finish the job. Therefore, the operator has 2 minutes surplus time unutilized in the operation. In other cases, the machine might be waiting for the operator for loading and unloading. The surplus resource capacity within the structure of an operation indicates the necessity of the structural improvements to balance the use of resources.

3. Synchronization Problem between Operations

This problem occurs when the output of an upstream operation does not synchronize with the input time requirement of the downstream operation. This problem occurs due to the variation in the operation time of the two consecutive operations. If the operation time of the upstream operation is more than the downstream operation, then the downstream operation waits for the input and vice versa. This waiting time is the time lost that could have been used for production. In this situation management have to provide some waiting space between operations to prevent the blockage of the system. Thus the synchronization problem between operations in the production process leads to two kinds of extra costs.

a. The cost due to the non-utilization of available resources during the waiting time

b. The cost due to the additional requirement for the storage space between operations to store the output of the upstream operation to avoid the operation blocking, plus tied up capital resource in inventory. This additional space and inventory between operations is not required if the synchronization problem between operations does not exist.

4. Synchronization Problems between Customer Demand and Production Supply

To handle variations in the customer demand, the products with long shelf or technical life are produced and stocked, using small capacity production plants continuously. In some cases, the shelf or technical life of products e.g. food items, is very short and these products are produced to order. In other cases, the materials to be processed have short shelf life and high volume seasonal supply e.g. fruits and vegetables, and must be processed in a short time period. In such cases, the production plants have large production capacity built in, to fulfill the varied size of orders or to handle varied size of seasonal supplies in a short duration. In such cases, the employed resources in production remain under utilized, but still must be available to handle the large order sizes in short duration.

5. Idle Production Capacity

In some cases, the demand for the product reduces over time due to many reasons e.g. demand saturation and increased production capacity. In other cases, management plans to have additional production capacity for the product to meet the planned or possible unforeseen demand in the future. The idle plant capacity carried in the system adds its share of cost to the cost per unit of output.

6. Production Problems that upset the Synchronization in Production Systems

There may occur miscellaneous problems in production operations that may cause delays in the production operations. The production delayed in one operation has its effects throughout the production chain of the system. These kinds of problems cause a significant productivity reduction in manufacturing systems. Some of the problems that often occur in production operations are listed below.

1. Breakdown and repair of machinery and / or fixture in operations
2. Missing work tools
3. Non-availability of the designated operator at the operation site
4. Missing parts
5. Broken or defective parts
6. Lack of vital supplies and utilities required for the operation.

These problems cause further increase in the synchronization problems described above.

Summary

The Resource Cost Productivity Deficit is the result of the six causes listed above. It represents the total non-use cost of resources in production systems, and is used to identify the share of each cause in the total productivity deficit.

The identification of the share of productivity deficit for each cause is further used to determine the absolute size of productivity loss in terms of monetary units e.g. dollars, that guides management to identify priority areas to make production improvements to reduce the cost of production.

8.4.2 DEFINITION AND EXPLANATION OF TERMS

To measure the Resource Cost Productivity, and Resource Cost Productivity Deficit, 5 new terms related to the causes of productivity deficit are defined and explained in Appendix (1)

8.5 APPLICATION OF RESOURCE COST PRODUCTIVITY

The Resource Cost Productivity concept is applied to the "Touch-Up and Paint Shop" section of the tractor assembly plant of the tractor manufacturing company located at Winnipeg, Manitoba.

8.5.1 MANPOWER COST PRODUCTIVITY IN THE "TOUCH UP & PAINT SHOP" SYSTEM

In the "Touch Up & Paint Shop" section, three operations are performed.

1. Decal & Touch-Up Operation
2. Standard Paint Shop Operation
3. Rust Resistant Paint Shop Operation

The details about of 3 operations are discussed in Chapter 5.

In this system, 4 resource categories employed are:

1. Manpower
2. Space (In the form of touch-up booths and two separate paint shops)
3. Paint material and supplies
4. Tied up capital resource cost in inventories.

In this study only manpower Resource Cost Productivity is investigated in detail.

The system is simulated for 4 production scenarios discussed in Chapter 7.

In scenario # 1, 9 touch-up booths with 6 workers in 2 groups with 3 workers in each group, one standard paint shop with one worker in it, one rust resistant overcoat paint shop with one worker in it, are simulated. In scenario # 2, the touch-up booths reduced from 9 to 7 and other conditions were same as in scenario # 1. In scenario # 3, one driver added in the paint shop area to drive tractors in and out and other conditions were same as in scenario # 2. In scenario # 4, a group of 3 workers was added in touch-up area and other conditions were same as in scenario # 3.

8.5.2 MANPOWER COST PRODUCTIVITY DEFICIT

The computer simulated results for manpower usage and non-usage in the "Touch Up & Paint Shop" system for 4 production scenarios are given in Table 8-1.

The system's manpower usage represents the system manpower cost productivity. The system's manpower non-usage represents the system manpower cost productivity deficit, that is measured as the difference between the manpower cost productivity for an ideal system and the manpower cost productivity for the actual system.

In Table 8-1, column 2 shows the manpower cost productivity and column 3 shows the manpower cost productivity deficit in the system. The column 4 shows the contribution due to synchronization problems in the total manpower cost productivity deficit. The column 5 shows the contribution due to the manpower surplus capacity remained unused due to the structure of operations in the system.

