CONSTRUCTION PRODUCTIVITY MEASUREMENT AND IMPROVEMENT IN THAILAND BY IMPROVED WORK-SAMPLING

by

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This thesis is the fruitful of my industrious,
for my father…………

"It's good to work hard,
it's better to work smart,
but it's the best to work hard and smart."

DECLARATION

Arun Makulsawatudom

ABSTRACT

The Thailand construction industry is the database for this research, which consists of three main sections. As there has been a lack of research in the construction industry in Thailand, firstly, structured questionnaires were distributed to project manager, foremen and craftsmen, to observe general construction productivity and to find out if a work-sampling study could be tailored to detect these problems. The results indicated that lack of materials, incomplete drawing and lack of tools and equipment have the greatest effect on construction productivity in Thailand, and so a work-sampling study can be tailored to detect these problems.

Having confirmed that it is possible to undertake work-sampling to increase construction productivity, this thesis, secondly, has improved and clearly specified all the individual steps required to carry out a work-sampling study. In addition, this research has also reported the application steps of FDS. The work-sampling technique was applied to four construction cases and FDS was also carried out on two of the four sites. The results confirmed that a work-sampling study can highlight the productivity problems, and indicate how to overcome or alleviate them, and inferred that late start/early finish and crew imbalance are likely to be universal construction productivity problems in Thailand. In addition, these two techniques contribute to each other and should be implemented together.

The final part of this study applied the Markov process to predict the results of work-sampling at any particular periods of time in the future. This concept is not only able to predict the results, but also supports the principle of work-sampling which, if it is to be successful requires full support from management.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

It is widely accepted that a construction industry contributes a significant percentage to its country's GDP (Assaf and Al-Khalil, 1995; Chau and Walker, 1988; Koch and Moavenzadeh, 1979; Lim and Alum 1995; Okpala and Aniekwu, 1988; Sozen and Giritli, 1987; Yong, 1984). However, there is also no doubt that the industries are experiencing a decline in productivity (Anon, 1972; Borcherding, 1978; Kaming *et al.*, 1997a). Improvement in productivity, therefore, would provide significant financial savings for many countries all over the world, especially in Thailand, the author's home country, where construction productivity seems to be more important, as the country is experiencing an economic crisis.

Management should be responsible for productivity problems, rather than labour, as it is the management's duty to make sure that there are no barriers to interrupt work, for example, due to lack of materials (Hanna and Heale, 1994). Nevertheless, to overcome or alleviate the problems in order to improve productivity, it is necessary for management to know what and how to improve.

The work-sampling technique, which has been popularly and successfully implemented in the production industry as a productivity improvement tool, is a technique that has sometimes been applied to the construction industry and seems to be able to highlight productivity problems and imply how to improve productivity. Furthermore, it has been said that a work-sampling study usually improves productivity by 5%-10% (Oglesby et al., 1989).

Unfortunately, a clear approach of how to implement work-sampling in the construction industry has never been identified, so it may be difficult for others to carry out this technique. Consequently, it is intended to clearly specify every single step of work-sampling application, from the beginning to the end use of the results. If this aspiration is achieved many countries in addition to Thailand may gain benefit from improved productivity.

1.2 Aim and Objectives

1.2.1 Aim

The aim of this research is to improve the present steps of implementation of work-sampling to be more practical and rigorous, while maintaining its effectiveness, in respect of a productivity improvement tool, with and without supplementary foreman delay surveys (FDS).

1.2.2 Objectives

In order to achieve this aim, the following objectives are set:

- *To perceive a general idea of productivity such as its definition, classification, importance, etc.* These literature surveys are described in Chapter 2.
- *To provide a basic idea of work-sampling and to specify why work-sampling is suitable for construction work.* This discussion is included in Chapter 3.
- *To explain all statistical fundamentals concerned with work-sampling.* This can be viewed in Chapter 3.
- *To specify the problems with the present application of the steps of work-sampling, then to suggest an improved process and to clearly specify every single step of improved work-sampling implementation from the early stages to completion. In addition, to identify the time utilisation of all craftsmen, by observing 10 randomly selected craftsmen on each of 4 sites and to identify the delays and, from this information, to try to eliminate these delays in order to improve on site productivity.* These are demonstrated in Chapter 3.

- *To assign a clear approach to the application of foreman delay surveys (FDS).* This is provided in Chapter 3.

- *To identify research questions, research methodology and research variables.* The fundamental of this research can be seen in Chapter 4.

- *To validate the reliability of the results of the studies.* Validation is done by using *p* and *c* charts, which are described in Chapter 4.

- *To identify the factors affecting the productivity of the construction industry in Thailand.* This identification, which is illustrated in Chapter 5, employs a structured questionnaire as a research strategy, having project managers, foremen and craftsmen as the target groups.

