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NRCC-37001

National Research Council Canada
Conseil national de recherches Canada

Canada

Productivity in Construction

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IRC-P-3547
NRCC 37001
NR16-24/1993E
ISBN 0-662-21134-0
Ottawa, December 1993

Preface

NRC's Institute for Research in Construction is delighted to be instrumental in bringing this important guidebook to the construction professionals of Canada. This CSCE-NRC project is a good example of the kind of alliance that is increasingly important in support of the Canadian construction industry as it strives to find internationally competitive ways to do business. The pairing of the country's leading source for construction technologies with the senior national professional association in civil engineering has produced a definitive statement on the subject of productivity, which I commend to all readers.

G. Seaden, Director General
Institute for Research in Construction

Foreword

Contractors have often been heard to say, "As long as we are as aggressive and efficient as our usual competitors, we will always get our share of work." But in today's marketplace, being as efficient as one's neighbour does not suffice. Competition is no longer limited to contractors working in well defined geographical areas. The available work is being sought by firms from other parts of the country or even of the globe.

Canadian competitiveness, or rather the lack of it, has been in the headlines now for several years. For example, a report in the 25 June 1991 issue of *The Economist*, entitled "A Survey of Canada," claims that:

> *"In general, the growth of Canadian productivity is declining; yet if Canada is to remain a high-wage economy, it has to be a high-productivity one. Annual productivity growth, which has been 2.3% in 1946-73, fell to 0.9% in 1973-90. And the growth of Canadian manufacturing productivity has slowed relative to all other members of the Group of Seven rich countries. Cost competitiveness relative to the United States has declined particularly sharply...."*

There are also signs of slowed productivity in Canada relative to Japan. Between 1986 and 1990, the productivity of construction labour in Japan increased by 6.6% a year, while Canadian construction productivity rose by only 1.6%.

In response to this dilemma, the Construction Division of the Canadian Society for Civil Engineering (CSCE) developed and implemented a program with a view to improving productivity. CSCE, with the assistance of the National Research Council, formed an alliance with the Construction Technology Centre Atlantic Inc. (CTCA), according to which CSCE would produce a manual about ways to improve productivity and CTCA would organize seminars. Such seminars on productivity improvement have taken place across Canada since September 1990, usually in collaboration with the local construction association.

The Institute for Research in Construction has now decided to draw on the experience gained from the preparation of the manual and presentations, and publish this document, "Productivity in Construction." I hope that it receives the attention it deserves and that every supervisor of construction projects refers to it frequently for guidance.

Stephen G. Revay, F.EIC, F.CSCE
Past President (1989-90) CSCE

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1 Introduction

1.1 Productivity: More Achievement per Resource

Economists have been saying it, so have constructors, organized labour – everybody: to remain competitive, we have to produce more for each dollar spent on construction. And "we" is everybody – every worker at a job site can contribute to improved productivity.

Productivity issues can be divided into macro- and micro-level. At the macro-level, one deals with contracting methods, labour legislation, and labour organization; at the micro-level, with the management and operation of a project, mainly at the job site.

To improve productivity, we must be able to measure it. And we must be able to measure the effect of changes adopted on methods, effort, and systems. The measured values of productivity can then be compared either to those used to compile the estimate or to some production standards. Although no formal industry standards exist in North America, many sources of published productivity data, as well as the databases of various companies, can serve as production standards.

A number of complex and interdependent factors can influence productivity on a construction site. A Construction Industry Development Council task force developed a questionnaire of factors impairing construction productivity (CIDC, 1984). It lists seven categories and 95 factors. Table 1.1 lists the most serious factors within each of the seven categories.

Table 1.1 factors seriously impairing construction productivity

Category	Factors
Project Conditions	Weather variability
Market Conditions	Material shortages
	Lack of experienced design and project management personnel
Design and Procurement	Large number of changes
Construction Management	Ineffective communications
	Inadequate planning and scheduling
	Lack of sufficient supervisory training
Labour	Restrictive union rules
Government Policy	Slow approvals and issue of permits
Education and Training	Lack of management training for supervision, project management

Research findings by social scientists and construction researchers can be contentious, due to the difficulty in accounting for the many interdependencies. The impact of such factors as morale and satisfaction may be debatable, but that should not keep us from thinking seriously about improvements in productivity. (The idea of improved productivity is too important to be allowed to stumble over academic arguments.) Although we may not know the precise effects of many of these factors, we can observe the effects of combinations of them.

1.2 What is Productivity?

Many terms are used to describe productivity in the construction industry: performance factor, production rate, unit person-hour (p-h) rate and others. Traditionally, productivity has been defined as the ratio of input/output, i.e., the ratio of the input of an associated resource (usually, but not necessarily, expressed in p-hs) to real output (in creating economic value). To restate this definition for use in the construction industry: labour productivity is the physical progress achieved per p-h, e.g., p-hs per linear metre of conduit laid or p-hs per cubic metre of concrete poured.

The two most important measures of labour productivity are:

- the effectiveness with which labour is used in the construction process;
- the relative efficiency of labour doing what it is required to do at a given time and place.

Examples of the first measure are the labour dollars required to produce a square metre or square foot of living area, or the labour cost of providing one bed in a hospital. Another example is the labour content required, per barrel of output, to build an oil refinery. In these cases, technological innovations or design improvements have the most significant impact because it is the effectiveness with which labour is used in the building process that is being measured.

Contractors and organized labour are, however, more interested in the second measure, the relative efficiency of labour. Examples include the number of square metres of formwork or linear metres of conduit that can be installed per p-h at a given time and place.

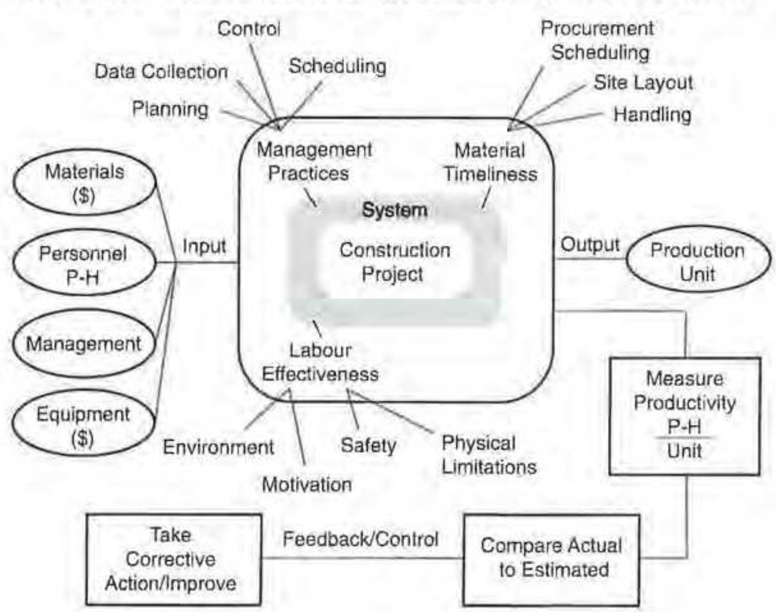
Labour efficiency is the basis of most tender estimates, as well as the yardstick by which performance is measured and monitored.

For example, it was reported that 837.4 p-hs were required to construct a house in 1930. By 1965, the requirement was reduced to 283.2 person-hours. The reduction in p-hs is equal to an impressive average annual growth rate of 3.2%.

It is not surprising that some analysts have tried to explain this as the result of steadily improving labour efficiency. The real improvement, however, had little to do with improved efficiency but was due to such technological changes as improved construction excavating equipment and the introduction of drywall to replace wet plaster.

When relative growth in labour productivity was equated with real improvement in labour efficiency, the construction industry was led to believe that no problem in declining productivity existed. Apparently lack of motivation is not seen as a problem, and the ever frequent financial losses were blamed either on poor estimating or on the impact of accelerated schedule performance. Construction supervisors eventually had to face up to reality and admit that labour efficiency has been steadily declining for some time. By accepting the reality and trying to understand both the magnitude of and the causes behind this decline, the construction industry is making strides toward improving productivity.

Figure 1.1 Framework for productivity improvement



1.3 Framework for Productivity Improvement in Construction

Productivity improvement in construction is best understood when the construction process is visualized as a complete system as shown in Figure 1.1. The system is made up of the construction project to which material, personnel, equipment, management, and money are inputs. They are consumed by the system in the process of producing the construction unit. Control of the system is achieved by collecting and processing information about the rates at which production is attained.

To measure input/output, the parameter defined as productivity, two types of input to the system are used: the person-hour/unit and the cost/unit. The first focuses only on labour and is used for labour-intensive operations. The second, cost/unit, combines all effects. The productivity of an operation is measured and compared to the values in the estimate or budget.

If the actual productivity does not compare favourably with the estimated values, the input categories affecting productivity in the system – namely material timeliness, labour effectiveness, and management practices – need to be examined.

To improve labour effectiveness, various factors can be addressed, including motivation, job safety, environmental factors, and physical limitations. Management practices include scheduling, planning, data collection, job analysis, and control. Material timeliness is ensured by proper procurement scheduling, site layout, and other issues.

1.4 Organization of this Publication

The purpose of this publication is to introduce the subject of productivity in construction. Each topic can be expanded and dealt with in more detail at every level of the construction process. The reader can pursue the topics further by referring to the books and papers listed at the end of each chapter. Some of these documents are cited in the text.

The subject matter, aimed at such construction practitioners as project engineers, superintendents or foremen, is presented in a format that can be easily read and understood. It gives practitioners the insights needed to gain an appreciation of productivity in construction. The publication, although an overview of the subject, covers each topic adequately and comprehensively.

Acknowledgment

The authors have drawn freely from written contributions to a seminar series jointly sponsored by the Canadian Society for Civil Engineering and the Construction Technology Centre Atlantic Inc. The seminars were entitled "Productivity on Canadian Construction Sites: An Overview. What Supervisors Should Know and Do."

The contributors were C. Fear, R. French, J. Gibson, G. Jergeas, K. Lemon, S. Perfect, K. Pressnail, S. Revay, A. Russel, L. Tardif, C. Trembley, L. Waugh, and S.P. Dozzi, who also served as the editor.

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2 Techniques for Measuring and Improving Productivity at Construction Sites

2.1 Introduction

The management of site-related issues in construction projects is often complex and difficult. The main problem is the quantification of all factors involved on site. The most accurate measure of productivity in construction is the number of units produced per person-hour (p-h) consumed, or its reciprocal, the number of p-hs consumed per unit produced. The productivity of a process can be measured indirectly by observing the level of activity of its resources.

Work studies and surveys may have a demotivating effect on the workforce. Special precautions must be taken to avoid the perception that the company is spying on its workers. Education and information sessions are recommended to create a team approach to productivity improvement. At a micro-level, workers are a valuable source of information concerning their performance or efficiency. Participation by the tradesmen[1] or supervisors can be expected only if requested.

This chapter deals first with proven techniques that are more widely used to measure the effectiveness (and, indirectly, the productivity) of construction workers and crews. Also discussed is the use of the data collected to improve the productivity of a construction process. A discussion on a method for measuring both effectiveness and productivity at the same time, the Method Productivity Delay Model, (Adrian and Boyer, 1976) follows. The second part of this chapter deals with more advanced methods to study and improve the productivity of a given construction process. With the increased use of computers, simulation is one of the more advanced techniques that could improve productivity. The idea of using systems simulation in planning and analyzing construction processes is introduced. To make this as practical as possible, the discussion is limited to the CYCLONE methodology (Halpin and Riggs, 1992) that has been developed specifically for construction operations analysis.

2.2 Measuring and Interpreting Work and Crew Effectiveness

2.2.1 Field rating

Field rating can be used to estimate crudely the level of activity of a construction operation. The method simply categorizes the observed worker as either "working" or "non-working" and uses the "working" fraction as a measure of effectiveness. To collect a random sample, an observer on site observes the workers. Once a sample has been collected, the field rating is calculated as total observations in the "working" category divided by the total number of observations, plus 10% to account for foreman and supervisory activity as follows:

Field rating = total observations of working/ total number of observations + 10%

The number should be roughly over 60% for a job to be satisfactory. For example, if a foreman made 100 observations of workers and only 40 were classified as working at the time, then the field rating would be 50%, i.e., 40/100 + 10. The job would, therefore, be considered unsatisfactory. The method does not tell the analyzer anything about the sources of problems or inefficiencies. It merely suggests that there is something wrong.

2.2.2 Work sampling

Work sampling is based on statistical sampling theory and is a slightly more sophisticated method than field rating. The basic objective is to observe an operation for a limited time and from the observations infer how productive the operation is. Statistical sampling theory is applied because the amount of time spent collecting data has to be limited. In addition, the number of workers observed is normally a small sample taken from the entire population of possible observations (every glance at the worker is considered an observation and therefore, every work sample can result in a multitude of observations). Instead of dealing with the whole population, the procedure is to collect a sample, analyze it, and build a confidence limit around it.

Work sampling estimates the percentage of time a labourer is productive relative to

[1] *The words, foreman, craftsman, and tradesman, are meant in a gender-neutral sense; likewise the word, workmanship.*

the total time the person is involved in the operation. To accomplish this, the following approach can be adopted:

1. Classify the worker's activity as one of three modes of activity: productive, semi-productive (involved in supporting the main activity), and non-productive.

   Note: There are a number of possible variations for this classification and readers can develop their own, once familiar with the concept. Flexibility can be enhanced by manipulating the semi-productive classification. One can easily define various modes of semi-productive activity, as shown in Table 2.1. For example, support work can be of the form "material handling," "instruction and decision making," "equipment maintenance," and others. However, more than a handful of classifications can make it difficult to collect data on site.

2. Develop a data collection form that will facilitate tallying the observations on site, as shown in Figure 2.1, for example.

3. Take random observations of workers involved in a given operation in the field. The observation should indicate the workers' activity mode, i.e., productive, non-productive, or semi-productive. Random, for all practical purposes, means without any bias as to who is being observed and that each worker will have the same chance of being observed as any other worker.

4. Record all observations on the form. Enter a checkmark under the appropriate mode of activity observed.

5. Add up all the checkmarks under each mode and calculate the percentage of activity. In the example (Figure 2.1), the 'percent productive' is calculated as 4/9 (= 45%), the 'percent non-productive' is 3/9 (= 33%), and the balance of 22%, semi-productive.

Table 2.1 Examples of activity classification

Classification (equivalent classification)	Productive (Direct Work) (Working)	Semi-Productive (Indirect Work) (Support Work)	Non-Productive (Delay) (Non-Working)
Description	Using trade tools	Supporting the main activity	Not contributing to the activity
Examples	mason laying brick, labourer mixing mortar, electrician pulling wire, welder welding pipe	tradesman getting material, travelling to work location, taking instructions	personal breaks, waiting for equipment to be fixed, waiting for more instructions, late start or early departure

Research indicates that the productive work category should normally be over 30%. Results of different work sampling studies vary from the low of 9.4% at Isle of Grain to a high of 64.4% measured by the National Association of Home Builders Research Foundation in 1973. Other representative samples reported are:

- 32% by the *Civil Engineering* magazine in 1977, measured at various nuclear power sites
- 34.7% by S.B. Palmater, measured at 13 nuclear power sites
- 46.5% measured by the University of Texas at random sites.

Improving the productivity of the process involves identifying the current activity rating and the sources of non-productive or semi-productive modes. This can be subjectively analyzed and depends heavily on the level of detail of the classification scheme adopted and the project being analyzed. A sample set of recommendations is given in Table 2.2.

Figure 2.1 Sample work sampling data collection form

Work Sampling Sheet

Project:

Date: **Observer:**

Notes:

Observation No.	Productive (Direct work)	Semi-Productive (Support work)	Non-Productive (Delay)
1	√		
2		√	
3	√		
4			√
5			√
6			√
7		√	
8	√		
9	√		
Total	4	2	3
Percentage	45%	22%	33%

Table 2.2 Sample causes of delay and recommended remedial actions

Causes of Delay (Excessive percentage of time spent on this factor)	Suggested remedial action (Each of these actions will require a detailed analysis)
Waiting for instruction	Pre-plan and pre-assign work duties.
Finding material	Improve site layout.
Getting material	Examine material handling and site layout.
Personal breaks	Examine human resource management and discipline.
Waiting for equipment repair	Use stand-by equipment where possible, pre-plan to reassign crews to other activities, schedule equipment maintenance to keep it in good working condition.
Waiting or queuing for service	Resolve resource allocation problems, possibly by balancing the resources.
Material handling difficulties	Improve site layout and address safety concerns.

For work sampling to be effective, the observer must make a large number of observations, a number that must be determined from statistical sampling theory. The minimum number generally accepted is 384[2] observations. This number is derived from a sampling error of 5% and a level of confidence of 95%. Tables, nomographs, and computer programs can be used to calculate the required number of observations for different sets of error limit or confidence levels.

Work sampling only attempts to indirectly measure productivity. It is difficult to determine the productivity of a carpenter, for example, by observing how many hammer blows it takes to drive a nail.

In decision-making, the results should be viewed with caution and used with discretion. They cannot be used to measure real labour efficiency, yet they are extremely useful to gain a better insight into motivation, and at the same time help explain the reasons behind drastic variations in production rates.

2.2.3 Five-minute rating

The five-minute rating technique, unlike work sampling, is not based on statistical sampling theory. The method relies on simply observing an operation for a short time. The observation does not result in a large enough sample to support work sampling. The method does, however, provide some insight as to the effectiveness of the crew and can identify areas where more observation is required.

The following procedure can be used to implement the 5-minute rating technique:

1. Identify the members of the crew to be observed and structure a form similar to that shown in Table 2.3, with the crew to be observed noted in the column headings and the time of observation listed in the rows of the first column.
2. Observe the crews as they are working. For the observation interval (in Table 2.3 the interval equals 5 minutes), determine whether the crew member has been active for over half the interval. If so, mark the observation cell with an "x"; if not, leave the cell empty.
3. Add the "x" observations for the entire table and divide the sum by the total number of observations. In the example of Table 2.3, 22 observations were positive out of a total of 32; therefore, the effectiveness is 22/32 or 68%.

Table 2.3 Sample five-minute rating data collection form

Time	Spreader	Screeder	Grader	Bull-Floater
9:50	x	x	x	
9:55	x	x	x	
10:00				x
10:05	x	x	x	x
10:10	x		x	
10:15	x	x		x
10:20	x	x	x	x
10:25		x		x
Effective observations	6	6	5	5

Total observations = 32 Effectiveness = 22/32
Observed effective = 22 5-Minute Rating = 68%

2.3 Field Surveys

The work sampling methods covered in Section 2.2 measure efficiencies in the site operation, but do not go far enough in identifying the leading cause for the inefficiency. For example, work sampling might indicate that a craftsman spent 25% of the time being delayed because the required material was not available. The method cannot, however, pinpoint the real cause of the delay or what can be done to reduce it.

Field surveys and questionnaires are organized ways of involving the foreman or craftsman in the site evaluation and productivity improvement process. Craftsmen are probably the persons most familiar with their work activity. They can easily identify sources of delay and obstacles in their progress. Likewise, a foreman is the person most familiar with the crew and the problems that restrict improvement in their productivity.