In scenario # 1, the total manpower cost productivity deficit is 30 %. About 26 % contributed by the synchronization problems between operations and 4 % contributed by the manpower surplus capacity built into the structure of operations.

TABLE 8-1
MANPOWER PRODUCTIVITY & PRODUCTIVITY DEFICIT IN TOUCH-UP & PAINT SHOP AREA

col. 1 Prodn. Scen. #	col. 2 System Mpower cost Productivity	col. 3 System Mpower Cost Prodtvt Deficit	col. 4 System Mpower Cost Synch. Loss	col. 5 System Mpower Surplus Capacity loss
1	0.70	0.30	0.26	0.04
2	0.67	0.33	0.30	0.03
3	0.64	0.36	0.24	0.12
4	0.52	0.48	0.16	0.32

Table 8-1. Manpower productivity & manpower productivity deficit In "Touch Up & Paint Shop" area

In scenario # 2, the reduction in the touch-up booths from 9 to 7, caused increase in the synchronization loss from 26 % to 30 % that led to the increase in the manpower cost productivity deficit to 33 %. In scenario # 3, the addition of one worker in the system as driver, to drive tractors in and out of the system helped reduce the synchronization loss from 30 % to 24 %. However, the addition of a driver into the system caused the increase in the manpower surplus capacity in the structure of operations that caused increase in the manpower surplus capacity loss from 3 %, in scenario # 2, to 12 % in scenario # 3. The total manpower cost productivity deficit increased from 33 % in scenario # 2 to 36 % in scenario # 3. In scenario # 4, the addition of 3 workers in the touch-up area of the system helped reduce the synchronization loss from 24 % to 16 %. But, the addition of 3 workers into the system further caused increase in the manpower surplus capacity in the structure of operations that led to the increase in the manpower surplus capacity loss from 12 % in scenario # 3, to 32 % in scenario # 4. Because, the added group of 3 workers in the touch-up system, did not have enough work to keep them occupied for the whole day. The total manpower cost productivity deficit increased from 36 % in scenario # 3 to 48 % in scenario # 4.

The production problems that occurred from time to time on the assembly line, for example, the lack of suitable parts, the lack of suitable tractor tires and less than the required number of trained workers on the workstations, caused an increase in the synchronization problems in the system, indirectly. The synchronization loss caused by production problems can be reduced to some extent by tightening the inventory control and inspection process on incoming parts and materials. The assembly line workers can also be trained to identify and handle production problems as soon as these occur, so that these are not transferred to the next operations.

8.5.3 USAGE OF WORKERS PER UNIT OF OUTPUT

In Table 8-2, column 2 shows simulated tractor output per year. Column 3 shows number of workdays, column 4 shows number of workers available per day and column 5 shows total work hours available. Column 6 shows work hours available per tractor, column 7 shows worker time usage, and column 8 shows the worker time used per tractor, for 4 production scenarios discussed above.

TABLE 8-2

USAGE OF WORKERS PER TRACTOR IN THE TOUCH-UP & PAINT SHOP AREA

col 1 Prodn. Scen. #	col 2 Tractor Prodn.	col 3 available Work Days	col 4 available * Workers	col 5 available Work Hrs	col 6 Work Hrs/ Tractor	col 7 Worker Usage	col 8 Hrs.Used/ Tractor
1	13048	286.97	8	36732.43	2.82	0.70	1.98
2	13035	309.37	8	39598.99	3.04	0.67	2.03
3	13052	280.89	9	40448.09	3.10	0.64	1.99
4	13026	260.61	12	50036.52	3.84	0.52	2.01

*** Workers are available for 2 shifts a day and 8 hours a shift**

Table 8-2. Usage of workers per tractor in the "Touch Up & Paint Shop" area

The workers time in terms of hours available per tractor has increased from production scenario # 1 to production scenario # 4. The worker time use in terms of percentage has reduced from 70 % in scenario # 1 to 52 % in scenario # 4. However, the workers time in terms of hours used per tractor is more or less the same in all scenarios.

8.5.4 MANPOWER USAGE & NON-USAGE COST PER UNIT

In Table 8-3, the manpower cost productivity deficit and its components, discussed and shown in Table 8-1 above, are translated into monetary units. Table 8-3 displays the system's manpower cost per unit, differentiated into manpower usage cost and manpower non-usage cost per unit. The manpower non-usage cost is further differentiated into manpower non-synchronization cost and manpower surplus capacity cost within operations per unit of output. These cost terms are defined above.

These values are calculated on the basis of the share of manpower synchronization loss, and the share of surplus manpower capacity loss, shown in Table 8-1, and the available manpower cost per unit of output, calculated using Operation Based Costing, discussed in Chapter 6.