[2] *Although this seems to be a large number, in actual applications, every glance at the work in progress is an observation. Therefore, 384 observations is not excessive.*

Figure 2.2 Typical FDS form

Problem Causing Area	Person-Hours Lost		
	No. of Hours Lost	No. of Workers	Total Person- Hours
Redoing work (design error or change)			
Redoing work (prefabrication error)			
Redoing work (field error or damage)			
Waiting for materials (warehouse)			
Waiting for materials (vendor furnished)			
Waiting for tools			
Waiting for construction equipment			
Construction equipment breakdown			
Waiting for information			
Waiting for other crews			
Waiting for fellow crew members			
Unexplained or unnecessary move			
Other:			

Comments:

Made by:

Date:

Table 2.4 Sample FDS results

Problem-Causing Area	P-hs Lost	Percentage
Redoing work (design error or change)	122	2.3
Redoing work (prefabrication error)	24	0.5
Redoing work (field error or damage)	52	1.0
Waiting for materials (warehouse)	33	0.6
Waiting for materials (vendor furnished)	22	0.4
Waiting for tools	12	0.2
Waiting for construction equipment	56	1.1
Construction equipment breakdown	15	0.3
Waiting for information	12	0.2
Waiting for other crews	14	0.3
Waiting for fellow crew members	10	0.2
Unexplained or unnecessary move	20	0.4
Other	70	1.3
Total	462	8.9
Total work in person-hours	5 210	

2.3.1 Foreman delay survey

Foreman Delay Survey (FDS) relies on a questionnaire which is to be filled out by the job foreman at the end of a working day according to a particular survey schedule, e.g., one work week in each month. The questionnaire is primarily meant to identify the number of hours of a day lost due to delays. Most FDSs are divided into rework and delay categories. Once a form has been filled out, the information is extracted in the form of percentages and action taken to ensure that sources of delays are properly dealt with. A typical FDS form is given in Figure 2.2.

The results of the survey are converted from p-hs into equivalent percentages and reported on a form as shown in Table 2.4. The information on the report sheet will identify concerns that the foremen have with the operation. The example in Table 2.4 reveals that too much time is being spent on redoing work due to design error – 2.3% of the time – and waiting for construction equipment – 1.1% of the time.

The FDS is a relatively low-cost method for analyzing the sources of delay during construction. It can be easily stylized and implemented. For further details regarding implementation of FDS in construction, refer to Tucker *et al.*, 1982.

2.3.2 Craftsman questionnaire

Craftsman questionnaire (CQ) is a questionnaire-oriented technique attempting to address issues and concerns that relate to a craftsman's productivity and motivation. The basic idea is to distribute a simple questionnaire, similar to the one shown in Figure 2.3, to craftsmen on a job site to complete. The aim is to identify major factors that inhibit the productivity of craftsmen and estimate the p-hs lost per craftsman per week due to specific causes.

The questionnaire can comprise 50 short questions addressing such areas of concern as material availability and site layout, equipment and tool availability, rework items and causes of rework, management interference and inspection, and suggestions for improving the process. In addition, the questionnaire asks for the hours lost per week per craftsman on each area of concern listed. This is often supplemented with personal interviews with some of the craftsmen to validate the responses and test the level of seriousness.

Once the questionnaires have been collected, results are compiled and statistics reported to all concerned in a form similar to Table 2.5.

Figure 2.3 Sample craftsman questionnaire

Personal data	Check √ the appropriate box for YES or NO, or fill the box with the required information.	
Craft		
Location		
Type of work		
Other		
	YES	**NO**
Material		
Is material always available when you need it?		
How many hours do you estimate are lost per week due to material not being available?	______h	
Tools		
Are tools always available when needed?		
Are tools in acceptable shape?		
Are tools supplied always the right ones for the job?		
Are there any specific tools in short supply (please name)		
How many hours do you estimate are lost per week due to tools not being available or acceptable for the job?	______h	
Equipment		
Question 1 (Add more questions as under material and tools)		
Question 2 (Add more questions as under material and tools)		
How many hours do you estimate are lost per week due to . . .	______h	
Rework		
Question 1 (Add more questions as under material and tools)		
Question 2 (Add more questions as under material and tools)		
How many hours do you estimate are lost per week due to . . .	______h	
Safety Concerns		
Question 1 (Add more questions as under material and tools)		
Question 2 (Add more questions as under material and tools)		
How many hours do you estimate are lost per week due to . . .	______h	
Others		
Question 1 (Add more questions as under material and tools)		
Question 2 (Add more questions as under material and tools)		

Table 2.5 Results from a CQ

Problem/Cause	P-hs lost per week	Percentage per week
Material not available or poorly located	5.2	13.0
Tools not available or suitable	3.2	8.0
Equipment not available or down for repair	2.0	5.0
Work redone	4.8	12.0
Management interference	2.1	5.3
Other	2.5	6.3
Total	19.8	49.5

The report in Table 2.5 implies that material availability (13%) and redoing work (12%) are areas of major concern: they contribute 25% of the time lost by a craftsman in a week. From the answers in the questionnaire itself, the reasons for the time loss could probably be identified.

The ability to improve the productivity of an operation from the conclusions drawn from the CQ greatly depends on how well the questionnaire is structured, detailed, and stylized, and on how serious the craftsmen's participation is.

2.4 The Method Productivity Delay Model

The method productivity delay model (MPDM) was proposed as a way to combine both time study and productivity measurement (Adrian and Boyer, 1976). MPDM relies on having an observer collect data, on a special form, pertaining to the cycle time of a leading resource on the operation. The observer also notes the nature of the delays during the period of observation. Once the data collection is complete, a set of computations is carried out that measures the productivity of the operation, indicates the major sources of delay, and gives other useful statistics.

MPDM can be an effective way of measuring productivity on site and the delays that undermine it. Experience with the technique has shown that it can be less confusing when implemented on an electronic spreadsheet. For the example presented in this section, Microsoft Excel was used. Any spreadsheet can be easily automated and generalized with macros, so that the computations are automatic, once the observations have been entered.

MPDM provides more information than other work sampling techniques. In addition to providing the user with a measure of productivity, it can also identify sources of delay and their relative contribution to the lack of productivity.

MPDM consists of the following phases:

1 Identification of the production unit, and the production cycle

The production unit is defined as a measurable amount of work that can be visually identified by the observer without much effort. Examples of this would be a bucket of concrete, a truckload of dirt, or a row of bricks. The production cycle is the total time that it takes the crew to place one production unit.

Table 2.6 Sample type of delays identified during MPDM data collection

Environmental	Equipment	Labour	Material	Management
Change in soil conditions	Equipment being positioned	Personal break	Not available when needed	Poor planning
Change in wall section	Temporary breakdown	Finding materials or tools	Defective and has to be replaced	Undecided as to what should be done
	Unscheduled maintenance	Getting instructions	Improperly located on site	Unavailable for instructions
		Late arrival, early departure		Interfering with other operations

Figure 2.4 MPDM data collection sheet

MPDM Data Collection Sheet

Date: June 6, 1992

Operation: Roof truss installation — Observer: SMA

Production unit: One truss — Unit of time: Second

Prod. Cycle	Cycle Time	Enviro. Delay	Equip. Delay	Labour Delay	Mat. Delay	Mngt. Delay	Processing column*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	354						12.83
2	465		x				98.17
3	343						23.83
4	445	x					78.17
5	504				x		137.17
6	470		x				103.17
7	395						28.17
8	345						21.83
9	360						6.83
10	400						33.17
11	460		x				93.17
12	385						18.17
13	360						6.83
14	353						13.83
15	372						5.17
16	505			50%**		50%	138.17
17	465					x	98.17
18	440					x	73.17
19	430	x					63.17
20	360						6.83
21	375						8.17
22	405		x				38.17
23	475		x				108.17

* This column is not part of the data collection. It is inserted in the Table to facilitate processing.
To fill out this column take column (1) minus the average of the cycle times where no delay occurred.

** To attribute delay to more than one source, use percentages.

2 Identification of the leading resource

The leading resource is that resource involved in the operation with the most impact on the productivity. In other words, the operation will come to a halt if the resource stops producing. An example would be a crane in a concrete placement operation, the mason in brick-laying, or a dozer in an earth moving operation. This resource will be the centre of observation and cycle time determination.

3 Identification of the types of delay that can be encountered in the process

Five possible types of delay include those caused by environment, equipment, labour, material and management. Experience shows that users should define their own types of delay.

4 Data collection

MPDM requires that the observer time the production cycle for each production unit placed. The observer must also determine whether a delay took place during a given cycle. If a delay occurs, the observer must indicate its nature based on the categories of delays given in Phase 3. Examples of the types of delay under each category are given in Table 2.6.

5 Data processing, model analysis and recommendations

The processing of the MPDM data is carried out by filling out the MPDM data collection sheet (Figure 2.4), and Tables 2.7 and 2.8, which are meant to be self-explanatory. First, column (7) in Figure 2.4 has to be completed. This is simply column (1) minus the average cycle time of cycles where no delay has occurred. This is also given in Table 2.7, column (3) for a non-delayed production cycle.

The observer can use the form given in Figure 2.4 to facilitate the data collection. Sometimes MPDM fails to work because the cycle time is too short to observe, or too long to keep track of. In such cases, the method is not recommended. If time-lapse film is available, short processing cycles can be captured.

To illustrate the data collection procedure, consider a simple process involving the installation of a roof truss. The production unit identified for the roof truss process (Figure 2.4) was the actual placement of a wooden roof truss. The production cycle began with the lifting of one truss and concluded when that same truss was permanently braced. The leading resource was the mobile crane used to place the truss members. The cycle times were timed by reviewing the time-lapse film of the operation.

Potential sources of delay were also recorded whenever noticed. If more than one delay is observed during the same cycle, then the share attributed to the delay should be noted

Table 2.7 Summary of MPDM computation

	Production Total Time	Number of Cycles	Mean Cycle Time	Σ[lCycle time-Non-delay cycle timel]/n
	(1)	(2)	(3)	(4)
Non-delayed production cycles	Sum of all cycles (in Col. 1 of Fig. 2.4) where no delay was observed	No. of cycles where no delay occurred	Col. 1 ÷ Col. 2	Col. 7 from Fig. 2.4 for non-delayed cycles ÷ Col.2
Overall production cycles	Sum of all cycles (sum of Col. 1 of Fig. 2.4)	Total number of cycles	Col. 1 ÷ Col. 2	Col. 8 from Fig. 2.4 for non-delayed cycles ÷ Col.2

Table 2.8 MPDM delay information

Time Variance	Environment	Equipment	Labour	Material	Management
	(1)	(2)	(3)	(4)	(5)
No. of occurrences	Total x's in Col. 2, Figure 2.4 for this type of delay				
Total added time	Sum of this type of delay from Col. 7, Fig. 2.4 **Note:** When percentages are used in Fig. 2.4, then the sum should be prorated to the source of delay.				
Probability of occurrence	Row a ÷ total number of cycles				
Relative severity	Row b ÷ Row a x mean cycle time for overall cycles, i.e., Row b, Col. 3 of Table 2.7				
Expected percentage of delay time	Row c x Row d x 100				

Table 2.9 MPDM processing for sample applications

	Prodution Total Time	Number of Cycles	Mean Cycle Time	Σ[lCycle Time-Non-Delay Cycle Timel]/n
	(1)	(2)	(3)	(4)
Non-delayed production cycles	4 402	12	366.83	15.47
Overall production cycles	9 466	23	411.57	52.81

Table 2.10 Delay information for sample

Time Variance	Environment	Equipment	Labour	Material	Management
	(1)	(2)	(3)	(4)	(5)
No. of occurrences	2	5	1	1	3
Total added time	141.3	440.8	69.1	137.2	240.4
Probability of occurrence	0.09	0.22	0.04	0.04	0.13
Relative severity	0.17	0.21	0.17	0.33	0.19
Expected percentage of delay	0.01	0.05	0.01	0.01	0.03

as a percentage (Row 16 in Figure 2.4, for example). On the first observation of the crane's cycle time, it took 354 seconds to place one truss; no delays were observed. The entry in Figure 2.4, Row 1 is recorded under Col. 1. On the second cycle, which took 465 seconds, an equipment delay was noticed. The entry in Row 2 Col. 1 records the cycle time, and an "x" was entered under Col. 3 to indicate an equipment delay. The remainder of the data collection form was filled in similarly.

Upon completion of the calculations performed according to Table 2.8, the MPDM equations can be used to compute the productivity of the operation.

Overall Method Productivity
= (Ideal Productivity)(1 - Σ expected % of delay time)

Note: Σ expected % of delay time is the sum of Row e in Table 2.8.

Ideal Productivity
= 1/Mean cycle time for non-delayed cycles

Note: Mean cycle time for non-delayed cycles is obtained from Row a, Col. 3 in Table 2.7.

The last step in the MPDM computations requires the development of the variability of the ideal and overall production rates. These rates must first be analyzed to assess the variability of method productivity. Adrian and Boyer (1976) state that the higher the overall cycle variability and the ideal cycle variability, the less dependable the productivity prediction. Ideally, these ratios should be small. The variability of the productivity indicators are calculated from Table 2.7 as follows:

Ideal cycle variability = Value of Row a, Col. 4 ÷ value from Row a, Col. 3

Overall cycle variability = Value of Row b, Col. 4 ÷ value from Row b, Col. 3

To illustrate the computations for MPDM, an example is given in Figure 2.4. The cycles that were identified as 'non-delayed' totalled 12 cycles with an accumulated cycle time of 4 402 seconds. The result is a mean cycle time of 366.83 seconds (6.1 minutes). The processing is then performed and the results are shown in Tables 2.9 and 2.10.

The ideal productivity would then be (60 hours/min)/(6.1 minutes/cycle) = 9.81 trusses/hour. The real productivity, however, is the ideal productivity adjusted for the expected percentage of delay time per production cycle. The real productivity is calculated to be 8.75 trusses per hour.

The variability rates would be:

Ideal cycle variability = 15.47/366.83 = 0.04 (or 4%)

Overall cycle variability = 65.281/411.57 = 0.13 (or 13%)

Such variability is considered to be relatively minor and would indicate that the productivity rates obtained are realistic values.

The results of the analysis can be used to determine what the productivity rate is and what can be done to improve the productivity. Table 2.10 indicates that the most expected delay can occur from equipment (5%), but the most severe (lengthiest) delay has occurred from material. The 22% probability of an equipment delay indicates that management should concentrate on solving the problems associated with equipment.

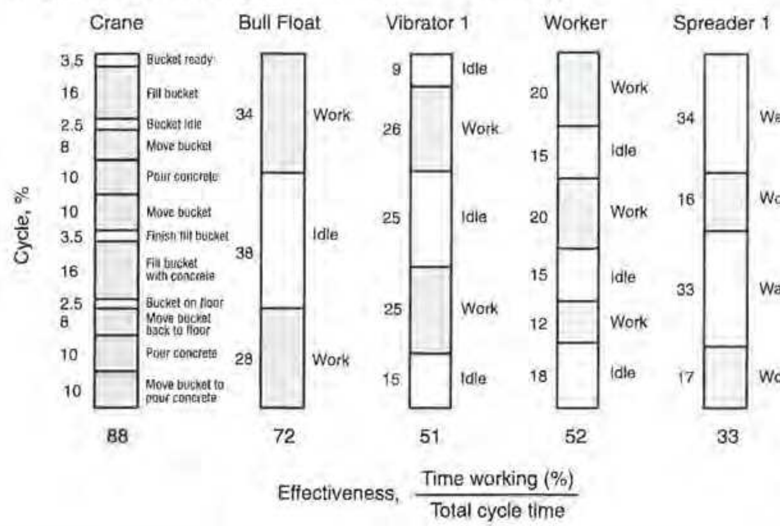
2.5 Charting Techniques: Crew-Balance Charts

Crew balance charts are a method of comparing interrelationships among various crew members and equipment required to carry out a task. This method is applicable to such cyclical tasks as placing concrete.

Vertical bars, as shown in Figure 2.5, represent each person or machine element involved in the task at hand. The ordinate of the chart expresses time either as a percentage of the total cycle time or the actual time of day. Each bar is subdivided vertically to show the time required for each activity involved in the task cycle, including idle, non-productive, and ineffective time.

To construct a crew balance chart, the time for each activity in the cycle is recorded for every worker or machine involved in the task. This may be done using a stopwatch or time-lapse film. The use of time-lapse film has many advantages over a stopwatch in that activity times for each element may be determined during one cycle. Conversely, the use of a stopwatch requires sampling from many cycles in order to record the activity times of each crew member. It is best to show only those elements that are pertinent to the problem at hand, because a crew balance chart may become cluttered with useless information, which reduces its effectiveness.

Figure 2.5 Sample crew balance chart for a concreting operation (Cycle time = 4 minutes)



From a crew balance chart, the user may determine interrelationships by comparing activities along a horizontal line since the time scale is the same for each crew member. In this manner, inefficient crew size or organization is identified and remedial action can be taken. By analyzing a crew balance chart, the user is stimulated to devise more efficient methods of performing the task. Reorganization of the crew may be all that is required or a different method may be in order.

2.6 Simulation Modelling and Analysis

Simulation in the context of this discussion is defined as "building a mathematical/logical model of a system and experimenting with it on a computer" (Pritsker 1986). This publication addresses simulation only with regard to the CYCLONE methodology. Although other techniques exist, none has shown so much promise in construction as the CYCLONE methodology.

2.6.1 The basic phases of construction process simulation

The simulation process consists of two basic phases: modelling and experimentation. CYCLONE provides the modelling elements and methods that a modeller can use to represent a construction operation in much the same way as a scheduler would build a Critical Path Method (CPM) network for a construction project, i.e., by specifying activities, and their logical relationships, durations and resource requirements. To model an operation using CYCLONE, the modeller focusses on the resources involved and their interactions. A resource can be in one of two states: active or idle. An active state of a resource is represented by a square; the idle state, by a circle. In the model, the resource can move between the two states and thus from one activity to the other. The whole idea of simulation revolves around the dynamic movement of resources. It is essential to distinguish between this method and a static system like CPM.

2.6.2 Building a CYCLONE model

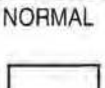
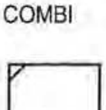
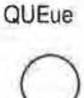
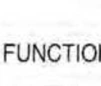
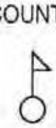
A CYCLONE model is constructed by using the CYCLONE elements shown in Table 2.11.

The rules for structuring CYCLONE network models using these elements are summarized in Table 2.11.

The CYCLONE modelling procedure uses the following steps:

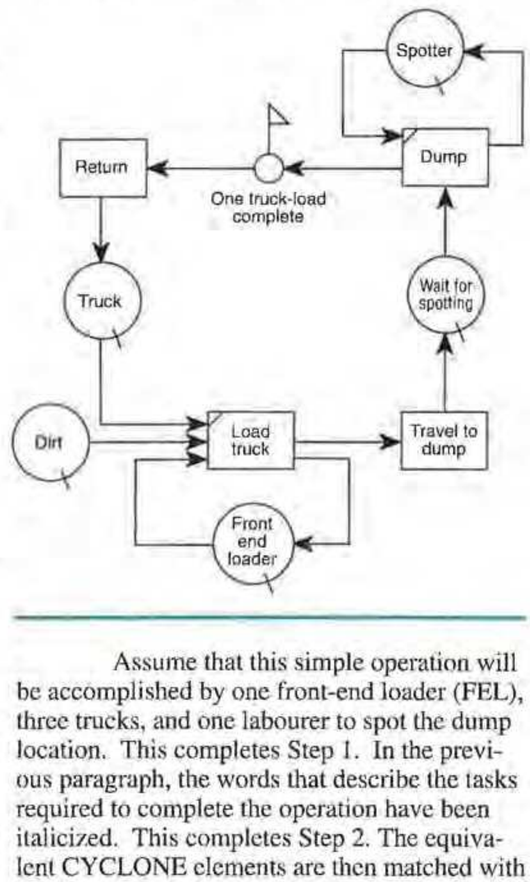
1. Identify all resources involved in the operation to be modelled.
2. Define the tasks (active states of a resource) composing the process to be modelled. Represent them with CYCLONE square elements (a task that is constrained by the availability of more than one resource is represented by a COMBInation element and a non-constrained task by a NORMAL element).
3. Define the resource requirement in the tasks and decide where they should wait when a constrained task is not available for service, i.e., it is waiting for other resources before it can proceed. This defines circle elements known as QUEue nodes in CYCLONE terminology.
4. Establish the logical relationships between these tasks (i.e., precedence and sequencing of the tasks) by connecting the COMBI, NORMAL, and QUEue nodes with directional flow arrows indicating where the resource would be moving from and to upon completion of a task. This makes up the CYCLONE network.

Table 2.11 Rules for structuring CYCLONE models

CYCLONE Element	Description and Rules for Model Building
NORMAL 	The NORMAL is not a restrained task. Any resource that arrives at a NORMAL is given access and is immediately processed. It is like a serving station with an infinite number of servers. Can be preceded by all other CYCLONE elements except for a QUEue node. Can be followed by all other elements except for a COMBI.
COMBI 	A task that is restrained by the availability of more than one type of resource. A resource arriving at a COMBI will have to wait until all other required resources are available before it is given access to the task. Can be preceded by QUEue nodes only. Can be followed by all other elements except COMBIs.
QUEue 	A QUEue node is a waiting area for a resource. Therefore it is used only when a task is restrained. A resource arriving at a QUEue node will stay in the node until a COMBI is ready to process it. A QUEue node has one other function in the MicroCYCLONE implementation, namely to multiply resources when specified. In other words, a modellor can specify that once a resource enters a specified QUEue node, it will multiply into a finite number of duplicate resources. Can be preceded by any element except a QUEue node. Can be followed by COMBIs only.
FUNCTION 	The FUNCTION element was devised to provide some flexibility. Different computer implementations of CYCLONE have somewhat different functions. In MicroCYCLONE, one type of function is allowed, namely the consolidate function. Its job is to take units and consolidate them into a specified number. Any unit arriving at this function will accumulate until a threshold value is reached, at which point only one unit is released from the function (all others are destroyed). Can be preceded by all elements except QUEue nodes. Can be followed by all elements except COMBIs.
COUNTER 	The counter keeps track of the number of times units pass it. It does not alter any of the resources or their properties. It just adds increments and keeps track of cycles and a few other statistics. Can be preceded by all elements except QUEue nodes. Can be followed by all elements except COMBIs.

A simple example of a CYCLONE network model of an earth-moving operation is given in Figure 2.6. A stockpile of dirt has to be moved from one location to another. The dirt would have to be *loaded* into hauling units first, the hauling units would *transport* the dirt to the required location where it will be *dumped*. After dumping its load, the hauling unit *returns* for another load.

Figure 2.6 CYCLONE model of an earth-moving operation



Assume that this simple operation will be accomplished by one front-end loader (FEL), three trucks, and one labourer to spot the dump location. This completes Step 1. In the previous paragraph, the words that describe the tasks required to complete the operation have been italicized. This completes Step 2. The equivalent CYCLONE elements are then matched with the proper task and arranged as shown in Figure 2.6. The loading task was restrained by the availability of both the truck and the FEL and therefore it is modelled by a COMBI node (similarly the dumping task, which requires the truck and the spotter, was modelled with the COMBI node). The travel to dump location requires the truck only and therefore was modelled by a NORMAL node. The truck-returning task was a NORMAL node for the same reason. When the task was restrained, it is preceded by two QUEue nodes where the respective resources wait. Loading was preceded by the FEL QUEue where the FEL waits until a truck is available. The dirt was modelled with a QUEue node and the truck waiting for loading also with a QUEue node. The truck waiting for the dumping was modelled by another QUEue node. This emphasizes that the state of the resource is modelled in CYCLONE methodology, rather than the resource itself.

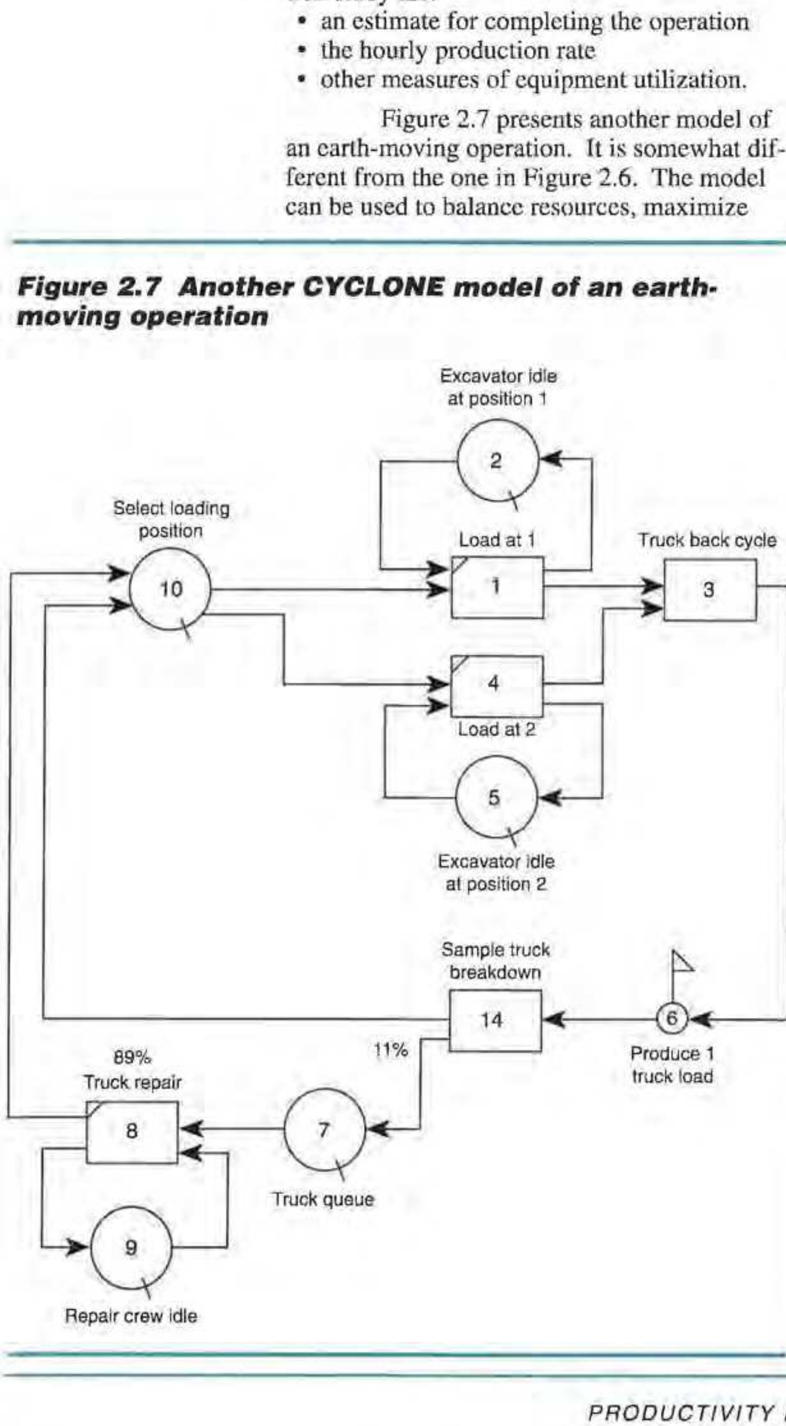
2.6.3 Experimenting, analyzing, and simulating

Once a model has been built, it can be entered into a computer program such as MicroCYCLONE for processing and performing the simulation study. The results of the simulation study are:

- an estimate for completing the operation
- the hourly production rate
- other measures of equipment utilization.

Figure 2.7 presents another model of an earth-moving operation. It is somewhat different from the one in Figure 2.6. The model can be used to balance resources, maximize productivity or achieve minimum unit cost, as well as to deal with uncertainty and risk.

Figure 2.7 Another CYCLONE model of an earth-moving operation



The operation considered in this model involves earth moving for a sports training facility in a university area. The earth is to be moved from the location of the training facility to the dump location about 3 km away. Two excavators remove earth at the job site at two different locations. A number of trucks carry the dirt, dump it, and return for another cycle. The truck would normally wait until one of the excavators is freed up before proceeding for loading. The operation was observed and data collected on the cycle times of the various equipment using a stopwatch. The observer also noted that the trucks break down on almost 5% of the cycles due to overloading (e.g., from flat tires).

The CYCLONE model of the operation was prepared as discussed previously. One main difference is the modelling of truck breakdown. The branch coming out of dummy NORMAL node (No. 14) indicates that every time a truck passes this task, it has 5 chances in 100 of ending up being tied in the repair task (No. 8); 95 times in 100 it continues in its cycle. Upon repair, it is released back to its original cycle. This is how equipment breakdowns are modelled in CYCLONE to simulate actual breakdown in the operation.

Now the model can be entered into MicroCYCLONE. The MicroCYCLONE user manual (Halpin, 1990) gives the reader all the required information. The first step is to transfer the graphical model into a written text file in the MicroCYCLONE syntax. The model in Figure 2.7 translates into the file shown in Figure 2.8.

Figure 2.8. Simulation input file

```
NAME 'Earth-Moving' LENGTH 5000 CYCLE 100
NETWORK INPUT
1 COMBI SET 'LOAD @ 1'FOL 2 3 PRE 2 10
2 QUE 'EXCAVATOR1 IDLE'
3 NOR SET 2 'TRK BACK CYC' FOL 6
4 COMBI SET 3 'LOAD @ 2'FOL 3 5 PRE 5 10
5 QUE 'EXACVATOR2 IBLE'
6 FUN COU FOL 14 QUA 1
7 QUE 'TRK QUEUE'
8 COMBI SET 4 'TRUCK REP' FOL 9 10 PRE 7 9
9 QUE 'REPAIR CREW'
10 QUE SEL LOAD POSITION'
14 NOR SET 5 'TRK BREAKDOWN' FOL 7 10
 PRO 0.05 0.95 SEED 101
RESOURCE INPUT
1 'EXCAVATOR' AT 2 FIX 129.38
4 'TRUCKS' AT 10 FIX 50.86
1 'EXCAVATOR' AT 5 FIX 129.38
1 'REPAIR CREW' AT 9 FIX 28
DURATION INPUT
SET 1 5
SET 2 35
SET 3 9
SET 4 60
SET 5 0
ENDDATA
```

This is entered into MicroCYCLONE and the simulation is started from the program. We started with four trucks working with the two dozers. The program outputs a productivity curve as shown in Figure 2.9.

Now a multiple simulation scenario is run to find the best combination of trucks and dozers. The assumption is that two bulldozers and 25 trucks are available. The simulation is performed and the results of production per hour versus number of trucks as well as the cost/unit versus the number of trucks are given in Figure 2.10. The combination yielding the highest productivity in truck-loads/hour is about 16 trucks. The best cost/unit value is for 12 to 16 trucks and jumps slightly with 10 and 18 trucks.

Figure 2.9 Productivity curve for the simulated process

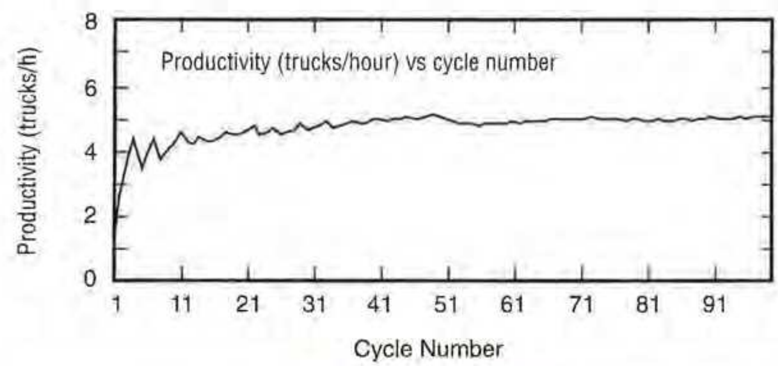
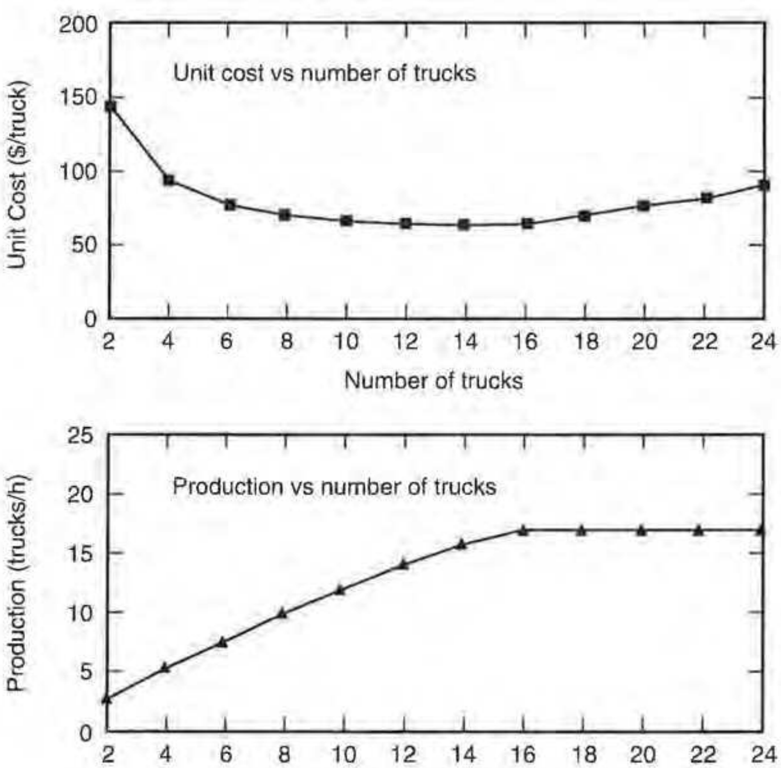


Figure 2.10 Summary of the simulation results



The possibilities of analysis are almost endless, once the simulation model has been constructed. The modeller can, for example, try different combinations of equipment, check what happens to the system if the dump location is changed, estimate the time required to move a specific quantity of dirt, and so on.

2.6.4 Simulation and Productivity

Simulation can be a very effective tool to plan for productivity. Moreover, simulation studies have been conducted to understand better the effect of various factors on productivity. Simulation can also be used to support claims due to loss of productivity from bad weather, unexpected delays, changed conditions, changes in the contract, and other factors. Similar studies can be conducted to analyze the effect of particular human factors on productivity.

The construction industry is far more complex than the service and industrial sector. Construction projects often take place in an open environment that changes with every project. Repetition is not obvious and the workforce is diversified. Construction is a unique industry and we should view it as such when we examine a technique used for managing it.

The methods described here have been tried on numerous projects. Unfortunately, the construction industry, which is traditionally craft-oriented, has not taken the steps required to use more advanced tools in its attempts to improve productivity. Initiatives to use new methods and techniques for measuring and improving productivity should be taken at the individual level.

Additional Readings

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Tucker, R.L., D.F. Rogge, W.R. Hayes, and F.P. Hendrickson. 1982. "Implementing Foreman Delay Surveys." *ASCE J. Const. Div.* 108 (4):577-591.

3 Human Factors and Productivity Improvement

3.1 Introduction

The motivation of workers can be enhanced through job enrichment (increasing the things that satisfy workers about a job) and by lessening the demotivators (the things that workers dislike). Reducing demotivators only, the predominant practice of North-American management, is not enough; it should be supplemented with job enrichment.

Workers are motivated by completing productive quality work, creating or building something, and social relations at work. Productive work can be produced by good planning and communications. Satisfactory social relations are simply working with other workers who are friendly and respectful. Individuals and organizations need goals to try to meet or exceed. Workers can often be motivated through goal-setting. Goals must be clearly established to elicit maximum performance and provide a feeling of maximum individual achievement. Individuals need a system or method by which to measure their achievements and compare their standings against a given target.

Construction work is varied, which can be satisfying. Workers are often motivated because they see the progress and results of their work. There are also many demotivators. The most common include:

- non-availability of the right material, tools, or equipment
- poor relations between workers and management
- poorly organized projects
- breakdown in communication
- lack of recognition of outstanding efforts
- disrespectful treatment
- unfair work assignments
- incomplete engineering/design work
- lack of cooperation between different crafts
- poor supervision
- rework
- no participation in the decision-making process
- restrictive or burdensome procedures.

Worker satisfaction and motivation can be increased by removing or reducing these problems. Questionnaires of the type described in Chapter 2 and suggestion boxes can be useful in bringing these problems to the surface.

3.2 Motivation

When applying motivational theories to everyday problems, three questions arise:

- What energizes human behaviour?
- What directs such behaviour?
- How is this behaviour sustained?

The answers given by various social scientists have been expressed in different words; nevertheless, they all seem to agree that human beings are energized by their physiological needs, and that their behaviour is directed by their expectations and sustained by obtaining just reward.

3.2.1 Motivation and the construction industry

The July 10, 1980 issue of *The Listener*, a magazine published by the British Broadcasting Corporation, contained an article describing the British experience in constructing nuclear power plants. The following is an excerpt from that article:

> "In recent years, no big plant has been put up on time. No big plant now being built is on schedule. The delay ranges from two to two and a half years for a chemical plant to four years for something as big as Grain (Nuclear Power Plant, Isle of Grain, G.B.). The rot is not solely or even mainly due to strikes; it is the result of almost unbelievably low levels of productivity. Do you believe that a man can spend eight hours on a site but do only 45 minutes' work in the whole day?
>
> No? But he can, and this is how they do it. In a standard eight-hour day, clocking on, walking to and from the job, tea-breaks, bad weather, union business, leave less than four hours available for actual work. Inefficiency, overmanning, and other bad habits will eat into another two or more hours, and you are left on a good British site with, at best, one hour and 40 minutes of actual working-time. On a bad site, where ten-minute tea-breaks have been known to stretch to an hour, the figure comes down to 40 minutes. Shop stewards can tell tales of awkward jobs that take hours to set up or high chimneys that take half an hour to climb up and thus explain away the little time a man spends with tools actually in his hands. There is, however, only one such chimney at the Grain.