TABLE 8-3
MANPOWER USAGE & NON-USAGE COST COMPONENTS PER TRACTOR FOR TOUCH-UP & PAINT SHOP AREA

col. 1 Prodn. Scen. #	col. 2 System Manpower Cost / Tractor	col. 3 System Mpower Usage Cost / Tractor	col. 4 System Mpower Non-usage cst/Trac	col. 5 System Mpower Synch Cost / Tractor	col. 6 System Mpower Surplus Cap. Cost / Unit
1	95.06	66.54	28.52	24.72	3.80
2	105.79	70.88	34.91	31.74	3.17
3	103.66	66.34	37.32	24.88	12.44
4	124.03	64.50	59.53	19.84	39.69

Table 8-3. Manpower usage and non-usage cost components per tractor for "Touch Up & Paint Shop" area

In Table 8-3, the cost per tractor in the "Touch Up & Paint Shop" area, is differentiated into the cost of manpower use and the cost of manpower non-use per tractor. The non-usage cost per tractor is further differentiated on the basis of causes of non-usage i.e. manpower non-usage cost due to synchronization problems, and the manpower non-usage cost due to the manpower surplus capacity in production operations. For example, in scenario # 1, $ 28.52 total non-usage cost per unit is the combined effect of $ 24.72 due to synchronization problems and $ 3.80 due to manpower surplus capacity lost due to the structure of operations. In scenario # 4, $ 19.84 synchronization cost and $ 39.69 manpower surplus capacity cost add up to make $ 59.63 as total non-usage cost.

8.5.5 POWER OF COST NUMBERS

The yearly cost numbers show the significance for making improvement decisions in the system of production. For example, Table 8-3 displays, for scenario # 1, $ 24.72 manpower synchronization loss per tractor. It is a significant loss per tractor in production process that can be saved to a great extent by improving the system.

The Table 8-4 displays, total 13,048 units of output per year in scenario # 1, and the total synchronization loss is $ 323,901. This is a huge number in terms of dollars that a manager can hardly ignore. Similarly $ 507,414 surplus manpower cost, unutilized in scenario # 4 is difficult to ignore by the plant management. These cost numbers indicate the savings in cost that can be achieved by reorganization of manpower resources in the system.

The Table 8-4 shows that the synchronization cost is much higher than the manpower resource surplus capacity cost in scenario # 1 and scenario # 2 and these cost numbers suggests management examine the production alternatives that can reduce synchronization problems to the minimum level without increasing other costs. In scenario # 3, the synchronization cost reduced, but the manpower resource surplus capacity cost within operations increased. In scenario # 4, the synchronization cost reduced but the manpower resource surplus capacity cost within operations almost doubled that of the synchronization cost.

Table 8-4
MANPOWER USAGE & NON-USAGE COST COMPONENTS FOR TOUCH UP & PAINT SHOP AREA

Simulatn. Scenario #	System Mpower Cost /Unit	System Output Per Year	System Output Cost Per Year	System Mpower Usage Cost	System Mpower Non-Usage Cost	System Mpower Synch. Cost	System Mpower Surplus Cost
1	95.06	13048	1,240,291.50	871,552.83	368,738.66	323,901.75	44,836.91
2	105.79	13035	1,378,961.01	923,490.19	455,470.82	414,113.87	41,356.96
3	103.66	13052	1,352,956.44	870,627.47	482,328.97	320,734.28	161,594.69
4	124.03	13026	1,615,556.60	845,420.77	770,135.83	262,721.74	507,414.09

Table 8-4. Manpower usage & non-usage cost components for "Touch Up and Paint Shop" area

It is found that the emergence of synchronization problems in the "Touch Up & Paint Shop" area is also enhanced by the various production problems that occur in upstream operations. The assembly lines and the tractor run-off operation areas are the upstream operations for the "Touch Up & Paint Shop" system. The production problems that caused increase in the synchronization problems, in the "Touch Up & Paint Shop" area, are:

1. Absence of inspection and repair workers in the tractor run-off area workstations, because they were asked to provide assistance to assembly line workers on the assembly line.
2. Starting problems in tractors that keep the booths occupied without work
3. Motor oil leakage through seals
4. Leakage of hydraulic pumps
5. Missing parts on tractors
6. Non-specific parts assembled to tractors. For example, some times the specific tires required for a tractor are not available and to move the tractor off the assembly line non-specific tires are used that are replaced later in the run off area.

Production related problems that occur due less number of trained workers in the assembly line area and in the tractor run-off area can be solved by having more workers trained. The problems that occur due to the parts and materials supplied can be solved by tightening the specifications.

The cost numbers shown in Table 8-4 are for the manpower resource category only. The other resources categories, such as, space, paints & material supplies, and capital resources tied-up in inventories, are also employed in the production process to produce the required units of output. If a similar cost analysis exercise is performed for these resource categories in the system, then the total cost numbers for the system will be higher than displayed in Table 8-4.

8.6 CONCLUSIONS

In this chapter, Resource Cost Productivity, and Resource Cost Productivity Deficit, concepts are defined. The four main causes responsible for productivity deficit in the system are synchronization problems, surplus resource capacity within operations, idle production capacity and production problems that emerge from time to time that upset the synchronization in production systems. Synchronization problems can occur between resource suppliers and production operations, between any two consecutive production operations, and between production systems and customer demand. The productivity deficit due to each cause can further be identified using simulation techniques.

In the case study, the manpower cost productivity deficit is quantified, in terms of percentage values and absolute cost values, to highlight the amount of cost that can possibly be reduced by improving the production system. In the "Touch Up & Paint Shop" System, the synchronization problems between operations were further increased by various production problems that occurred from time to time in the system.

In the case study, it is also demonstrated that all causes of productivity deficit identified may not exist in all production systems.

CHAPTER 9

COMPARISON OF OPERATION BASED COSTING TECHNIQUE WITH ACTIVITY BASED COSTING TECHNIQUE

9.0 ABSTRACT

In a competitive business environment, long run profitability of the company depends largely on the continuous incremental reduction in the cost and continuous improvement in the quality of production.