These are all actual, audited figures and they reflect deterioration; productivity at the Grain is about 30 percent worse than it was at two earlier and comparable power stations built...."

The technique used to measure 'productivity' at the Isle of Grain site was 'work sampling' (see Chapter 2). One measures through random observations the ratio of productive time to total available time. For the purposes of such studies, productive time is defined as the time spent on cutting material, hoisting equipment, installing components, or erecting formwork, in general, working with tools in hand.

To understand the influence of motivation one must analyze all factors that affect efficiency. Labour efficiency is the rate at which workers do what they are required to do at a given time and place. To the extent that the terms 'labour efficiency' and 'labour productivity' are used interchangeably, labour productivity in this context means the rate of physical progress of a single task per p-h, where the added value has resulted from the input of human efforts only. In simplistic terms, labour efficiency is governed by both workers' attitude toward their assigned task and their ability to perform it. Unfortunately, this definition tends to put the entire responsibility for efficiency, or the lack of it, onto the shoulders of labour, which is obviously wrong, because management has as much, if not more, control over efficiency than labour has.

The factors that control labour efficiency include extraneous constraints, such as governmental regulations, climatic conditions, union rules, skill or inherent attitude of labour, and management practices.

Motivation is divided into two components, namely:

- Attitude possessed by the individual when arriving at the site. This attitude may be the result of the individual's social background, family relations, religion, or even political affiliation.
- Motivation resulting from the various job-related factors controlled by management.

3.2.2 Factors affecting motivation

Based on the experience gained from work sampling studies, management practices that affect motivation can be good planning, efficient communication, and a good work environment. Cleanliness, safety, adequate sanitary facilities, protection from inclement weather, fair but firm discipline, and provisions to apportion and distribute just rewards are the attributes of a good work environment.

3.2.2.1 Planning

Planning includes both overall job organization and work distribution at site level. Higher-level planning must provide for efficient sequencing of the various phases, e.g., design must precede the preparation of construction drawings and on-site construction should not start until adequate drawings are available. Similarly, subsequent trades should not be called to the site until the preceding trade has made enough progress to allow an uninterrupted work flow. Site management must ensure that required material is available in sufficient quantity for continuous progress. Good planning motivates workers because they can build up and maintain momentum toward completing their assigned task without interruption.

Good planning practices include proper use of scheduling techniques, site-layout planning, procurement scheduling, work assignment and organization, and proper approaches to crisis management. Good planning also involves feedback and control mechanisms. (For further information about these planning issues, consult such project management textbooks as Ahuja, 1984; Halpin and Woodhead, 1976; and Hendrickson and Au, 1989.)

3.2.2.2 Communication

To be able to contribute to the success of a project, a worker must be told exactly what tasks are expected of him. Therefore clear explanations of tasks and expectations are required. Employees must also know where their instructions come from, i.e., there must be a visible communication chain on the job. Instructions from an unknown source will be disregarded. Moreover, to be totally successful, the communications should flow both ways. The 'bottoms-up' management system practised in Japan does improve productivity. The system works because it nurtures the idea of communicating ideas both upward and downward.

Instructions and drawings are two methods of communication. Each must be complete and timely to allow good planning. Recent developmemts in scheduling and control software allow stylizing reports for individuals. In other words, a foreman in charge of formwork can get a report which only addresses activities of concern to his or her particular line of work and responsibilities. Foremen can thus focus on the required resources, and the start and progress of each activity for which they are responsible. This can greatly enhance the instructions provided to personnel responsible on site and enhance the communication process.

3.2.2.3 Work environment

Creating the proper climate for the motivation of construction workers depends to a great extent on the attention given to the basic personal comforts. This issue, when neglected by management, can be devastating to the attitude of labour and becomes a demotivator.

Basic personal comforts on a construction job represent the conveniences which a human being has come to expect in today's environment. They should include drinking water, proper sanitary facilities, site access, parking and protective gear.

3.2.2.4 Discipline

In addition to remaining alert for uneven application of the rules, a manager should be prepared to recognize and praise exemplary performance. Failure by supervisors to enforce discipline or take corrective action can demotivate the entire labour force. Favouritism must be avoided.

3.2.2.5 Rewards

Rewards can mean advancement in the chain of command, social recognition, or monetary compensation. They may take the form of a pat on the shoulder or the satisfaction of a job well done, depending on the circumstances and the character of the individual. But in all cases, the worker should be aware of both the reason and the nature of the reward. Moreover, the size of the reward should be commensurate with the reason for it. Unearned or unduly large rewards can have the opposite effect. Finally, rewards alone, without the other motivating factors being satisfied, are of little value on construction jobs.

3.2.3 Motivators

Frederick Herzberg, one of the best-known researchers of human behaviour, proposed the following principles as the means of enhancing motivation:

- remove some controls while retaining accountability
- increase the accountability of individuals for their own work
- give a person a complete natural unit of work
- grant additional authority to an employee in his or her activity
- make periodic reports directly available to the worker
- introduce new and more difficult tasks
- assign individuals specific or specialized tasks, enabling them to become experts.

The principles can be applied at any level on a construction site.

3.2.4 Demotivators

Demotivators have only a negative effect. Eliminating them does not result in enhanced motivation.

3.2.4.1 Overtime

Overtime generally means working in excess of 40 hours a week. Most studies indicate that 40 hours a week is the optimum work period and that working more hours reduces the rate of output. There are several reasons for this slowdown. Workers tend to pace themselves by slowing down to accommodate the longer day. The resulting productivity loss, according to some sources, may exceed the time worked beyond the normal 40-hour week. Simply stated, after nine weeks of continuous overtime, the output achieved in a 50-hour week is less than that which could have been achieved in a 40-hour week. Table 3.1 illustrates the resulting loss in productivity with overtime.

Table 3.1 Loss of productivity with overtime

			Inefficiency Factor			
Days/ Week	Daily Hours	Weekly Hours	7 Days	14 Days	21 Days	28 Days
5	9	45	1.03	1.05	1.07	1.1
5	10	50	1.06	1.08	1.12	1.14
5	11	55	1.1	1.14	1.16	1.2
6	9	54	1.05	1.07	1.1	1.12
6	10	60	1.08	1.12	1.16	1.21
6	12	72	1.13	1.2	1.26	1.32
7	8	56	1.1	1.15	1.2	1.25
7	9	63	1.12	1.19	1.24	1.31
7	10	70	1.15	1.23	1.3	1.38
7	12	84	1.21	1.32	1.42	1.53

This table has been derived principally from a Detroit-area study performed in 1964. It fits quite well with other studies by the Mechanical Contractor's Association, and the Electrical Contractor's Association, a Proctor and Gamble evaluation and a major Engineering Procurement and Construction contractor's estimating guide.

An alternative to overtime is alternate work hours. Here are some examples of alternate work hours:

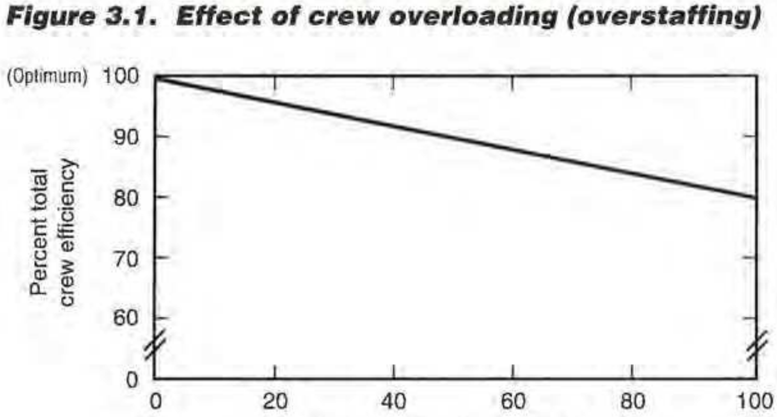
- Four 10-hour days have lower daily start-up costs, reduced equipment downtime, levelled peak staffing demands, and decreased absenteeism.
- If a project has been satisfactorily completed ahead of schedule, the construction crew might receive some time off – with pay – for their extra effort. Or if workers satisfactorily complete their assigned amount of work, commensurate with an 8-hour workday, they can go home, yet still receive a full day's pay.

With rolling fours, workers work 10-hour shifts: on 4 days, off 4 days. This type of work week reduces on-site population, decreases overall time for completion, reduces equipment demands, and avoids fatigue by cycling different groups of employees every 4 days.

3.2.4.2 Overstaffing

Overstaffing occurs when more workers are assigned to a task than are required to work productively. Overstaffing may take the form of increased crew size (for a given operation) or the deployment of multiple crews; in either case, a loss of productivity will occur. Figure 3.1 shows the effect of increasing crew size over the number required to perform a task within the allocated time.

Figure 3.1. Effect of crew overloading (overstaffing)



Adapted from: U.S. Department of the Army Office of the Chief of Engineers. 1979. *Modification Impact Evaluation Guide*. Washington, D.C. 20314, p. 4-14.

Optimum crew size for an activity represents a balance between an acceptable rate of progress and the highest possible level of productivity. Experience shows that on a greatly overstaffed project, the rate of progress may, at times, be improved by reducing the number of workers or equipment on the site. Overstaffing dilutes supervision, slows down material delivery because of competing demands and, in general, affects the morale of the workers.

The optimum crew size is the minimum number of workers required to economically complete a task within the scheduled time frame. As the number of workers is increased or decreased from optimal level, productivity will vary proportionally.

3.2.4.3 Stacking of trades

Stacking of trades (creating congestion) is a problem that develops when different trades, which should be working sequentially, are obliged to work simultaneously in a limited work space. When this occurs, the work area becomes smaller (or at least, appears so) because all trades are trying to bring in the material required for their work. Each trade tries to complete its work but the sequence of their activities is not coordinated. As a result, newly completed work often has to be torn out. Such congestion can also give rise to unsafe practices and conditions and leads to lost productivity in all trades involved.

3.2.4.4 Crowding

Crowding can be considered in a manner similar to the scheduled acceleration of tasks because the contractor attempts to complete more work activities in the same period of time or a designated amount of work in a shorter period of time. More workers are placed in a given space than can function effectively.

Figure 3.2 illustrates the upper limit of the loss in efficiency with the percentage of crowding. The meaning of crowding is subject to a wide interpretation. Crowding occurs when the work space per worker is reduced below a minimum required to work effectively. For example, if 18 workers are in an area that can only accommodate 15, the overcrowding is $3/15 = 20\%$. According to Figure 3.2, 20% overcrowding results in an 8% efficiency loss, which is equivalent to an 8% increase in the normal duration of all activities being performed in the work area during the period of overcrowding.

(Figures 3.1 and 3.2 are meant to serve only as a general guide; no precise information should be derived from them.)

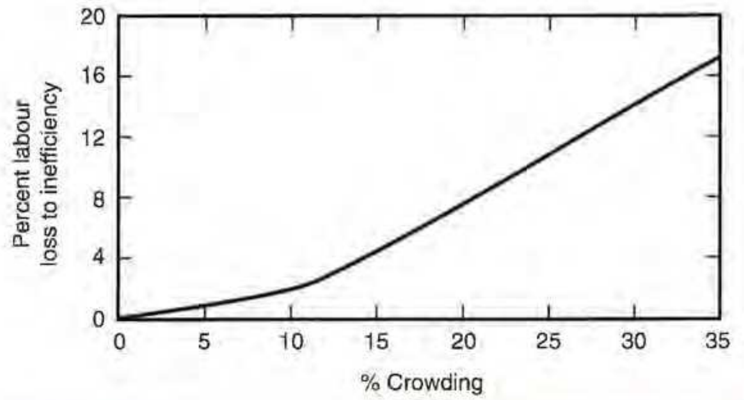
3.2.4.5 Multiple shifts

Introducing multiple shifts is another less distractive way of adding more workers to the workforce. Double- or even triple- shifting can be a reasonably economical method of accomplishing more work within the same period of time, but depending on the type of work, it can also give rise to a chaotic situation. Trades requiring fine motor skills are ill-suited for double-shifting; where activities require high precision, overall output may be even lower with a double shift than it would have been with a single. Gross motor skill trades, on the other hand, and equipment operation, such as bulk excavation or building an earth-fill dam, can be double-shifted very effectively.

A second shift, one that starts after the regular shift (i.e., after 5:00 p.m.) is less productive than the regular shift. People who work shifts face many problems that other workers do not. These problems come from changing eating, sleeping, and working patterns.

When shift cycles are changed, the first several days are periods of change and employees will be less alert, less accurate, and less safe. Sometimes shift rotation is invoked as a means to be fair to all workers, but it is actually unfair. It takes almost a month for the human body to

Figure 3.2 Effect of congestion of trades (crowding)



Adapted from: U.S. Department of the Army Office of the Chief of Engineers. 1979. *Modification Impact Evaluation Guide*. Washington, D.C. 20314, p. 4-14.

adjust to a different schedule. Moving workers back and forth from shift to shift does not let them adjust to a schedule and consequently they will not perform at their best.

3.2.4.6 Stop-and-go operation

Stop-and-go operation occurs when an essential component of an activity is not available when it is required. The component might be a drawing, a decision about a contemplated change, the acceptability of workmanship, pre-purchased material, or equipment. The activity is halted temporarily and the crew moved elsewhere to a new task. Breaking the rhythm, taking time to make a decision on the next step (usually referred to as reaction time), packing up tools, moving to the next activity, unpacking, orientation, and obtaining the required supplies, are all non-productive activities. Additional labour input is required without a corresponding increase in output, resulting in a net loss of productivity. At times, losses can be in the order of 30 to 40%.

3.2.5 Absenteeism and turnover

The major reasons for absenteeism, listed here in order of importance in the construction industry, are:

1. personal or family illnesses
2. poor overall management
3. poor supervision
4. excessive travel distance to the job site
5. excessive rework
6. unsafe working conditions.

The major reasons for turnover in the construction industry, also listed in order of importance, are:

1. inadequate tools and equipment
2. excessive owner surveys of on-site work
3. poor planning
4. poor overall management
5. mediocre supervision
6. overtime available on another job site
7. unsatisfactory relationship with boss.

Many of the reasons for absenteeism and turnover can be affected by management. By simply being aware of their major causes, supervisors may be able to make improvements on their sites.

Absenteeism and turnover have the following negative effects on productivity:

- Crew members waste time waiting for replacements.
- Time is spent transporting replacements to and from other work locations.
- Supervisors lose time in reassigning work activities and in locating replacements.

Other losses are incurred from not having the workers available, administrative costs (payroll, personnel, etc.) for terminating and hiring people and the disruption to fellow workers.

On average, it is estimated that 24 p-hs of paid time are wasted for each resignation.

3.3 Human Factors Related to Productivity

Human factors related to productivity fall into two groups:

- Individual factors, such as personal attributes, physical limitations, the learning curve, teamwork and motivation;
- The worker's environment, such as climate, work space, and noise.

Since construction work is labour-intensive, site workers clearly play a major role in the construction process. Although human factors are often not given much consideration, they strongly influence job site productivity and are key to the success of any project.

3.3.1 The individual as a factor affecting productivity

Persons with an optimistic and positive attitude are likely to have more initiative and think of imaginative solutions to various problems. A caring, considerate, and friendly person with a sense of humour can help increase productivity. Humour in the workplace puts people in good spirits, relieves stress, and develops teamwork.

A safe and healthy person is more productive. Respect for safety and safe practices must be encouraged, not only for the well-being of the workers, but to minimize 'down-time' on a project.

A creatively thinking person can contribute to increased productivity. Often it is the workers who come up with the best solution to a problem. Workers who demonstrate leadership skills should be encouraged to develop their potential because construction crews need good leaders to be successful and productive. Leadership skills include such characteristics as honesty, responsibility, good judgment, co-operation, being organized, and being a good listener.

Finally, experience plays an important role in the productivity of a worker.

3.3.2 Physical limitations

Humans are somewhat like machines in the sense that they require fuel to operate and produce energy (the capacity to do work), and they become exhausted if they are not looked after properly. Many construction tasks are physically demanding.

The type of work that persons are performing will dictate how frequently they need to rest and regain energy to continue working. Figure 3.3 illustrates this with a water reservoir analogy. An average young male adult can develop approximately 21 kJ (5 kcal.) of energy per minute, of which approximately 4.18 kJ (1 kcal.) per minute is needed to sustain life and the rest is available for expenditure in the form of work. If workers perform light work, then the energy reservoir remains full and they can continue working for long periods of time. However, if the work requires more than 17 kJ (4 kcal.) of energy per minute, the reservoir will drain and when it empties, they require rest to refill it with energy.

> "For an average construction task requiring 6 kilocalories [25 kJ] per minute including basic metabolism, work at this pace could continue for no longer than 25 minutes before the worker becomes exhausted. An average male, sawing and hammering with an energy demand of 8.1 kilocalories [34 kJ] per minute, must rest after about 8 minutes." (Ogelsby *et al.*, 1989)

To avoid short-term fatigue, tasks should be designed to avoid activities such as holding heavy loads or pushing hard against non-moving objects. Use tables, supports, props, jigs, fixtures and tools or other devices as a substitute for muscular effort.

The right amount and type of tools can increase productivity. Cutting and welding torches and welding-rod holders should be positioned to reduce effort and make work more visible. Sanders, grinders, drills, hacksaws and similar tools should have good weight balance and handgrips. Wheelbarrows and buggies should be designed so weights are balanced, thus requiring little lifting. Pneumatic tires increase ease in pushing and guiding.

If a worker has to put himself in an awkward position to perform a particular task, it can lead to discomfort and even injury. Persons working in an uncomfortable position are more likely to take breaks and work less productively. Working overhead tires the arms and can put the back in odd positions. Constant bending also puts unnecessary strain on the back. Back injuries are very common in the construction industry and these could be avoided if more work were done at waist-height.

3.3.3 The learning curve

The first time any person performs a certain task, they will work slowly because they are learning how to do it. With additional repetitions, the time needed to perform the same or similar tasks will decrease. It is therefore desirable, where possible, to have the same person perform a task several times rather than making personnel changes along the way. After a considerable number of repetitions, the learning curve approaches a plateau that reflects the minimum time required to perform a task (Figure 3.4).

This principle applies to highly repetitive manual operations. If delays occur between repetitions, the 'unlearning curve' effect can be noted as the worker gets out of practice and can no longer perform the task as well. It

Figure 3.3 Water-tank analogy of the human body's energy storage-replenishment capacity (Ogelsby et al., 1989)

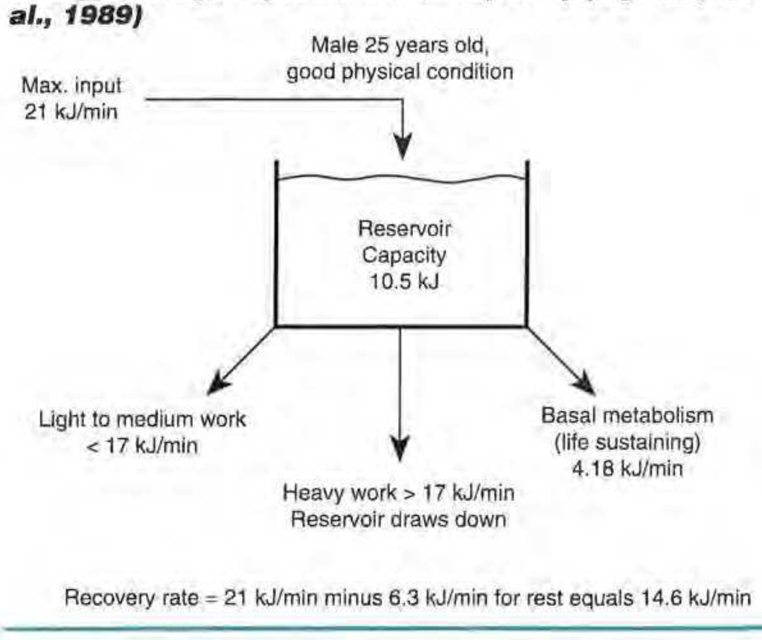
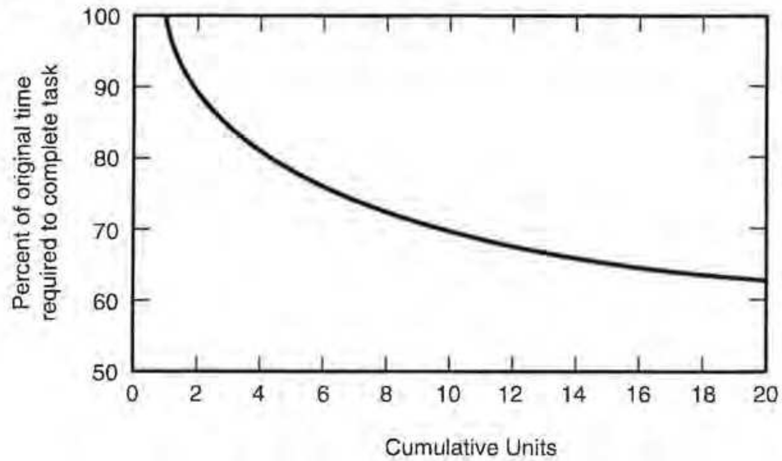


Figure 3.4 The learning curve

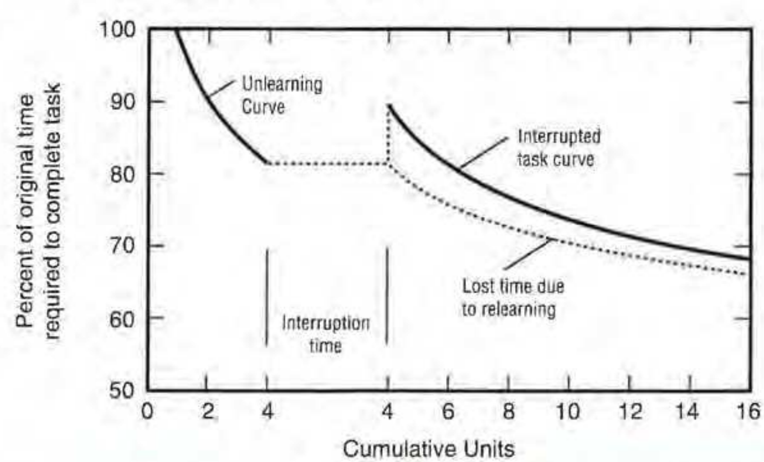


takes time for the worker to re-learn how to do the task. The same effect will be noted after personnel changes are made as the new workers must learn what to do. The unlearning curve is illustrated in Figure 3.5.

3.3.4 Crews and teamwork

Construction usually requires that a group of diverse workers act as a team with specific objectives. Teamwork can be maintained or improved by good, open, two-way communication. In that vein, workers should be asked for suggestions and solutions. Not only does this make workers feel that their opinions are valued and important, but it usually results in a solution to the problem.

Figure 3.5 'Unlearning' curve



This idea was developed in Japan through the use of quality circles. Groups of workers would meet and develop solutions to problems in their work, which would then be presented for management action. Supervisors and managers should aim to produce a productive environment and set goals for the team.

People enjoy not only the challenge of meeting and exceeding production targets but also contributing to solutions to problems. Mild competition in production objectives is also healthy and useful, i.e., productivity competitions between crews or between shifts. Supervisors can achieve higher levels of productivity by appealing to a worker's pride, competence, sense of duty, and team play.

3.3.5 Environmental factors

"Other things being equal, human beings perform relatively continuous physical or mental work most effectively when the temperature falls between 10 and 21°C at a relative humidity (R.H.) of 30 to 80%, under dry conditions, with the atmosphere clear of dust and other atmospheric pollutants, and without excessive noise. Departures from these conditions have adverse effects on productivity, comfort, safety and health" (Ogelsby *et al.*, 1989).

3.3.5.1 Weather conditions

Workers must slowly become acclimatized to working in hot weather. Heat stress occurs at temperatures above 49°C (120°F) at an R.H. of 10% and 31°C (88°F) at an R.H. of 100%. Above these temperatures, heat injuries can occur, which include sunburn, heat cramps, heat exhaustion, and heat stroke. These illnesses can be prevented by using acclimatization, adequate rest periods, proper clothing, and adequate water and salt intake.

Similarly, the ill effects of cold weather can be warded off by wearing proper clothing and having temporary shelters near the work area; heaters may be installed as long as they are well ventilated. The optimal temperature appears to be 5°C. At this temperature the productivity of indoor work is not greatly affected.

Table 3.2 shows the reduction of work efficiency in cold weather. It is assumed that efficiency is 100% at 21°C (70°F).

Table 3.2 Reduction in work efficiency in cold weather

Temp. °C	Loss in Efficiency (%)	
	Gross Skills	Fine Skills
4	0	15
-2	0	20
-7	0	35
-13	5	50
-18	10	60
-23	20	80
-28	25	90-95+ (probably can't work)
-34	35	—

Table 3.3 Relationship of temperature and humidity to productivity

R.H.	Temperature (°C)												
	-23	-18	-12	-7	-1	4	10	16	21	27	32	38	43
90	56	71	82	89	93	96	98	98	96	93	84	57	0
80	57	73	84	91	95	98	100	100	98	95	87	68	15
70	59	75	86	93	97	99	100	100	99	97	90	76	50
60	60	76	87	94	98	100	100	100	100	98	93	80	57
50	61	77	88	94	98	100	100	100	100	99	94	82	60
40	62	78	88	94	98	100	100	100	100	99	94	84	63
30	62	78	88	94	98	100	100	100	100	99	93	83	62
20	62	78	88	94	98	100	100	100	100	99	93	82	61

Table 3.3 shows the combined effect of temperature and relative humidity on productivity. This table, developed by the National Electrical Contractors' Association, can be used to predict the effects of weather on productivity for most construction tasks. This information can be useful when planning and estimating work and preparing construction claims.

3.3.5.2 Noise

Noise can interfere with work. It may create a safety hazard by not letting workers hear warnings or instructions. Noise may not affect the amount of work accomplished, but it will affect the quality, especially if concentration is required. Moderate, steady background noise, such as music, may actually increase performance. It covers up random, disruptive sounds and sets a pace to work by. Studies suggest that 90 decibels is the noise level at which possible hearing damage and decreased work performance result.

Effects of noise can be mitigated by reducing the noise at the source, separating noise sources from the workers, or having workers wear ear-plugs or other protective gear.

3.3.6 Workspace

The workspace should be set up so that it provides workers with a safe, healthy, and comfortable environment. It should be organized in an efficient and appropriate manner for the nature of the work being done.

Spending the time to keep the site clean is worth the effort, because it helps keep the project organized. Workers who feel that the worksite is safe will be more productive.

The workspace should also be well lit and well ventilated, and comfortable, so that the ill effects of the environment on the workers' productivity are minimized.

3.4 Job Site Planning

Planning a site for the most efficient use of all construction facilities leads to improved productivity for everyone. The degree of planning will depend on the complexity and size of the job. A good job site plan, the result of good job site planning, is of utmost importance to ensuring a productive workplace, regardless of project size.

3.4.1 Job site planning considerations

The preparation of one or more drawings with accompanying text should form the basis of the job site plan. A documented plan is equivalent to building the project on paper, where mistakes can easily be corrected and alternatives can be tested at little cost.

Many government agencies, utilities, and traffic planners require the information indicated on a site plan before issuing various construction-related permits. Timely receipt of these permits is required in order to avoid delays. Completion of the plan with subsequent revisions will require input from the entire project team.

In conjunction with the key trades, a plan for excavation, shoring, and de-watering should be developed. In the development of this plan, all previously established information from the preliminary site plan, with particular consideration to adjacent property encroachments and living restrictions, is used.

Considerable lead time is required to address environmental concerns properly. A plan has to be established at the project planning stage for the removal of contaminated materials and other substances, if such work has been identified.

Temporary access points for initial and final excavation ramps should be established to minimize interference with temporary construction services and be coordinated with the actual succeeding construction program, permanent hoarding entrances, and traffic flow requirements.

3.4.2 Temporary electrical service

The power requirements and the availability of power on a project should be reviewed as soon as possible to avoid unnecessary delays once the project has started.

Furthermore, to avoid delays on the project associated with inadequate electrical distribution, this activity must be planned in detail by individuals knowledgeable in the field. Too often trades are faced with electrical distribution systems that are inadequately sized, lacking in sufficient outlets, or unsafe to use. The inability to operate electrical tools and equipment effectively will result in an obvious loss in productivity. Associated with this problem is that of an improper temporary lighting system which can produce safety concerns, an unproductive work environment and potential labour disruptions.

3.4.3 Temporary heating and hoarding

The type of hoarding, the amount of heat required and the time for which it has to be applied, depend upon the work occurring at the particular area or stage of the project during the winter months. There are entirely different requirements for rough carpentry than for taping or painting. All of these considerations have to be taken into account when establishing the heating system.

As with the temporary electrical service, the gas utility companies require sufficient lead time in which to provide temporary services.

An undersized heating system, a system that does not protect the entire work area, or an inadequate hoarding system will ultimately produce downtime on a project. Choose high-capacity heaters with ducted fresh-air supply, where possible, to provide cleaner, dryer heat, and better fuel efficiency.

3.4.4 Miscellaneous systems

Job site efficiency can usually be improved by using:

- communications systems as part of a properly organized project
- a central compressed-air system accessible by all trades
- a water distribution system
- a refuse removal system.

The cost of supplying these systems is minimal compared to the time lost by not having them.

3.4.6 Offices, lunchrooms, and sanitary facilities

The location of owner, consultant, general contractor, and sub-trade offices should be as close to the site as possible and close to each other. Each site has its own characteristics and requirements for office locations. Similarly, the job site plan should carefully consider the location of the on-site workers' storage and lunch facilities, keeping in mind local union requirements, if applicable. Good sanitary facilities should be placed in reasonable locations to ensure that the workers do not spend unnecessary unproductive time travelling to and from their work station.

3.5 Safety Issues

Everyone, from owners to workers, benefits from a safe construction environment. In the context of macro-productivity, a safe site is a productive site. The Business Roundtable Study, "*Improving Construction Safety Performance*," concluded that accidents cost $8.9 billion (U.S.) or 6.5% of the $137 billion spent on industrial, commercial, and utility construction in the United States in 1979. This 6.5% figure is probably low. If the same percentage is applied to all types of construction in Canada, then the cost of accidents today may be conservatively estimated at over $5 billion.

The apparent high cost of accidents in construction easily justifies expenditures on construction safety. While owners, construction managers, and contractors have long recognized a moral obligation to provide a safe work environment, the economic reasons may not have appeared so compelling.

3.5.1 Economic impact of accidents

Three basic cost categories are directly related to accidents. These costs include compensation for injured workers, liability claims, and property losses.

Direct compensation costs for injured workers are largely made up of the cost of compulsory injured workers' compensation insurance. In Ontario, for example, a contractor involved in steel erection was required to pay $25.67 for every $100 of wages paid to an ironworker in 1988. Such compulsory insurance payments are based upon the loss or claim history of the particular class of construction workers. The median worker's compensation costs were found to be approximately 1.9% of the total project costs; these costs vary from 1% to 4% of the total project costs.

While the cost of property loss may be quite small compared to workers' compensation costs, the resulting indirect losses due to damaged property may be substantial when expressed in terms of a ratio of direct costs. In one study (*The Business Roundtable* 1982), the ratio of indirect to direct costs was found to be approximately 5:1 for various cost categories.

3.5.2 Safety and productivity

Most construction accidents occur during non-productive periods. Sloppy job sites reduce productivity and increase the chances for accidents to occur. Management should play an active role in ensuring safety. Craftsmen are more productive when they know that management is genuinely concerned about their well-being.

Workers who are more likely to have an accident are those with a bad attitude, those who are frequently absent – especially on Mondays and Fridays (Hinze 1981) – and those who have a history of accidents. Pre-employment screening keeps workers with poor records or high accident potential off the job or at least out of hazardous situations. Orientation, which includes training, and attention to new workers, is especially important. Twenty-four percent of all accidents happen to workers in the first month of work and 46% occur in the first six months.

All workers new to the crew should be assessed by asking about their previous work experience, and closely supervised. If new workers are to work as part of a group, the supervisor must ensure that they are accepted by the group. Those who are to work alone, should be put to work only after their skills have been fully tested and the supervisor has made sure that all procedures are understood.

Instruction and toolbox meetings should be relevant to ongoing work. Assignments and their safety implications should be discussed and meetings held when safety requirements change. These occasions can be used to stress safety and that unsafe work practices will not be tolerated.

Pressuring the crew or individuals if there is a productivity problem may cause workers to work more quickly and less safely. Instead, productivity problems and solutions should be discussed. Safety is good business: it affects worker morale and attitude, and has an economic impact on the project.

The human resource is extremely important in construction, more so than in any other industry. This is simply because construction projects are unique and complex. These characteristics inhibit full automation compared to other industries. The individual skill of each craftsman, the abilities to communicate, make decisions, work with others, and share information, makes this resource unique and irreplaceable in the foreseeable future. To get the most out of this resource, the manager has to realize what motivates the worker, what demotivates, what the physical limitations are, and what factors inhibit performance.

The understanding of these issues is important not only during the progress of construction. At the bidding or planning stage, the estimator often has to make personal judgments about productivity under anticipated conditions of the project. Certainly the effects of weather, safety, and site congestion must be accounted for during estimating. This chapter has provided an overview of these human resource issues and their relation to productivity.

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4 Measuring Productivity from the Cost-Reporting System

4.1 Introduction

On any project there are numerous activities that could be tracked. The most significant are usually those of greatest scheduled duration. In selecting the detail and extent of control of activities, the method should be kept simple and only the degree of control needed should be exercised. Therefore activities where the maximum concentration of hours occurs should be the focus.

Figure 4.1 Time card

TIME SHEET

Employee Name: ____________ Job No: ________
Employee No: ____________ Pay Period No: ________
Pay Period Date: ________

	Date	Reg	O.T.	T.T.		Date	Reg	O.T.	T.T.	
W										
T										
F										
S										
S										
M										
T										
Total					Total					

Certified Correct
Employee: ____________ Supervisor: ____________
Remarks: ____________

Productivity and productivity factors can be reviewed at any level required. Computerization can produce overwhelming amounts of data, much of it superfluous. The more data processed by a system, the costlier the process. A costing system can produce productivity data for a small additional cost. It is these productivity data that are necessary to gauge performance on the project.

4.2 Data Collection and Processing

This section provides a simplified description of the origin, collection and processing of individual pieces of data for measuring productivity and work progress. Only the general aspects of cost reporting are discussed. More detailed discussion can be found in numerous books (for example, Halpin, 1985; Adrian, 1979).

Data in construction projects are collected on various forms and for different purposes. Data collected for the financial control system are organized primarily as required for tax and other legal purposes. These data are not sufficient to control the cost of a project; additional information must be collected. To illustrate: a financial system keeps track of the payroll of all workers on a project, but it does not necessarily account for the hours of labour spent on a particular work package. (A work package is a group of related tasks.) For cost control and productivity calculations, the person-hours spent on the activity must be collected. Accordingly, a company normally maintains a dual-purpose system. For financial purposes, data are gathered at an aggregated level; for cost control and productivity measurement, data are tracked at a more detailed level.

Data useful for cost control and productivity measurement on a construction project are gathered in three categories: labour, material, and equipment. Variations in these categories are tailored to suit the requirements of each company.

The data-collection process is initiated at the construction site by collecting the labour, equipment and material information from time cards (Figure 4.1), daily reports (Figure 4.2), and material-issue tickets. To make use of this

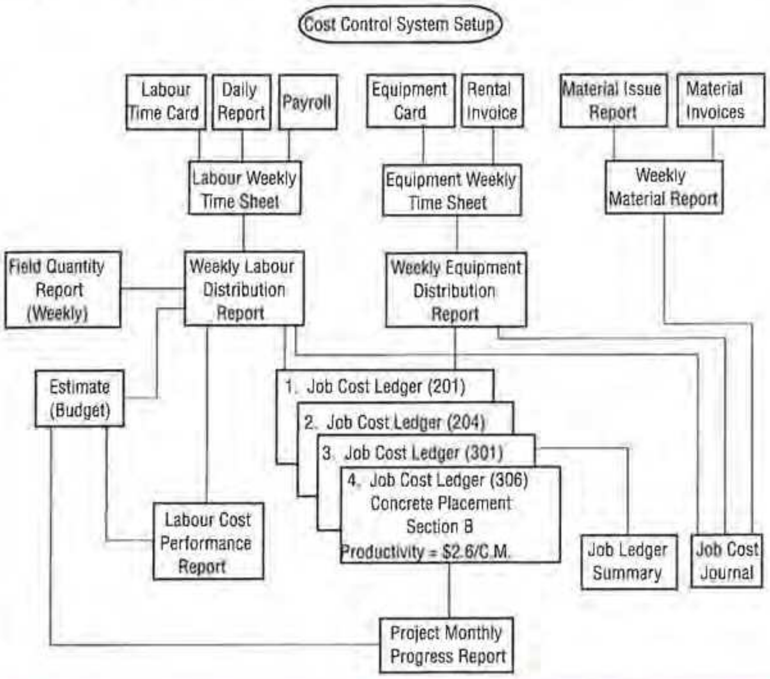
Figure 4.2 Sample daily work report

Daily Work Report

Project: | Prepared by:
Date: | Comments:
Temperature:
Weather conditions:

Work pkge. code	Description	Labour (h)	Supervision (h)	Craft-1 (h)	Craft-2 (h)	Craft-3 (h)	Total (h)
2-20	Concrete formwork	64	8	–	–	–	72

Figure 4.3 Information flow summary on a typical reporting system



information it must be further refined and consolidated. The data are normally organized in what is referred to as a cost-reporting and control system, either computerized or manual. A simplified cost-reporting system is illustrated in the flow chart displayed in Figure 4.3.