The objective of measuring cost by engineering professionals is not to provide the cost per unit of output, but to generate cost information for improving the use of resources in for reducing the cost of production.

Activity Based Costing technique do not provide enough detailed cost information about production operations to be helpful in guiding production executives to improve the system, to reduce the cost of production.

The Operation Based Costing system is formulated to meet the information needs of production executives. This costing technique can be helpful in measuring the cost at various levels of details in production operations.

In this chapter, Operation Based Costing technique is compared with Activity Based Costing technique to highlight the basic differences between the two techniques.

9.1 INTRODUCTION

In 1980s' Robert Kaplan and Robin Cooper developed Activity Based Costing technique to measure cost of products more accurately as compared to traditional costing techniques. The relative accuracy of technique attracted the attention of engineering professionals to use this technique to measurure costs. A few of them used this technique and published their ideas in engineering publications. However, this technique does not help measure the cost of resources used in operations in detail, a key input requirement for improving operations.

The Operation Based Costing is developed to measure cost of resources used in operations, cost of operations and cost of production at different levels of detail at the organizational level.

In this chapter, important differences between Operation Based Costing, and Activity Based Costing are highlighted for the clarity of the readers.

9.2 COMPARISON OF OPERATION BASED COSTING WITH ACTIVITY BASED COSTING

The following are the differences beween Operation Based Costing, and the Activity Based Costing.

1. Difference in basic objectives

Activity Based Costing is developed to provide relatively more accurate cost information about products in a multi-product production systems as compared to the traditional costing technique. However, the cost information generated about activities, does not provide sufficiently detailed information about the level of resource use in each activity.

The Operation Based Costing technique is developed to provide the detailed cost information to shop-floor engineering professionals who try to raise the productivity of a system. It is done through the identification of the resources and their level of use, for each operation and for the total system of operations.

2. Definition of the basic unit of work and its structure

In Activity Based Costing literature, Turney, B.B (1991) has defined an 'Activity', as a 'Unit of work' without defining its structural details. The lack of detail makes a 'Unit of Work' comparable to the Black-Box perception, discussed in detail in Chapter 3. An 'Activity' as a unit of work implies a very broad definition of a work unit, without any indication of its boundary and a detailed structure of work included in it. In this broad definition, a group of activities can be labelled as one activity. Also, a single activity may be including a group of activities called sub-activities. In this kind of an arrangement the size of an activity can vary from person to person and from organization to organization.

In the Operation Based Costing method, discussed in detail in Chapter 6, an 'Operation' is defined as a set of predefined actions performed in a particular sequence, to convert the material undergoing an operation into a required item. Each operation takes some time for its completion from start to finish and during this time operation resources are used or consumed that contribute towards the cost of a unit of output undergoing an operation.

The resources that are used in any kind of operarion are grouped into a maximum of 8 categories, shown in Figure 6-1 in Chapter 6. These are described in terms of Materials, Machines, Fixtures, Operators, Space, Contract, Incentives and 'Tied-Up' resources. These 8 basic categories of resources used in an operation use or consume a variety of other resources for keeping them functional or operational. For example, Machinery may require power or gas for its working. Operators require wages or salaries for their maintenance. Work Space require utilities regularly for efficient conduct of operations. Contractors are paid regularly for Material inputs and services. Incentives are regularly provided to insure quality and timely delivery of Materials.

In Operation Based Costing system, resources and operations are identified and defined logically for a production process. There is little chance of creeping subjectivity and misunderstanding among concerned executives related to identification and definition of resources and operations.

The Operation Based Costing technique has a conceptual structure that matches the structure of real production operations. The system uses information related to production quantity, production time, and other resource related data collected directly by the production department personnel. The system also provides direction and hints to look for the relevant data related to operation cost from the accounting, finance, purchase and sales departments. For example, for machine related information, such as, purchase price and transportation cost, information can be collected from the purchasing department. Machine installation, maintenance and repair cost information can be collected from the maintenance and repair department. Interest and tax related information can be collected from the accounting and finance department. The resale value of machine can be taken from the resale market.

The information related to operation time, production output, resource employment, resource use, busy and idle time can be collected directly from the production departments.

Operation Based Costing technique perceives each operation as it operates in reality on an operation floor. Anyone involved in the estimation of operation cost will not fail to include all those resources that are actually being used or consumed in operations. The chances of having an entirely different perception of an operation by anyone are very remote.

3. Sub-division of a unit of work

In Activity Based Costing, each activity may have sub-activities representing sub-units of work. The definition of an activity does not help differentiate the components of work between activities and sub-activities. The distinction between an activity and sub-activity is subjective. For one person, a unit of work may be an activity and for another it may be a sub-activity, as explained in Chapter 3.

In Operation Based Costing, an 'Operation' is a real unit of work, defined by its internal structure and limited by its boundary. There is little chance of perceiving a real operation as a sub-operation. Every operation can have a maximum of 8 structural cost components. All other costs incurred in an operation are channelized through these 8 basic cost components of an operation.

4. Unique nature of an operation

In Activity Based Costing, two or more different type of activities can carry the same activity label that can result in the calculation of an average cost of an activity.

In Operation Based Costing, every operation is taken as unique from resource use point of view, and there no significant chance of accidentally averaging the costs of two different operations.