The most basic information in this system is obtained from three sources:

- labour time cards, daily reports and payroll records
- weekly field quantity reports
- the original estimate (budget).

Figure 4.4 Weekly labour report

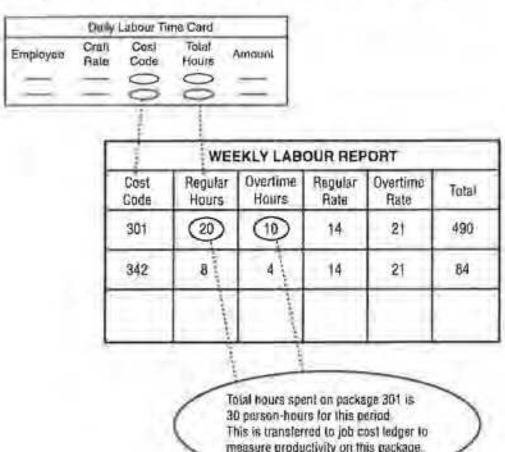
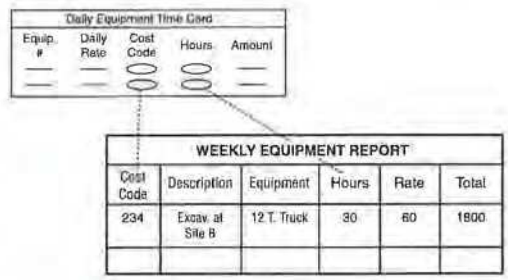


Figure 4.5 Weekly material report

Weekly Material Report

Supplier	P.O. #	Description	Terms	Cost Code	Amount
Big Lumber Inc.	2104	Forms	Net 10	301	$4,002
Ready Mix Co.	2361	Concrete	Net 10	305	$6,700

Figure 4.6 Weekly equipment time sheet



The data from the first source flows into the weekly labour, equipment, and material reports (Figures 4.4 through 4.6). The weekly reports summarize all information by work package (with unique cost codes). The information collected represents the labour hours spent, rates, and total labour cost on each work package.

The accuracy of the entire system depends on the correct application of the hours worked to their respective work packages, identified with cost codes. The weekly labour, equipment, and material time sheets are subsequently used to compile a weekly distribution report for labour, equipment, and material, as illustrated in Figure 4.3. The weekly distribution report summarizes, for every work package, the labour expenditure for the given week and the quantities placed in that time. The quantities are obtained from the field quantity report shown in Figure 4.7.

Figure 4.7 Weekly field quantity report

Weekly Field Quantity Report

Work Completed This Week:

Cost Code	Description	Unit	Total Completed This Period	Total to Date
302	Concrete Placed	C.M.		
304		C.M.		

Figure 4.8 Weekly labour distribution report

WEEKLY LABOUR DISTRIBUTION REPORT

From Weekly Labour Report

From Weekly Quantities

From Estimates

Cost Code	Description	Labour Cost		Quantities		Estimated Cost	
		Week	Cumulative	Week	Cumulative	Per Unit	Total
302	Concrete Frmwk	1240	5020	400	1200	$2.5	$7500
		Σ	Σ				

Labour

Total/Expenditure: This period = $6200

To date = $15400

Figure 4.9 Job cost ledger

JOB COST LEDGER

Cost Center Name: Concrete Placing Code 301

Source	Description	Labour	Material	Equipment	Subcontracts	Other	Total
LD-12	Labour Distribution Report #12	341					341
C-123	ACE Hardware		73				73
LD-1		237					237
	XYZ Excv. Inc				1800		1800
		578	73	1800			2451
		578	73	1800			2451
		578	73	1800			2451
					200		200
					200		200
	Totals	—	—	—	—	—	26510

Estimated Quantity = ______

Productivity: $= \dfrac{\text{Person-Hours}}{\text{Quantity}}$

$= 0.1$ P-H/C.M.

$= \dfrac{\text{Total Cost \$}}{\text{Quantity}}$

$= \$2.65$/C.M.

Totals From Weekly Labour Report
For our example: 102 P-H

From Field Quantity Reports
For our example: 1000 C.M.

The weekly labour distribution report shown in Figure 4.8 becomes the basis for further data reductions, as illustrated by the information flow shown in Figure 4.3.

The weekly distribution reports on labour, equipment, and material are used to compile two additional reports, namely the job cost ledgers and the job cost journal. The job cost ledger is prepared for every work package. The job cost ledger (Figure 4.9) summarizes all expenditures on the given task including labour, equipment, material, and subcontracts. The ledger also shows the total expenditure on the task to date, the estimated quantity of work, estimated total cost, total person-hours spent to date, and the productivity achieved on this task.

For each cost ledger, productivity rates in cost/unit and person-hours/unit can be calculated. The entries in the job cost ledger show an example of the task of concrete placing. The total cost to date (sum of Col. 6) is \$26 510. The quantity excavated to date from the field quantity report is 1000 cubic metres (C.M.). The weekly labour report shows that the total number of p-hs spent on the task to date is 102. The productivity is estimated as \$26 510/1000 C.M. or \$2.65/C.M. and 102 person-hours/1000 C.M. (or 0.10 p-h/C.M.). The original estimate shows that the unit cost on this work package is \$2.45/C.M. and the p-h budgeted per unit is 0.15 person-hour/C.M. A comparison of actual versus estimated reveals negative cost and positive person-hour variances. The cause of the variances could be the hourly labour cost and better unit production rates or other factors, such as better than anticipated equipment.

The job cost ledgers are summarized into one document as the cost ledger summary (Figure 4.10). This document provides an effective means of viewing the status of the project by displaying a summary of each task.

The job cost journal (Figure 4.11) is a weekly itemization of all expenditures. It shows total costs for material, labour, equipment, etc., for the entire project. Another use of this document is to double-check the work done to date. (The totals on the job cost journal and the job ledger summary should match.)

Productivity, as defined earlier, is input/output, i.e., person-hours used to install an amount of material. This is shown at the bottom of the job cost ledger (Figure 4.9).

The final pieces of the job costing system, as illustrated in Figure 4.3, are a labour cost performance report and a project monthly progress report. The labour performance report (Figure 4.12) draws information from the estimate and the weekly distribution report for labour, reduces it, and presents it by task. For

Figure 4.10 Cost ledger summary

COST LEDGER SUMMARY

Cost Code	Description	Quantity	Labour	Material	Subcontracts	Other	Total
302							
304							

Summary of each cost account from the Job Cost Ledgers

Totals should agree with Job Cost Journal

Figure 4.11 Job cost journal

JOB COST JOURNAL

#	Cost Code	Period	Description	Labour	Material	Subcontract	Other	Total
1		Wk 1	Payroll	3004				3004
2		Wk 1	Payroll taxes				290	290
3		Wk 1	P.O. # ____ Freight ____		5000		300	5300
4								
				Total Labour	Total Material	Total Subcontract	Total Others	Total

From Labour Distribution Report

From Weekly Material Report

Figure 4.12 Labour performance report

LABOUR PERFORMANCE REPORT

Cost Code	Description	Quantities			Cost Per Unit			Variance		Total Cost		Estimated % complete	
		Per.	Cum.	Est.	Per.	Cum	Est.	Period	Cum.	Forecast	Est.	Quantity	Cost
302	Concrete formwork	300	600	3300	0.2	0,25	0.3	30	30	825	990	18.2	15.2
304													

From labour distribution report

From estimate

(0.2 - 0.3) x 300 = 30

(0.25 - 0.30) x 600 = 30

0.25 x 3300 = 825

600/3300 = 18.2%

$\frac{0.25 \times 600}{0.3 \times 3300}$ = 15.2%

each task, the quantities installed during the reporting period (one week in this case), the cumulative installed to date for the package, and the original estimated quantity are presented. Under the heading, cost ($) per unit, the unit costs for the period, cumulative unit costs to date, and the unit costs in the bid estimate are shown. The variance columns indicate positive (underrun) and negative (overrun) cost deviations for this period and the accumulated costs to date. The total columns present the forecast and the estimated total costs for each. In the far right-hand column, the 'percent complete' based on quantity installed and cost incurred is shown. This is a complete summary of the status of the project labour cost as of the reporting period. This information enables management to ascertain the status of each package and how well the whole project is progressing. Achieved productivity in cost/unit for all work packages are displayed next to the estimated cost/unit rates. The manager is then able to view all tasks, compare their status to the original estimates, and take corrective action where needed.

The final report is the project monthly report, which is mainly compiled from the job cost ledgers and the original estimates. The information for this report is shown in Figure 4.13. The illustration contains five sets of information:

- actual quantities, costs and unit costs
- quantities and costs required to complete the package
- a forecast of the total cost
- the estimated quantities, unit costs, and total costs
- variance from estimate, as well as an idea of performance.

This final monthly report, derived from the cost-reporting system, summarizes construction progress and the productivity for the month.

4.3 Tracking Person-hours instead of Costs in the Cost-reporting System

The basis of cost control is the dollar spent on a given task. Productivity is also measured as cost/unit. Although the measure of person-hours/unit is possible for each package, it is not the basis of the system. It can instead track p-h expenditure, rather than dollar values, in the control system. Both techniques have merit. Advanced computer tools provide systems that can easily report both. Three measures of output – estimated 'percent complete,' physical measurement, and earned value – can be derived from a person-hour-based system.

4.3.1 Estimated 'percent complete'

The estimated 'percent complete' is simple and a relatively inexpensive measure used to calculate the quantity completed. The calculation is:

Estimated Quantity Completed = Total Quantity x Estimated Percent Complete

This measure has two disadvantages:

- Estimated 'percent complete' is subjective (someone's guess).
- This method is not sensitive to changes in scope of work.

Figure 4.13 Monthly cost summary

MONTHLY COST SUMMARY

		Actuals			To Complete		Forecast Cost	Estimated			Variance	Index
Cost Code	Description	Actual Quantity to date (AQ)	Actual Cost to date (AC)	Unit Cost to date (AUC)	Quantity to Complete (CQ)	Cost to Complete (CC)	(FC)	Quantity (EQ)	Unit Cost (EUC)	Total (EC)		
				AC/AQ	EQ-AQ	CQ x AUC	AC + CC				EC - FC	EC / FC

From Job Cost Ledger for this account

Accordingly the 'percent complete' method is used for such straightforward items as masonry.

4.3.2 Physical measurement

The physical measurement requires the actual counting or measuring of the number of work units completed. Examples of work units are diameter centimetres of pipe welds, number of doors hung, and square metres of formwork installed. This method is objective and detailed, and scope changes are accurately included. Physical measurement is, however, time-consuming and expensive, and its use is generally restricted to tracking bulk material quantities, especially in fabrication shops.

4.3.3 Earned value

The earned value (EV), a measure widely used in construction, is a technique for calculating the 'percent complete' of a control account. It is more objective than the estimated 'percent complete' measure but not as detailed and expensive as the physical measurement. EV is, in a sense, a compromise between the two measures. The p-h input is taken from the craftsmen's time cards. Only direct work is used for calculating productivity.

For each code of accounts, the foreman reports the actual quantities installed. Based on some rules for taking credit or on the estimated 'percent complete,' credit is taken and an earned value is calculated as follows:

EV = actual quantities x estimated (or budgeted) productivity per unit of quantity output.

For example, p-hs earned = actual C.M. installed x estimated p-h/C.M.

Rules of credit provide a structured method of allowing credit for intermediate milestones or partial completion. In formwork, for example, it can be agreed upon, in advance of the work being undertaken, that credit will be taken as follows:

- fabricate 60%
- erect 20%
- remove 15%
- clean forms 5%.

Table 4.1 shows a typical performance report. Column 11 shows 645 p-hs earned based on the rules of credit.

4.3.4 Performance factors

Of two approaches for measuring productivity on sites, the most common one is based on the use of performance factors (PFs) that can be determined from data produced by the costing system and the EV measure. By definition,

PF = Earned p-hs/Actual p-hs
(Cols. 13 and 14 in Table 4.1)

Earned p-hs are calculated based on estimated values for unit p-h, e.g., p-h/tonne. The use of actual p-h (Cols. 1 and 2 in Table 4.1) and estimated values of unit p-h (Col. 7 in Table 4.1) can lead to inaccuracies because the estimate could be wrong, hours worked could have been charged incorrectly to accounts, and measurement of the physical progress could be inaccurate.

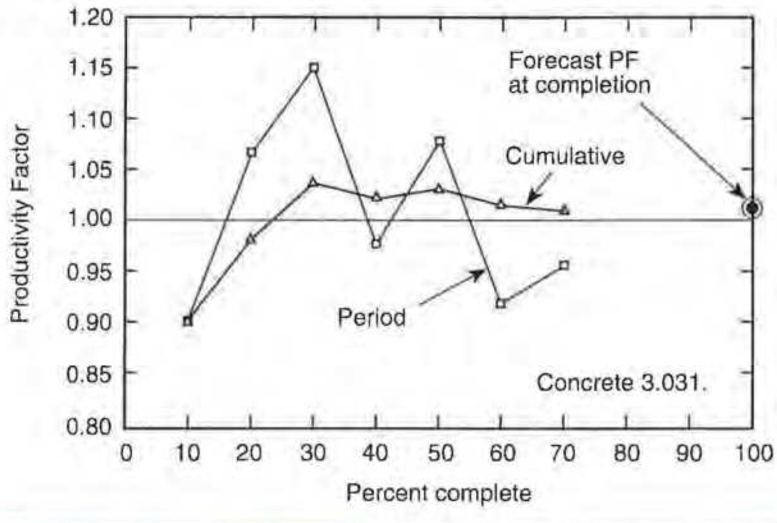
PFs are used to help in the control of a project. Figure 4.14 graphically shows cumulative and time period productivity. Performance regarding the project or a particular account are readily evident. Besides the actual value of PF, it is very important to interpret the trends displayed by these curves. Initial productivity can be expected to be low (0.9) because the start-up activities are, on average, more time-consuming than other activities. With time, repetition and familiarity contribute to lower p-h rates per unit and improved productivity.

Table 4.1 Typical person-hour performance report

Activity	Acct. No.	Actual p-hs		Quantities				Unit p-hs			Budget p-hs	Earned p-hs		Performance Factor		Projected p-hs
		This Period	To Date	Current Budget	This Period	To Date	Unit Meas.	Budget	This Period	To Date		This Period	To Date	This Period	To Date	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Formwork	3.03100	680	37,100	82,000	620	34,000	m^2	1.04	1.10	1.09	85,200	645	36,380	0.95	0.98	86,940

Notes
Column
1 Actual p-hs for latest reporting period [from daily time sheets (see Figure 4.4)]
2 Summation of actual p-hs
3 Total estimated quantity for the account
4 Earned quantity in place for the latest reporting period [from quantity in place report (Figure 4.7)]
5 Summation of earned quantities in place
6 Unit of measurement
7 Budgeted productivity rate (based upon historical records)
8 Col. 8 = Col. 1 ÷ Col. 4
9 Col. 9 = Col. 2 ÷ Col. 5
10 Col. 10 = Col. 3 ÷ Col. 7
11 Col. 11 = Col. 4 ÷ Col. 7
12 Col. 12 = Col. 5 ÷ Col. 7
13 Col. 13 = Col. 11 ÷ Col. 1
14 Col. 14 = Col. 12 ÷ Col. 2
15 Col. 15 = Col. 10 ÷ Col. 14

Figure 4.14 Trends of productivity factors



There are two types of PFs: period PF and cumulative PF. The period PF is a short-term measure used for immediate control purposes, and action can be taken to remedy a disturbing trend. The cumulative PF is a long-term measure of productivity used for forecasting the cost at completion.

The least common methods for evaluating productivity are input utilization techniques, i.e., activity surveys or time measurements, such as work sampling, foreman delay surveys, and craftsman questionnaires. The disadvantage of these techniques is that more data on worker performance, in addition to that provided by the costing system, must be generated and that adds costs to the project.

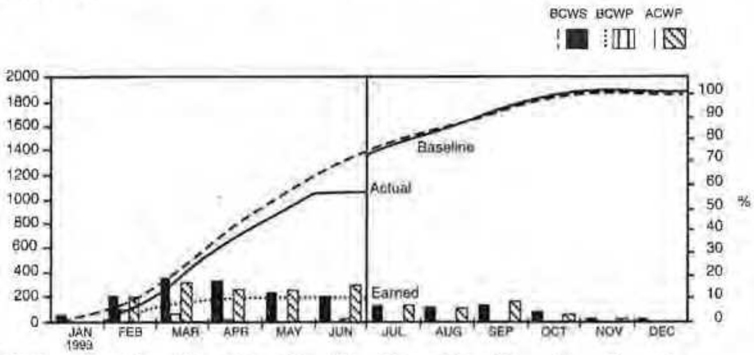
4.4 Cost Reporting and Analysis Using Project Management Software

The introduction in the preceding sections to a manual cost-reporting system conveys an understanding of the basic concepts: how data are reported and accumulated, how to feed information into the various computer programs, and how to interpret the output.

To illustrate how a commercial package can be used in this context, Figure 4.15 presents a graphical report from PARADE (a Primavera Systems Inc. product) regarding the progress of a project made up of a number of work packages. The performance curves on the graph show that the actual expenditure and progress on the project falls behind the planned curve (baseline). The project is obviously behind schedule and over cost.

The tabular summary of costs at the bottom of the figure is presented in cost/schedule control system criteria (C/SCSC) format. The budgeted cost of work scheduled (BCWS) is the cost baseline, the cost based on the original plan and the operating budget. The budgeted cost of work performed (BCWP) is the real value of the work performed and is recorded from reports compiled from the project site reflecting the actual progress and budgeted cost expenditure on each task. The actual cost of work performed (ACWP) is what has been actually expended, regardless of the value of the work. To analyze the performance of a project, a set of variances is defined: the schedule variance (SV) given by SV = BCWP – BCWS and the cost variance (CV) given by CV = BCWP –

Figure 4.15 Sample project performance report from PARADE



CUM BCWS	49	212	356	319	240	220	130	119	138	72	10	0
CUM BCWP	0	104	61	12	5	0	0	0	0	0	0	0
CUM ACWP	0	209	319	266	253	12	0	0	0	0	0	0
ETC	0	0	0	0	0	320	151	119	159	72	10	0
CUM BCWS	49	261	617	936	1176	1396	1526	1645	1783	1855	1865	1865
CUM BCWP	0	104	165	177	182	182	182	182	182	182	182	182
CUM ACWP	0	209	529	795	1048	1060	1060	1060	1060	1060	1060	1060
LRE	0	209	529	795	1048	1380	1530	1650	1808	1880	1890	1890

Scale 1 : 1000

ACWP. (CV is the difference between the monetary value of the work accomplished and the actual costs incurred.)

Summary of Abbreviations

ACWP = actual cost of work performed
BCWP = budgeted cost of work performed
BCWS = budgeted cost of work scheduled
C/SCSC = cost/schedule control system criteria
CPI = cost performance index
CV = cost variance
EV = earned value
PF = performance factor
p-h = person-hour
SPI = schedule performance index
SV = schedule variance

A schedule performance index (SPI) is given by:

$$SPI = (BCWP/BCWS) \times 100$$

SPI reflects the efficiency of a task expressed as a percentage of EV. Low SPIs require immediate attention or they will cause schedule delays. Tasks with SPI over 100 are ahead of schedule.