5. Unique nature of each operation cycle

It is possible that each activity cycle uses a different quantity of the same group of resources, causing a unique cost for each activity cycle. For example, for an 'Ore hauling' activity, each cycle of Ore haulage by a truck, from one end to the other, may a carry a different quantity of load.and may travel a different length of distance and for each cycle may use different amount of time. In the Activity Based Costing technique, the cost of each cycle of an activity is calculated as an average cost, and there is no provision to look into the cost of each cycle of an activity.

In Operation Based Costing, the calculations involve the time factor to calculate the cost of the operation. Therefore, there is a provision to analyze the cost of each resource of an operation for any operation cycle that uses a different amount of operation time. Thus, the Operation Based Costing technique can be very effectively used to cost specialized customized products and services in terms of cost contribution of each resource in production process.

6. Tracing cost of resources

In Activity Based Costing, tracing of resources used to conduct, start from the accounting & finance departments. The cost is distributed to various activity pools, and then to product pools controlled by activities. In Operation Based Costing, the identification of resources used, start at each operation level and then the cost of these resources are traced from various departments including the accounting & finance department of the organization.

In Activity Based Costing, costs are distributed to activities from above whereas in Operation Based Costing, costs are traced on the basis of actual use of resources in operations.

7. Depreciation of assets (Resources)

In Activity Based Costing, the book value of assets at the end of a period is used to arrive at the cost of activities. For example, the value of land and building may appreciate over time, but in accounting books, it will show loss in value after depreciation. The depreciated cost figure will become part of the cost calculations in Activity Based Costing.

In Operation Based Costing, accounting book values after depreciation of assets (resources) are not used. The asset's contribution to the cost of the operation for a any given period is calculated by using the market value of assets at the end of the period.

8. Measurement of cost of idle resources

Activity Based Costing technique is designed to measure the cost of activities and cost of products. It does not have the structure to measure the cost of idle resources for each activity and for the total set of production operations in an organization.

The Operation Based Costing technique also helps measure the cost of resources that are used during an operation. In addition to that, it can also measure the cost of resources to the organization for the time for which resources remained idle, for any reason. For example, a paint shop may be used in only one shift per day and in this case, the cost of the paint shop during the work shift can be separated from the cost of the paint shop for the idle shift. This kind of information is very useful for utilizing the production systems more efficiently and cost effectively.

The Operation Based Costing system can also be used to make the detailed cost information available about each operation. For example, the cost of the time for which a paint shop, painter and painting machines were waiting for material to be painted. This kind of information is useful to improve the operation function, thus making the use of resources in each operation more cost effective.

9. Evaluation of production scenarios

There are many ways to improve the working of a production system. For example, it can be through reorganization of manpower or reorganization of material flow or both, within a given system. It can be the addition or subtraction of manpower or machinery or both. It can be through changes in layouts or production procedures. Operation Based Costing, can be useful for the evaluation and improvement of different production scenarios in terms of production cost through computer simulation. It can also be used to measure the gain and loss of productivity by simulating changes in production processes and production inputs.

Activity Based Costing is difficult to use for simulation puposes as it lacks the structure of an operation.

9.3 CONCLUSIONS

In this chapter, the Activity Based Costing technique is compared with the Operation Based Costing technique to highlight their basic differences. Both techniques are compared on the basis of their basic objectives, basic structures, basic definition of activities, sub-activities, operations and sub-operations, uniqueness of operation and activity cycles, use of depreciated cost for cost calculations, measurement of cost of idle resources, and evaluation of production scenarios. In this chapter, it is shown that the Operation Based Costing technique is formulated to handle the information needs of the production executives for improving the productivity of operations, wheras Activity Based Costing is designed to only measure the cost of production more accurately in a multi-product production enviroment.

CHAPTER 10

CONCLUSIONS

10.1 INTRODUCTION

Profit is the main objective of business organizations, and companies use different strategies for different market conditions to increase the volume of their profits. In a competitive business environment, companies have to submit to market pressures and reduce the price of their products and services, that leads to a reduction in their profit margins and their total profits. In order to maintain their profit levels, companies look for ways to reduce their production costs and increase their sales volume.

The responsibility for reducing production cost is generally assigned to engineers who work with the production processes at the shop floor level. However, engineers do not have information about the cost contribution of the various resources to production costs. The accounting and finance departments in companies do not supply cost information about resources, operations, and other functional areas to engineers and production managers. Engineers, themselves, are not trained to estimate and analyze costs in production systems during their professional education and training in engineering schools.

In this chapter the objectives of the study are concluded, limitations of the study are emphasized, and future research direction is briefly discussed.

10.2 MEETING THE OBJECTIVES OF THE STUDY

Five objectives were established for this study, and each one is discussed briefly in this section.

OBJECTIVE 1

To show that cost analysis is a part of the Industrial Engineering profession

Cost analysis of production systems is not considered part of the engineering profession, and engineers involved in production processes measure efficiency of production in terms of the efficiency of the physical inputs employed.

In Chapter 2, historical evidence from the engineering literature is provided to show that the subject of cost analysis is a part of the engineering profession since its inception. However, over a period of time it has been removed from the engineering curriculum.

In order to reduce cost of production by improving operations, engineers require cost information about the areas of operations for which they are responsible. The available cost analysis techniques, i.e. the traditional and the activity based, have been designed with the objective of providing cost information to outside parties, but not to the shop floor managers and engineers for improving production processes.

OBJECTIVE 2

To show that physical productivity measures do not always represent the cost behavior of the resources employed in production

Engineers are trained to use physical resources in production processes more efficiently. However, efficient use of a physical resource in a production operation does not mean improvement in the productivity of the production system. The efficient use of a physical resource in one operation may actually cause the inefficient use of other resources in the same operation, or the same resource in other operations.

In Chapter 5, it is shown that companies use different physical productivity measures for different functional areas, presenting a segmented picture of productivity. This does not allow the reporting of the impact of productivity improvement in one functional area on the productivity of other functional areas.

In Chapter 7, it has been demonstrated that improvement in the physical productivity measure of a physical resource in a production system, does not always mean increase in the productivity of the production system in terms of cost, the ultimate measure of productivity.

OBJECTIVE 3

To develop a comprehensive cost analysis technique to accurately measure productivity in production systems

Traditional and Activity Based Costing techniques are not developed with the objective of providing the cost information about the use of resources in operations and in departments.

The Operation Based Costing technique is developed with the objective of providing detailed cost information of about employment and use of resources in operations and departments to engineers and managers responsible for improvement of shop-floor system of operations. The technique is described in detail in Chapter 6. The structure of the technique is based on 8 resource categories called cost elements. These resource categories are in the form of Machinery, Fixture, Operator, Space, Contract, Incentives, Materials, and Inventories kept for production process. Two cost elements of the 8 cost elements, that is Materials, and Inventories tied for production, were discovered in the course of this research.

All kinds of resources employed in production processes can be categorized in these 8 cost categories. Therefore, the structure of the technique can be fitted to the structure of any real production operation. The technique was tested for measuring the cost of resources employed in operations, and in departments. The technique was also tested to measure changes in productivity in terms of cost in response to the changes made in production system.

In Chapter 7, the Operation Based Costing technique is used for measuring the productivity of resources in terms of cost, and the results obtained are used to compare the cost of the resources with their physical productivity measures.

OBJECTIVE 4

To measure the productivity of a production system in terms of monetary units, using the Operation Based Costing technique, with the information generated by computer simulation models.

The information generated to simulate a real production operation, using a computer model, can be used to determine the cost of available resources and the cost of resources used in different production scenarios. In Chapter 8, the technique is used to measure the cost of available resources, and the cost of their actual use, employing the resource utilization information generated by the computer simulation models. The comparison of the available resource cost with their actual use cost helps determine the resource productivity and the resource productivity loss in terms of monetary units, for operations and for production systems. The determination of productivity loss in monetary units for different production plans and for different production scenarios, helps engineers estimate the savings in cost that can be made by making improvements in production systems.

OBJECTIVE 5

To identify the causes and share of productivity loss in the use of resources at the operation level, department level and system level, for making improvements in the production system

The computer simulation technique is found to be useful to determine the causes of productivity loss in production systems and the Operation Based Costing technique is found to be useful to determine the loss in productivity in monetary units, for various causes of productivity loss individually. The quantification of productivity loss due to various causes have been discussed in detail in Chapter 8 of the research study.

The determination of the causes, and the quantification of productivity loss due to each cause in production systems, help engineers to design solutions to reduce the cost of production by eliminating the causes of productivity loss.

The use of the technique with computer simulation models can also be used to test future production plans and production scenarios before making actual capital investments in plant and machinery.

COMPARISON OF COSTING TECHNIQUES

The comparison of the Operation Based Cost Analysis technique with traditional and the Activity Based Costing techniques was not a part of objectives listed for this study.

However, it is found to be necessary to compare them, in order to emphasize the main differences in their objectives, perceptions and uses. The techniques are compared in detail in Chapter 9.

10.3 LIMITATIONS

In manufacturing systems, products are produced to specifications. However, sometimes the extra quantity of materials beyond the required specifications goes out as part of the product sold.. Similarly, there is a possibility of a product or service, that is of better quality than required in the specifications. The extra material and extra quality of the products and services sold to the customers, increases costs to the company.

It has been found that companies do not collect information about extra material and extra quality of products and services. In the absence of this information, it is not possible to find out the cost of the extra material and extra quality, using the Operation Based Cost Analysis technique. However, if the information is made available, then the cost of extra materials and extra quality of products and services can also be determined.

For this research project, the Operation Based Costing technique is tested on shop floor operations in manufacturing. However, it also needs to be tested in other production and service operations as well.

10.4 FUTURE RESEARCH DIRECTION

The Operation Based Cost Analysis technique needs to be tested for service operations in service industries, e.g. health related services in hospitals. The other important area that needs to be explored for measuring productivity, using the technique is the system of managerial decision making that appears to be complex, because it is difficult to track the time for which a manager's mind was involved in thinking over a particular managerial problem. However, this is an interesting challenge for research in the future.

The Operation Based Costing technique in combination with computer simulation modeling techniques can also be used to test the various production strategies of companies. The application of the technique for production strategy development and implementation at corporate levels needs to be explored and tested. This area of research can be useful to managers who are involved in the evaluation of various production strategies.

Productivity of a nation's economy is dependent upon the productivity performance of various industrial sectors and each industrial sector is dependent upon the productivity of its units. If the general causes of productivity loss are identified in each industrial sector, then it is less expensive to fix them in relatively short time throughout the industry to raise the productivity of the total sector. How to identify the general causes of productivity loss in each industry and how to find general solutions to the common causes of productivity loss in industries in a short time is the research area that also needs to be explored.