A cost performance index (CPI) is given by:

$$CPI = (BCWP/ACWP) \times 100$$

CPI represents the cost efficiency of a task expressed as a percentage of the EV. Values below 100% indicate a cost overrun; over 100%, a cost underrun.

With the aid of programs like PARADE, project managers can input the required information regarding the progress of a project every month and acquire performance reports that can assist them in controlling the costs and schedule of a project. Whereas Figure 4.15 is a sample of such a report in graphical format, Figure 4.16 is a tabular report with the various indexes. The report encompasses the period, cumulative, and forecasted-to-completion PF.

According to Figure 4.16, \$1,140,000 worth of work was scheduled for this period. Only \$182,000 was performed with an actual cost of \$1,059,500. This yields an SV = -\$958,000 and a CV = -\$877,500. Obviously an unfavourable situation.

Reports can be by task, work packages, or for the entire project. Through them, a project manager can pinpoint the problem areas in a project. To illustrate, a report was obtained for Package 1.1 on this project (made up of four major packages each down to 10 sub-packages). The report given in Figure 4.17 shows that the performance curves for a particular work package are unfavourable and look similar to those of the entire project.

Others besides the cost engineer or project manager should be concerned and knowledgeable about productivity. When the project engineer, superintendent, and foremen understand how productivity is measured and how its results are interpreted, they can provide more input into the control process. After all, they are the most familiar with the site and its operations. The resulting information can be used when remedial actions must be taken to improve productivity. When productivity in cost/unit is not as high as management predicted for a given work package, the superintendent can provide the information required to assess the situation. An increase in cost/unit value can be the result of factors quite apart from crews and their effectiveness. They could be the techniques used, higher-than-usual hourly rates for craftsmen during the construction season, or simply management practices, including poor planning. For the intermediate managers to be able to provide positive input into the corrective process and action plan, they must have an appreciation of the costing system. How the information flows, where it is initiated, how it is evaluated, and what can be derived from it are essential factors in cost communications and control.

Figure 4.16 Tabular report on project performance from PARADE

Page 1A of 1B — Page 1B of 1B

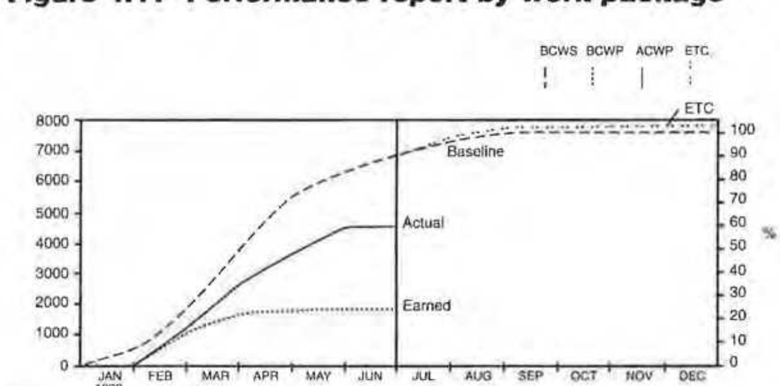
Parade (R) Primavera Systems, Inc. — Cost Performance Report - Work Breakdown Structure — Report Date:

Title: Demo for Productivity in Construction — Start Date: — Period End Date: — Report Period: 2

Item	Current Period					Cumulative to Date					At Completion		
	Budgeted Cost		Actual Cost	Variance		Budgeted Cost		Actual Cost	Variance				
WBS Level 1	Work Scheduled	Work Performed	Work Performed	Schedule	Cost	Work Scheduled	Work Performed	Work Performed	Schedule	Cost	Budgeted	Latest Revised Estimate	Variance
Sample Parade Project 1	1140.3	182.0	1059.5	-958.3	-877.5	1189.0	182.0	1059.5	-1007.0	-877.5	1865.0	1890.0	-25.0
Cost of Money													
Gen and Admin	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Undistributed Budget	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx					xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx					.0	.0	XXXXXXXX
Subtotal	1140.3	182.0	1059.5	-958.3	-877.5	1189.0	182.0	1059.5	-1007.0	-877.5	1865.0	1890.0	-25.0
Management Reserve	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx					xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx					.0	.0	.0
Total	1140.3	182.0	1059.5	-958.3	-877.5	1189.0	182.0	1059.5	-1007.0	-877.5	1865.0	1890.0	-25.0

(All items in 1000)

Figure 4.17 Performance report by work package



	JAN 1993	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CUM BCWS	487	1799	3811	5514	6331	6877	7263	7538	7650	7650	7650	7650
CUM BCWP	0	1041	1651	1767	1820	1820	1820	1820	1820	1820	1820	1820
CUM ACWP	0	1174	2605	3583	4504	4545	4545	4545	4545	4545	4545	4545
LRE	0	1174	2605	3583	4504	6874	7463	7738	7850	7850	7850	7850

Scale 1 : 1000

Additional Readings

Adrian, J.J. 1979. *Construction Accounting: Financial, Managerial, Auditing, and Tax.* Reston, Va.

Halpin D.W. 1985. *Financial and Cost Control Concepts for Construction Management.* New York: John Wiley and Sons.

5 Management Issues

5.1 Introduction

Factors affecting productivity in construction can be divided into two categories: human-related factors and management-related factors. These factors affect the morale and motivation of individuals.

Quality of supervision, material management, site planning, constructability, and change management are the most significant management-related factors that influence productivity directly.

5.2 Quality of Supervision

Quality of supervision can be viewed in terms of leadership and team-building. These abilities create a positive environment for the individual worker. Everyone wants to be on the winning team. Good supervision has an obvious direct impact on productivity. Workers can be demotivated with ill-informed, poor supervision, or ineffective supervision due to a high worker to supervisor ratio. Approximately 10% of the time on a project is spent communicating instructions, and this can be done effectively through good supervision. Management and supervision are perceived by the worker as either competent, informed and concerned, or not. This perception, if positive, influences behaviour favourably and pays dividends through improved productivity.

5.3 Material Management

"The construction industry lags far behind the manufacturing industry in applying the concepts of materials management." (The Business Roundtable, 1983)

More recently the construction industry has become cognizant of the importance of the management of project materials and equipment, which can amount to 50% or more of project costs. An estimated labour productivity gain of up to 6% may be attainable through improved material management. Traditionally labour productivity receives the most attention because the productivity of direct work can be measured at a reasonable cost. Within the construction industry, there is a wide divergence in the degree of material management applied to projects. No common methodology is used to measure its effectiveness.

Some companies in the construction industry, for example, the large Engineering Procurement and Construction contractors, aware of the importance of material management, have established computerized material-tracking systems. They realized the need for better material management, especially for large complex projects that use thousands of components. The negative cost impact of shipping delays and poor procurement procedures became increasingly important to the project, and therefore these companies had to lead the way in integrating good material-management systems into their operations.

The general building industry is beginning to appreciate the importance of material management and the tremendous potential for increasing productivity and safety on construction projects. Smaller construction projects do not require elaborate material management systems. But regardless of size, some system, whether manual or computerized, is necessary.

As part of overall material management, some database systems track the status of major pieces of equipment and critical items. Spreadsheets are a convenient tool for tracking. More comprehensive, integrated systems address all material-management functions for both engineered equipment and bulk material. There are costs associated with the system chosen. Equipment, software, and training costs depend on the size and complexity of the system. Care must be exercised in selection of the system because of the costs and staffing required and to avoid costs disproportionate to the size of the operation or company. For large projects with thousands of material items, extensive computerization is necessary; for smaller projects, manual methods or spreadsheets will suffice.

Material handling is a significant component of material management and studies have shown it to be a large percentage of site labour. In a series of 22 productivity studies (O'Brien, 1989) carried out in Ontario, it was found that mechanical and electrical tradesmen were spending only 32% of their day on direct installation work, 20% on material handling, 15% on indirect work, and the remaining 33% on ineffective and miscellaneous operations. Obviously many areas required improvement, but the magnitude of material handling is especially noteworthy. A productivity improvement program was instituted, which increased direct installation to 52%, and reduced material handling to 12%.

Other studies show similar ratios of direct to indirect work, with material handling and waiting for materials amounting to a significant percentage of the person-hours. These macro-studies highlight material handling and management as opportunities for productivity improvement. The traditional approach to productivity improvement has been to devote more effort to the analysis of direct operations, such as cutting, assembling, and joining of components. A more effective method of improving on-site productivity would be to reduce the person-hours spent on indirect work, such as waiting for materials and material-handling. A worker should have the right materials at the right time. For this to happen requires more than good material-handling; it requires good material management.

Material handling and movement can be a hazardous activity. Most tradespersons are not trained in material handling, lifting, and transportation. Good material management will, through planning and control, improve productivity and also reduce risk by ensuring that material handling is performed by trained and qualified tradesmen. Productivity must be considered with the associated level of safety; productivity and safety are closely related.

Figure 5.1 Material management steps

Material Management Steps

Sequence	Contributing Action/Documents
1. Request for Quote (RFQ)	Drawings, specifications Material bills Terms and conditions
2. Bids	Approved bidders list Pre-qualification of bidders Bid evaluations
3. Purchase Orders (P.O.)	Bid clarification Notice of award
4. Expediting	Vendor data Manufacturer inspection Delivery Routings
5. Transport	Carrier and route Ownership en route Customs
6. Receiving	Inspection and acceptance Receiving report Storage
7. Inventory	Dispersal (material handling) Inventory level Surplus disposal

5.3.1 Material management steps

This section deals mainly with the attributes of material management and the responsibilities of those involved in performing them. A detailed understanding of each contributing function is required to comprehend the interfaces between material-management functions. A material-management system includes the major functions of identifying, acquiring, distributing, and disposing of materials at a construction site (CII, 1988).

By definition, material management is the management system for planning and controlling all efforts necessary to ensure that the correct quality and quantity of materials are specified in a timely manner, obtained at a reasonable cost, and available at the point of use when required (The Business Roundtable, 1983).

Each firm has its peculiar material-management system. Usually the responsibility for the various activities has been spread between engineering, purchasing, and construction. Some assign full responsibility and accountability to a material manager; for most firms, the responsibility is divided and therefore prone to problems. In fact, the more divided the responsibility, the more potential problems exist.

The steps in Figure 5.1 represent the process from identifying material needs to delivering the materials when required at the point of use. They are only the key elements which make up the whole material-management process.

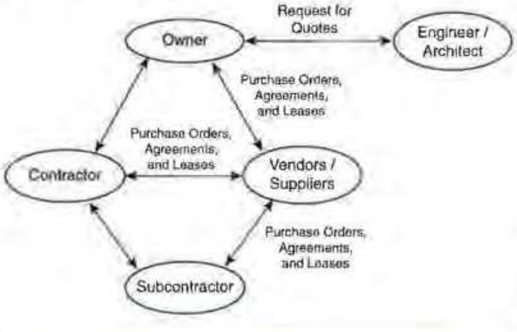
5.3.2 Responsibilities

Responsibilities and authority of the participants in the material-management process must be clearly established. An efficient material-management system leads to improved productivity and necessarily includes all participants. The scope of each participant's involvement must be clearly defined in contractual documents. If not, increased effort will be expended to rectify errors in quantity, quality, or cost. Unexpected effort reduces productivity of the operation. Poor quality in the material-management process becomes apparent immediately at the point of use. By comparison, poor quality of engineering, for example, may not become apparent at all.

Figure 5.2 shows the contractual relationships and the key documents used to establish the scope of material management for each participant.

If an owner purchases a long-lead item and later assigns the purchase order to the contractor, a clear understanding of the purchase order is required, as well as full knowledge of any relevant correspondence, to ensure that nothing slips through the cracks.

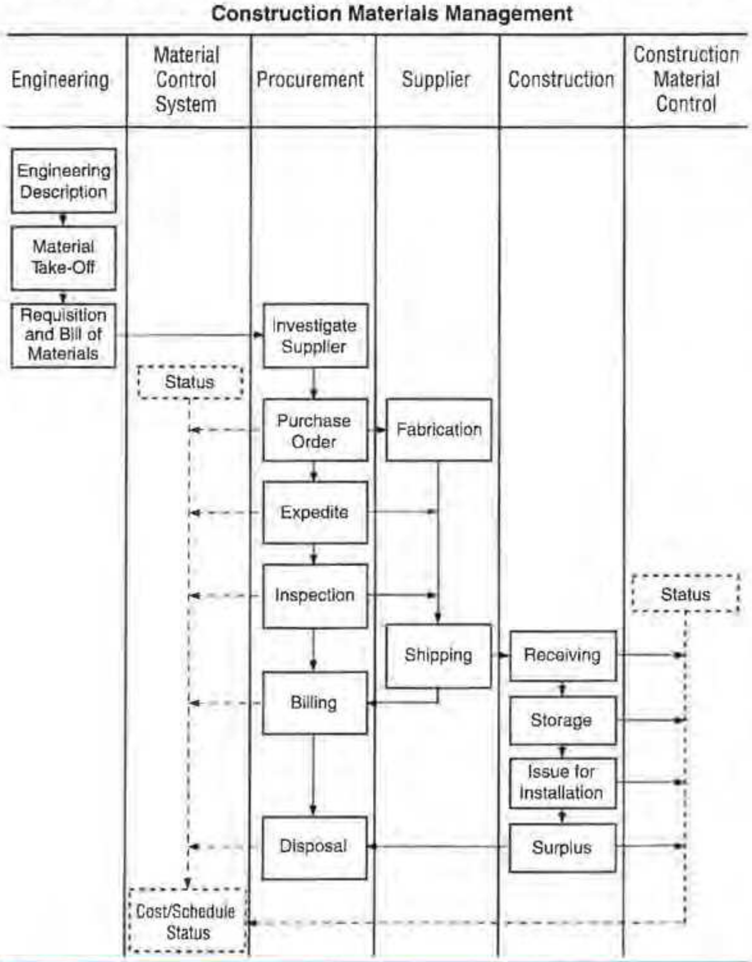
Figure 5.2 Relationships and key documents



5.3.3 Interfaces and their implications for productivity

A material-management system consists of numerous logical components, as shown in Figure 5.3. As with any system, most problems arise at the interface of functions, and management attention is therefore required. The system includes the documentation and procedures, as well as trained personnel to execute the functions.

Figure 5.3 Construction material management



Although all major departments are involved in a material-management system, the key departments are Engineering, Procurement, and Construction. Project needs are usually identified by Engineering, which also determines the specifications and quantities. Engineering generates a request for a quote (RFQ), which is completed by Procurement.

Procurement develops a bidders list, solicits quotations or bids, evaluates bids with the assistance of Engineering for technical aspects, and issues a purchase order. Other departments within Procurement expedite, inspect, and look after transportation.

The Construction Department receives the materials, inspects them upon receipt, stores, and ultimately issues them to the work stations.

Computerized systems are being increasingly used, especially for large projects. The most important needs of these systems are to provide a communication tool and to save time on the execution of such functions as take-off and material lists. Any tool that satisfies these needs improves productivity by minimizing the cost to acquire materials and improving efficiency at the site, especially by the timely delivery of the required materials. The level of sophistication depends on several circumstances, among them company size, and project size and complexity. An organized program has a positive effect on staff and clients.

Material-management problems can occur in the form of quantity and quality errors. Shortages disrupt the work pattern and require re-planning around the shortages. If the system cannot detect shortages far enough in advance of material needs, the result is last-minute shuffling of work crews. If the quality of materials supplied is sub-standard, either the material is rejected or it is used, but requires additional person-hours to install. Rejected material must be removed and replacement material handled; both operations require unanticipated person-hours. Products of inferior quality, such as a lower grade of wood, may require additional person-hours to accommodate excessive warpage. (Beware of the dollar saved in purchasing; it may not necessarily be a dollar saved on the project.)

The most noticeable effect of poor material management is delays in delivery. These delays have an effect similar to errors in quantities, because the work flow is disrupted and must be replanned. Disruptions cause lost time and necessitate non-productive work to remedy the situation.

Those who have experienced projects where everything happens as planned will recall that the right material was delivered at the right time, and everyone associated with the project was aware that the project was well planned. Morale rises on well managed projects. The converse is true of poorly managed materials programs, and the message to the workers is that management (or engineering) does not care. The result: productivity suffers.

With an integrated material-management system, materials are more likely to be available when needed and supervisors can plan the work around material availability. Returning to a work area to replace a missing item wastes person-hours; this can be regarded as rework. It has been reported that foremen spend as much as 20% of their time hunting for materials and another 10% of their time tracking purchase orders and expediting them (Bell and Stackhardt, 1987). A material-management system has a payback commensurate with the amount and quality of the effort input.

5.3.4 Preplanning

Front-end planning is probably the single most important determinant of a successful material-management effort (CII, 1988). Material management has to be an integrated activity, with clearly established responsibilities assigned to the owner, engineer, or contractor. Important decisions, such as site access and laydown areas, schedule compression, cash flow restrictions, expenditure approvals and audit requirements, are made early. All these decisions have an impact on costs and productivity.

5.3.5 Material control

The material-control function includes determination of quantities, material acquisition, and distribution. The objective is to purchase materials in a timely manner to avoid costly labour delays resulting from delivery delays and non-availability of materials.

Bills of materials are merged with materials specifications to establish quantities and quality for ordering. A milestone schedule should be established for major items, so that a complete plan is available (Figure 5.4). This plan includes the required-at-site date and final issue of drawings and data for vendors, vendor data, manufacturers' schedule, and delivery time.

Field material control is required to plan storage and issue of materials. A material-management system should provide an alert for potential shortages. Control of inventory is required to prevent theft or unauthorized issue, and provides warranty protection for environmentally susceptible items.

Various techniques can be adopted. A just-in-time technique requires careful planning and a good system. By this method, materials are bought for delivery just before they are needed, i.e., expenditures are incurred only when required and no sooner. This technique yields significant cash flow benefits. Just-in-time is better suited to large purchases but applies to such bulk materials, for example, as ready-mix concrete and asphalt paving.