A new technique takes some time to master for its application and use. The Operation Based Costing technique is also a new technique developed to accurately measure the productivity loss in production systems. In industry, engineers involved in the improvement of production process want to know the level and causes of productivity loss very quickly. If the Operation Based Cost Analysis technique is transformed to a ready made software solution package that can make the separation of costs easy for its use, then a lot of time can be saved for making improvements and putting resources to more productive use. How to translate this technique into a software package for its easy and quick use and what should be the contents and structure of the data base required to fit the software package is an other dimension that needs to be researched.

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APPENDIX (1)

DEFINITION OF NEW TERMS USED

CHAPTER 6:

1. Operation

An Operation is a set of predefined actions performed in a particular sequence, to convert the material undergoing an Operation into a required item.

2. Operation Time

Operation time is the time to complete an Operation, from start to finish, on a unit of material undergoing an Operation.

3. Operation Resources

Operation Resources are the resources that contribute to the cost of a unit of product or a unit of a service in an Operation.

CHAPTER 8:

1. Productivity

Productivity is defined as the ratio of output to inputs. It is the most common measure used for making comparison between any two sections or departments with in an organization.

Most often, the ratio of output to input is measured using a single input, in terms of physical units of input used to produce output. Sumanth (1979), has labeled these type of physical measures of productivity as partial productivity measures, because these measures provide the output information related to only one input factor.

Managers involved in production decisions, generally, tend to take decisions on the basis of information generated using physical measures of productivity at shop floor level.

2. Change in Productivity

Productivity measured as the ratio of output to inputs at two different points of time show the change in the measure of productivity. The positive change in productivity means increase in productivity. The negative change in productivity means decrease in productivity. The zero change in productivity means no change in productivity or productivity remained same.

3. Productivity in terms of cost

Inverse of cost per unit of output is shown as the basic reliable measure of productivity in Chapter 7. The cost considered in this case is the operational version of the cost that actually happens at the shop floor as described in Chapter 6, and not the accounting version of cost. This measure can be used to evaluate the improvements made in production systems. If the cost per unit of output through operations, is reduced by making improvements in the system of operations, then the inverse of cost per unit of output will increase indicating the increase in productivity of the system and vice-versa.

4. Resource cost productivity, & Resource cost productivity deficit

To increase the productivity of a production system, it is necessary to measure the costs of resources per unit of output, and the efficiency of cost dollars spent, i.e. the dollars spent on the actual producing function, in producing that unit of output. For example, a worker hired for a day, was occupied with work for 2/3[rds] of the day, and was waiting for work, to be given to him, for 1/3[rd] of the day. It means, the actual worker use in the production process is 67%. 33% of his paid time was lost, because he was not given enough work to do. If the worker costs $30.00 per unit of output, then the worker cost productivity is 67% of the $30.00, i.e. $20.00 per unit. 33% is the worker's cost productivity deficit, i.e. $10.00 per unit. It means, a unit of output has $10.00 worth of the worker's non-usage or non-utilization cost in it.

The Resource Cost Productivity, and Resource Cost Productivity Deficit, can be measured for all available resources in each operation and in the total production system. These measures indicate the extent of resource utilization, and non-utilization in terms of the dollars spent.

In actual practice, most production systems are not balanced. In such cases, Resource Cost Productivity will always be less than 100 %. It means the available resources are not as productively used as theoretically possible, and there may be a window of opportunity to reduce the cost of production by increasing the productivity of the system, using industrial engineering techniques.

To measure the resource cost productivity, and resource cost productivity deficit, following terms related to the causes of productivity deficit are defined and explained.

5. System Cost

System cost is the cost of a unit of output at its designed capacity level for an ideal system that is continuously running. It is the minimum level of cost that can be reached for the given level of technology for a given production system. Beyond this, the unit cost can not be improved without upgrading the system's technology.

For example, if the system is designed to produce 100 units of output per day and 100 units are produced at 100 % capacity utilization with a total production cost of $100.00 (say), then the system cost per unit of output is $1.00.

6. Cost due to Non-useable Resource Capacity within the Structure of a Production Operation

This cost in a unit of output, is due to unutilized resource capacity within each operation due to the built in structure of the operation, and is discussed above in detail in the causes of resource productivity deficit. The high percentage of the unutilized surplus resource capacity within operations, provides an opportunity for management to reduce it either by improving the functional structure of the operation i.e. the mechanical engineering approach, or by balancing the resource use time within operations i.e. the industrial engineering approach. For example, in a 10 minutes operation, the operator finishes his part of the job in 5 minutes and for the other 5 minutes he does not have any other job to do, and waits for the machine to complete the operation. In this case, for every operation the operator's service is utilized only for 5 minutes. In an ideal situation the operator's service could be used for the whole 10 minutes by allocating his work time on 2 machines instead of one.

7. Non-synchronization Cost

In a majority of production systems, the designed production capacity of the system may not be achieved due to synchronization problems between resource suppliers and the operation, between any two consecutive operations, and between the production system and its customers. Due to these synchronization problems, a system designed to produce 100 units (say) per day may actually produce less than 100 units per day. For example, if 80 units are the highest production for a plant with a 100 unit designed capacity with a total cost of $100.00, then the lowest achievable cost is $1.25 instead of $ 1.00 per unit. In this case, the system's synchronization problems add extra $0.25 in the cost of each unit produced i.e. 20 % of the cost.