Figure 5.4 Sample procurement milestone schedule

Legend			
1	Data sheets complete	7	Prelim vendor data
2	RFQ issued	8	Certified data
3	Receive bids	9	RAS date
4	Bid tab complete	10	ETA jobsite
5	Eng'g release PR		
6	PO award		

Sample Procurement Milestone Schedule

Company XYZ
Re-vamp project

Mechanical Procurement Schedule

Contractor Co.
Status to 90 08 20

		June					July				August				September					October				November					December				Forecast	Vendor	Req'd	Bidders
Week beginning Monday		1	8	15	22	29	6	13	20	27	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30	7	14	21	28	Del.	Promise ETA	At Site RAS	(R=Received) (N=No bid) (S=Successful Bidder)
Week Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
P-3306A/B M.F.O.H. Liquid Pumps Sulphur Guard Bed	P																																			New Impellor
	A/P																																			
X-632 SGB Steam Pre-Heater Suphur Guard Bed	P							2			3	45	6		7			8									10						14 wks			Shop (Dim and Cor Checks)
	A/P					1				2		3	45	6		7				8								10								
V-687 & V-688 Reactor and Clay Filter Jet A Merox (Supply Mat'l)	P								2			3		45	6								10										12 wks			
	A/P					1				2			3	45	6								10													
V-659/660/666/667/672 Misc. Vessel Work Jet A Merox (Supply Mat'l)	P									1		2		3		45	6						10										6 wks			
	A/P										2		3		45	6						10														
Catalyst & Acetic Acid Eductor Jet A Merox	P																																			Hold
	A/P																																			
B.S.-1/2/3/4/5/6/7/8 Basket Strainers Jet A Merox	P									1		2		3	45	6							10										8 wks			
	A/P																																			
Catalyst & Acetic Acid Addition Drums Jet A Merox	P																																			Hold
	A/P																																			
P-262 Condensate Pump Jet A Merox	P					1			2				3	45	6		7				8							10					12 wks			New
	A/P							1			2			3	45	6		7				8							10							
P-266 Caustic Pump Jet A Merox	P					1				2				3	45	6											10						10 wks			
	A/P							1			2			3	45	6		7				8						10								

Another approach is the inventory buffer approach, which can be costly from the standpoint of cash flow and losses due to theft. In a more extreme case, it can result in increased storage and double-handling which, in turn, may increase costs and lower productivity. It is, however, unrealistic to expect every item to arrive at exactly the right time. Some buffer is required, depending on the material and complexity of the job. Most foremen want to be assured that all materials are available for a particular operation, to avoid reassignment of crews because of shortages.

Trade-offs are necessary between just-in-time and inventory buffers. Often the inventory buffers are a form of insurance to provide continuous and unimpeded operations. The more material stored at a site, however, the more double-handling is required.

5.3.6 Procurement

Procurement includes purchasing of materials, equipment, supplies, labour, and services for a project. Associated with the purchasing are the related activities of tracking and expediting, routing and shipping, inspection and acceptance, handling, and storage and disposal of surplus. Procurement can be grouped under three categories: the procurement of materials, labour, and subcontracts.

Four cost categories (Barrie and Paulson, 1992) must be considered to optimize the procurement of materials for minimum cost, and to some extent these same considerations apply to the procurement of labour and subcontracts. These four cost categories are purchasing, shipping, holding and shortage costs, and trade-offs between the categories must be optimized to achieve minimum costs. In these discussions, the maximization of productivity is equated to the minimization of total costs.

On large projects it is common practice to produce a subcontract schedule and a procurement schedule for major pieces of equipment. For example, Figure 5.4 is a portion of a schedule taken from an actual refinery modification project. A scrutiny of the equipment plan reveals milestone dates for the completion of key steps, such as issue of the RFQ, purchase orders, and vendor drawings, bid requests, award of contracts, and required-at-site delivery.

5.3.7 Material handling

A large percentage of site labour activity involves material handling. As stated previously, in the Ontario studies (O'Brien, 1989), 20% of the labour was initially for material handling until a concerted effort was made to reduce this to about 12%. Reducing material handling is the key to improving productivity and safety.

Material handling can be categorized by the following five sections:

- containerization and packaging
- movement to site
- off-loading at site and storing
- horizontal movement
- hoisting and vertical handling.

Containerization and packaging. Containerization and packaging require careful planning and organization. Various types of pallets, containers, and protection are available. The sequence of packaging or loading is important, especially for congested high-rise construction sites.

The use of skid-mounted equipment and equipment modules reduces on-site labour. Modules require considerable preplanning and, because of the up-front engineering and manufacturing effort, numerous person-hours are transferred from the field to a shop environment. Overall the result is improved labour productivity on the site and lower project costs.

Movement to site. Movement to site usually involves trucking but can include rail, ship or air transport. Planning of the arrival of shipments at the site is important so that crews and equipment can be available when required. Unplanned shipments result in waiting time for the trucker or a deployment of workers to handle the shipment. The most efficient methods of material movement could require winter roads, wide-load permits, or partial load restrictions. For special size loads, route planning is necessary to avoid stalled shipments.

Off-loading at site and storing. Unloading at sites requires trained material-handling crews with the proper handling equipment. Avoid handling material several times.

Horizontal movement. Horizontal movement methods depend on the material being handled. Trucks and trailers are the usual conveyances but conveyors and cranes are also common. Insufficient handling equipment, capacity or size have obvious negative effects that lower productivity.

Hoisting and vertical handling. Vertical movement and hoisting require material and personnel hoists, cranes or other lifting devices. Several decisions are required in planning the equipment for a job. The required capacity, most suitable type, i.e., mobile, crawler or fixed hoisting equipment, and best location on the site, are decisions that have a direct impact on project productivity.

For placing of concrete, which method is best? The choice could be a concrete pump or a tower crane. The better choice may be the tower crane, considering that it will be required anyway to handle formwork.

On a large bridge project, hoists costing $200,000 were installed to reduce travel time on site. The payback period was estimated to be 9 months for a project of 18-month duration. Numerous examples can be cited where productivity was improved through the use of proper equipment. In planning the construction of the 72-story First Bank Tower in Toronto, the owner-developer studied the good and bad points at various construction sites. Workers were each losing 3 to 4 hours a day at some sites because of the time required to get to and from their work stations. The owner-developer implemented a well conceived factory-like system for moving men and materials. The around-the-clock use of elevators was planned and priorities were established. Productivity for handling materials was increased 600% for the installation of marble, 400% for electrical wiring, 260% for glass, and 800% for drywall. The innovation saved 1.33 million p-hs.

Space requirements are usually at a premium because several trades may require the same space. At different times, many key decisions relating to space, egress, and access are made; all these decisions affect productivity. Considerations are traffic movement at the site, proximity of buildings and obstructions, types of roads, turning space, and parking – just to name a few.

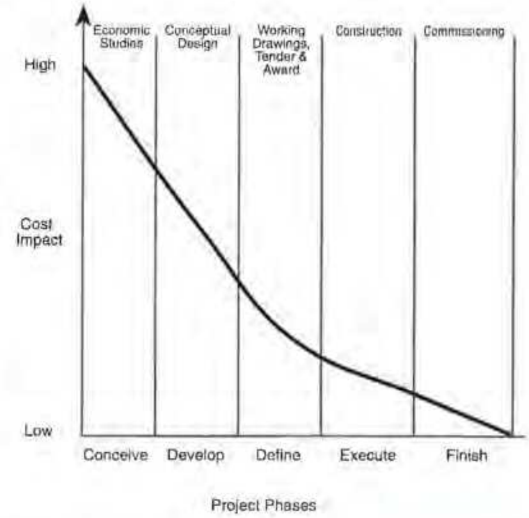
The concepts of material management are essentially the same for large or small projects; the differences are a matter of degree in the areas of organization and staffing, documentation, vendor relations and computerization. Material management has improved considerably in the last decade, with the development of better tools and methods resulting in improved cost effectiveness through better productivity.

5.4 Constructability

Constructability means making optimum use of construction knowledge and experience in planning, engineering, procurement, and field operations to achieve overall project objectives (CII, 1986). It is the effective and timely integration of resources and technology into the early phases of the project and then maintaining the involvement.

Maximum benefits accrue if all stakeholders – including the owner and contractor – with construction knowledge and experience participate early in the project, and remain involved. Figure 5.5 shows how decisions in the early stages have the greatest cost impact.

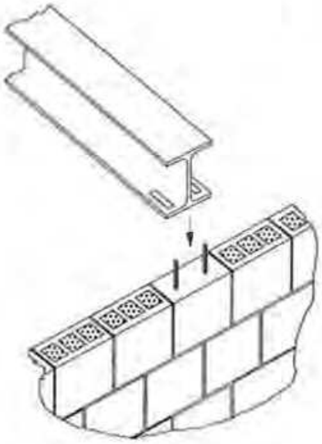
Figure 5.5 Cost influence of decisions as a function of project phase



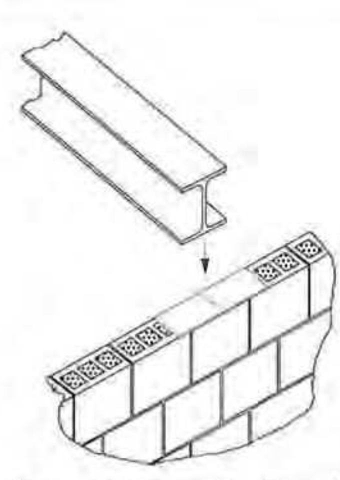
Constructability enhances the effectiveness of construction. It is a macro-productivity factor that should be the way of thinking of the entire project organization. It is management action (at all levels) that creates this culture; not a separate function, but an on-going process. It can be a motivator to the worker when the 'smart' details or methods are used.

For example, Figure 5.6 (a) shows details for a beam bearing on a masonry wall. Tight dimensional tolerances are required for the beam holes to match the anchor bolt location. This alternative would require an accuracy of construction that is costly and unwarranted. Figure 5.6 (b) shows a detail that better accommodates construction tolerances with a lower installed cost.

Figure 5.6 Beam bearing detail



(a) Anchor bolts grouted



(b) Bearing plate grouted with anchors on U/S plate. Beam field welded to plate

5.4.1 A traditional problem

As the construction process has evolved and become more sophisticated, the separation of the design and construction functions has increased under the traditional form of construction procurement. Traditionally the owner hires an engineer/architect who designs the facility. Construction is awarded to a contractor who procures material, labour, and equipment and executes the contract requirements. This method, which results in the separation of functions, is primarily responsible for any lack of constructability. A return to the master builder concept is heralded as a step toward more efficient and cost-effective projects.

5.4.2 Constructability concepts

During the conceptual phase of project planning, project objectives must be established, major construction methods selected, sites chosen, and a contracting strategy developed.

Overall project schedules must be construction-sensitive. A sequence of activities must be established with realistic durations to prevent costly overtime, schedule acceleration, or counter-productive high levels of labour for craftsmen.

Major construction methods should be considered during basic design. Special methods include prefabrication, pre-assembly, and modularization.

Effective site layouts can facilitate construction activities and reduce costs. Adequate storage spaces, access and roads, with particular emphasis on clearances for operating equipment and traffic flows, must be provided. The use of permanent facilities and utilities should be investigated.

To enable efficient construction, designs must avoid complex details and shapes so that they permit flexibility in construction methods and material substitutions. The design schedule must support the construction fieldwork sequence. Good quality drawings, specifications, and site information improve productivity.

Drawings are frequently criticized for lack of clarity and content, forcing field crews to devise their own solutions. This transfers part of the design function to the site, which is costly, disruptive, and inefficient. Those undertaking the dimensioning should consider construction needs and not scatter the dimensions over several drawings.

With vendors and suppliers, constructability is enhanced by timely engineering data, pre-assembly, shop-testing of components, and the provision of lifting lugs.

Constructability is enhanced by standardization, such as the use of manufacturers' standard dimensions, standard steel connection details, piping assemblies, off-the-shelf electrical and mechanical equipment. Designs can be standardized to realize the benefits of duplication, symmetry, and repeatability. For example, if the formwork for every member is a new experience, costs will skyrocket. Montreal's Olympic Stadium and the Sydney Opera House in Australia are classic examples of large projects where the cost of formwork went out of control. Numerous examples exist where the use of modular design can reduce costs. Concrete formwork and house construction are examples where wastage could be minimized through modular design.

Structural constructability considerations include the use of such elements as precast staircases in high-rise cores. Straight reinforcement bars, prefabrication of cages, and detailing of reinforcement to suit pour heights, are cost-effective steps.

Effective design and construction require that construction expertise be utilized early in the project schedule. Constructability improvement is possible with construction-sensitive designs and construction-driven schedules.

5.5 Change Management

Projects are characterized by change. A change typically results from a revision to project scope or to the details of construction, and the rework required to rectify errors.

Changes have a ripple effect on the project, causing disruptions and delays. Consider the sequence of events that occur due to a single change. The project manager is notified of the change. This information is communicated to the foreman, who then has to stop supervising or planning the other work. The workers are informed of the change and are moved to another work activity. Later, when full details of the change and revised materials are available, the work will be restarted. During the entire change process, additional effort is required from supervisory, management, and other support functions.

The simple change, for example, may be to relocate a door; this is readily quantifiable. There are, however, unseen impacts of the change that are disruptive and time-consuming. Time is lost during the scramble to relocate and re-instruct the workers for a suitable substitute task.

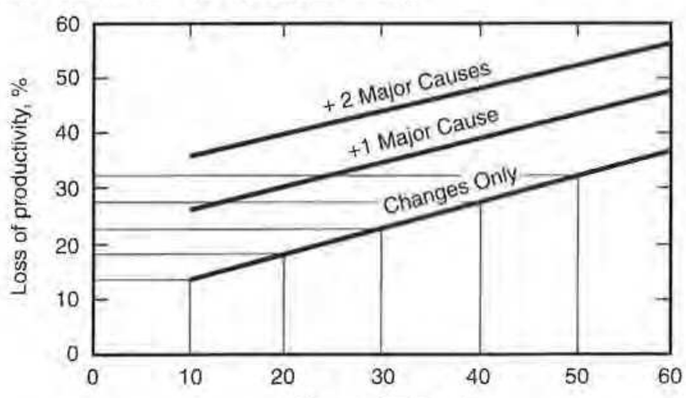
Because of the interdependency of construction operations, changes affect the productivity of other activities that are not a direct part of the change. This can also influence labour productivity in the form of the learning and unlearning impact discussed in Chapter 3.

Figure 5.7 (Revay Report, 1991) illustrates the loss of productivity because of change orders on mechanical and electrical work. Similar figures exist for civil and architectural work.

Of the three curves shown, the lower curve results from changes only. Additional major causes of productivity losses have, as shown, a cumulative negative effect.

Disruptions and delays affect productivity because of the stop-and-go of the operation, work being out of sequence, repetition of the learning cycle, unbalanced crews and fluctuation in staffing levels. The work force can become demotivated because the managers and supervisors are perceived as incompetent and indifferent.

Figure 5.7 Loss of productivity due to changes – electrical and mechanical work



A gradual deterioration of the planning and scheduling will occur with an increasing number of changes. The introduction of changes is similar to the addition of a new activity to the scope of work, and this often requires schedule acceleration.

Some of the impact of changes is readily apparent; some is not. The management of change has a major impact on productivity.

Additional Readings

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6 Conclusion

6.1 Macro- Versus Micro-Productivity

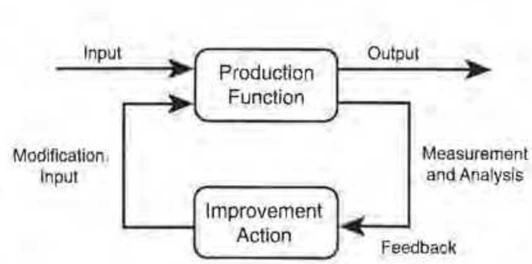
It is important to differentiate between macro- and micro-level productivity factors in order to analyze cause/effect relationships and take appropriate action. Macro-level factors that influence the effectiveness of construction are those that often attract considerable rhetoric but not enough specific actions or economic support. Many talk about the need to improve productivity because it is the key to economic survival. There is abundant scope for industry and government actions to enhance and promote an atmosphere for sustained progress. Japanese industries have developed a model for cooperation and effective support. The individual Japanese worker is not more productive than a North American worker; it is their system that is more productive. Government, industry, and the financial community must eventually cooperate to provide synergistic support at a macro-level. In Canada very little money is spent on research or improving productivity in construction. The industries that reinvest sufficient resources to remain competitive will survive and therefore the industry and construction companies must continue, and indeed increase, their contributions at a macro-level. If the construction industry, which constitutes approximately 15% of the GDP, does not improve, foreign competition will continue to make inroads into Canada's traditional markets.

These are the macro-level concerns, which must be addressed, but are beyond the scope of this book. However, the individual construction company or person has an obligation to improve productivity at a micro-level. The efficiency of labour and methods are the foundation for competitiveness and more effort must be paid to the measurement of productivity. It may not be possible to separate the individual effects of all influences. But this should not deter efforts to quantify their effects and impacts on construction efficiency. Productivity improvement and measurement of the effects of related factors must become part of the daily construction routine.

Productivity improvement is a continuous process, as shown in Figure 6.1, and an integral part of total quality management. Ideally, as quality and productivity improve, both the contractor and the end user are winners. It is a win-win situation.

The production function produces data, which are analyzed and provide feedback for action toward improvement. The cycle continues until the required level of productivity is reached. An analysis of productivity is complete only when quality and safety are also considered. The construction industry must become serious if it is to improve in quality, safety, and productivity. Supervisors and tradesmen must continue to improve their efficiency which, of course, is the thrust of this book.

Figure 6.1 Productivity improvement as a continuous process



6.2 Miscellaneous Ideas for Improving Productivity in Construction

Construction is a unique industry where field experience plays an important role in maintaining high levels of productivity. The qualities of the field-management team will eventually determine the levels of productivity achieved on a given project. An experienced person can tell about the level of activity on a project in a variety of ways. For example, a unique and inexpensive technique for measuring productivity is observing the sound level on a project. Not that a noisy project is a productive project; however, a silent project is a non-productive one. The trained and experienced ear can detect when a job is moving well by the productive 'hum' or tempo to a project: the roar of the crane every 5 or 6 minutes, the sound of welders arcing, or the fleeting of an air tugger.

Topics that were not covered in the previous chapters, yet can affect productivity, include job security, safety, and advanced telecommunication. All successful construction firms – large, medium, and small – practise the job security theory. Job security can significantly affect the tradesman's efficiency for obvious reasons.

Safety issues were briefly discussed in Chapter 3. One consideration, perhaps underemphasized, is the effect of a serious accident on productivity. A project that is moving along well and encounters a serious accident or fatality, never gets back to normal or regains its original tempo. Installing the proper safety program and taking safety seriously can help avoid such a scenario.

New technological innovations can be put to work in construction. This can greatly enhance productivity as it provides timely information, reduces travel to remote sites, and facilitates immediate corrective action in case of emergencies. Examples include the closed-circuit television communication systems that are being used to conduct meetings between engineers in remote project locations and the main office. In addition to timely information and access to the main office's immediate expertise, this eliminates routine, time-consuming, and expensive air travel. Telecommunications facilitate solving design-related problems by providing computer linkage between site personnel and the engineer or architect. Similar systems are in use for the review of drawings and other contract documents, providing instantaneous decisions, thus improving productivity and reducing cost. Other applications include CAD-based crane-planning systems which improve construction productivity through faster and improved engineering and planning. Multimedia use in training is catching on. This facilitates explaining to the site crews how a certain material or equipment can be installed. Walk-through programs have also reached the personal computer market. A complex 3-D design of a plant can be tested for constructability using such programs prior to construction, thus reducing chances of redoing work and effectively enhancing overall productivity.

When measuring productivity, it is important to know where the project stands. Improving productivity combines the scientific understanding of the issues affecting productivity, supplemented by work experience.

The construction industry should make better use of automation to improve the planning and control processes to remain competitive, especially in a global market.