The high percentage of non-synchronization cost provides an opportunity to management to try to reduce the synchronization problems in the system, to reduce production cost.

In practice synchronization problems between operations are solved to some extent, by keeping buffer stock in between operations. This buffer stock helps reduce synchronization problems, but also adds cost to the production system by adding the cost of keeping extra storage space between operations, and by tying-up capital resources in carrying extra stock between operations.

8. Idle Plant Capacity Cost

In some cases, manufacturing plants have more capacity, but management decides to produce less due to less demand, discussed in detail in the causes of Resource Cost Productivity Deficit in detail. For example, production of 60 units, satisfy the current market demand for a system with 100 units designed capacity and with 80 units as the highest achievable production capability. The plant can produce 20 units more if the demand increases in future. If the total production cost is $100.00 for 60 units, then the unit cost will be $1.66, of which about $0.25 is due to the synchronization problems and about $0.41 is due to the excess production capacity carried to meet the unforeseen demand.

A high percentage of idle capacity cost provides an opportunity for management to reduce the cost of production by bringing in more business to use the unutilized production capacity of the system.

9. The Resource Usage and Non-usage Cost

The resource usage cost is the cost of resources due to their actual use in operations. The resource non-usage cost is the cost of resources due to the non-use of these resources in production systems due to any combination of reasons mentioned above. Resource usage cost represents the Resource Cost Productivity, and resource non-usage cost represents the Resource Cost Productivity Deficit. For example, in a system of production, the manpower resource may actually be used for 80 percent of its total time. The manpower cost productivity in this case will be 80 % of the cost paid for that resource, and the manpower cost productivity deficit will be 20 % of the total cost paid for the manpower employed.

The resource non-usage cost is composed of 4 main cost components i.e. synchronization problems that may occur between production operations, the cost due to non-useable resource capacity within production operations, the cost due to idle plant capacity, and the cost due to miscellaneous production problems in production system

APPENDIX (2)

PRODUCTION SCENARIOS

For 'Touch-up & Paint Shop' section, 4 production scenarios outlined by the manufacturing manager were evaluated using computer simulation. The summary of variables for each scenario, is shown in Table 5-1

TABLE 5-1
VARIABLES FOR PRODUCTION SCENARIOS

Prodn.	Touch Up Area		Std.Paint shop area		RR Paint shop area		Total # of
Scen. #	# Booths	# Workers	# Shops	# Workers	# Shops	# Workers	Workers
1	9	6	1	1	1	1	8
2	7	6	1	1	1	1	8
3	7	6	1	1	1	1 + 1* = 2	9
4	7	9	1	1	1	1 + 1*= 2	12

* Addition of Tractor Driver in Paint shop area

Table 5-1. Variables for production scenarios

The time and resource related data used for simulating production scenarios was collected from the department during two weeks production period in July 1999. Before running the production scenarios, the model and its results were validated with the actual production results. The model and its results were discussed with the manufacturing manager and the department supervisor for their inputs.

PRODUCTION SCENARIO # 1

The 1st scenario was to study the production capability of the department with 9 touch-up booths and 6 touch-up workers in 2 groups, and 3 workers in each group. One paint-worker in standard paint shop and, one paint-worker in rust resistant overcoat paint shop. Total 8 workers in the department.

Work Responsibility in Scenario # 1

Touch-up workers, clean, decal and touch-up the tractors sent in.

The paint shop workers drive tractors in and out of their respective paint shops in addition to the paint job on each tractor.

The rust-resistant overcoat paint worker, whenever directed by the supervisor, also drives tractors into the touch-up & paint shop area from the tractor waiting area located outside the building. He also drives the serviced tractors out to the waiting space located outside the building. Whenever he has nothing else to do i.e. he is free, he is asked to drive serviced tractors waiting outside, to the shipping warehouse for parking.

PRODUCTION SCENARIO # 2

In the 2nd scenario, the touch-up booths reduced from 9 to 7. Everything else kept same as in scenario # 1.

Work Responsibility in Scenario # 2

As in scenario # 1

PRODUCTION SCENARIO # 3

As in scenario # 2, but with the following changes: One tractor driver added to assist shop painters in moving tractors in and out of the area. Total 9 workers in the department including one driver.

Work Responsibility in Scenario # 3

Work responsibility as in scenario # 1, but with the following change: The tractor driver, added to the department, drives tractors to the touch-up area from outside, whenever he is directed to do so by the supervisor. He also drives the serviced tractors from outside waiting space to the shipping warehouse area for parking and then walks back to the touch-up area.

PRODUCTION SCENARIO # 4

As in scenario # 3, but with the following changes: A group of three workers added in the touch-up area to expand the production capability of the operation. Total 12 workers in the department, including three workers added.

Work Responsibility in Scenario # 4

As in scenario # 3

OTHER RESOURCES EMPLOYED IN EACH SCENARIO

The following resources were used in all 4 scenarios:

Touch-up booth space for touch-ups, 9 booths in scenario # 1. 7 booths in scenario # 2, # 3, and # 4. One Standard Paint Shop Space. One "Rust-Resistant overcoat Paint Shop" Space. Paint material for touch-ups, standard paint and rust-resistant over-coat paint, paint spray guns. Other utilities and supplies such as electricity for light and fans, gas for heating the space and other expenses related to wash rooms.