- *To implement the improved work-sampling technique and foreman delay survey (FDS) on 4 construction sites in Thailand to find out how well these techniques work.* These implementations are described in Chapter 6.

- *To predict the results of future work-sampling studies.* Markov analysis is employed for this purpose and is clarified in Chapter 7.

- *To discuss the results of this research.* This is demonstrated in Chapter 8.

1.3 Hypothesis

Consequently, the hypothesis postulated in this thesis is:

"The current work-sampling procedure used in the construction industry can be improved to make it more practical and rigorous, and to increase its effectiveness, as a productivity improvement tool, that can highlight on-site construction productivity problems, with and without supplementary foreman delay surveys (FDS). This will lead to a correct reaction to alleviate or overcome the problems identified and, consequently, after this technique has been applied, the productive time of the construction site will increase."

1.4 Scope and Limitations

The first section of this research used structured questionnaires to reveal factors affecting construction productivity in Thailand and it is acceptable to indicate that the results are representative, as the number of respondents are statistically sufficient (34 project managers, 57 foremen and 128 craftsmen).

Unlike the first section, the second section of the study applied work-sampling technique to only 4 cases of the construction industry in Thailand (2 fabrication shops and 2 construction sites), so it is unreasonable to claim that the problems revealed are representative. Nevertheless, data collected may reflect only the particular characteristics of the industry in Thailand. This is, probably, different from other countries and it is incorrect to assume that those countries are experiencing the same productivity problems. However, the data could be compared and contrasted. Although the results of the study are inapplicable to other countries, the implementation steps of work-sampling study improved in this thesis may be universally applied.

Unfortunately, all participating site management prefer to keep their production rate and any other form of production measurement confidential, so it is impossible to obtain the actual saving achieved, with regards to a work-sampling study. In addition, actual validity of the Markov analysis cannot be carried out in this research, since the data collected are insufficient. Nevertheless, it can be done in future work by undertaking a series of work-sampling studies to record data and compare the results with those predicted.

1.5 Overview of Thesis Structure

The purpose of this section is to provide an overview of each of the twelve chapters of this thesis.

1.5.1 Chapter 1 – Introduction

Chapter 1 is the introductory chapter, which illustrates the basic idea that is the origin of this research. Furthermore, the aims and objectives, hypothesis, research methodology, scope and limitations of the thesis are outlined and established.

1.5.2 Chapter 2 – An Overview of Productivity

Chapter 2 begins with various definitions and classification of productivity. Basic steps for undertaking productivity studies and a variety of reasons to highlight the importance of productivity are also discussed. The chapter ends with identification of the relationship between management and productivity.

1.5.3 Chapter 3 – Productivity Management

Chapter 3 includes an overview of the work-sampling technique, by illustrating the relationship between work study and work-sampling and classification of this technique. Apart from that, the chapter specifies why work-sampling is suitable for application to the construction industry.

Sampling and the normal distribution curve and its characteristics, which are the fundamentals of work-sampling, are also explained in this Chapter. Next, the determination of the number of observations required for a study and the accuracy of the results after the investigation has been finished are discussed. Finally, the control chart, audit control and hypothesis test are explained in the last part of the chapter.

The chapter, also, highlights the problems with present work-sampling procedures, and then clarifies how they may be improved. Finally, the chapter clearly specifies how to implement of the improved work-sampling technique, providing the details for each individual step. The implementation stages clarified in this chapter are not limited to the construction industry, but also are applicable to other fields and industries. Finally, this chapter clearly specifies in detail the implementation stages of foreman delay surveys (FDS).

1.5.4 Chapter 4 – Research Methodology

Research questions, research methodology and research variables are described at the beginning of this chapter. Then, the validation of the reliability of the results of the studies, which comprised a validity test, a reliability test and a hypothesis test are explained.

1.5.5 Chapter 5 – Factors Affecting the Productivity of the Construction Industry in Thailand

Factors affecting productivity in the construction industry are specified in Chapter 5, by the use of questionnaires, which have project mangers, foremen and craftsmen, as target groups. These factors are ranked, by determining their relative importance index (RII). However, not only the factors, but also the general characteristics of the respondents and their organisations are identified.

1.5.6 Chapter 6 – The Applications of Work-Sampling and Foreman Delay Surveys

This chapter demonstrates the implementation of work-sampling at four locations in Thailand, which consists of two construction sites and two fabrication shops. In more detail, in one case from both categories (Sites 1 and 4) only work-sampling was carried out, while the remaining two (Sites 2 and 3) undertook both work-sampling and FDS.

1.5.7 Chapter 7 – Prediction of Work-Sampling Results

Chapter 7 clarifies the application of Markov analysis to this research in order to predict the results of work-sampling studies after further applications. Basic knowledge of the application is given, and an example is presented to make it easy for the reader to understand. Similar to chapter 4, the demonstration will be just an example, so only data from site 1 will be employed.

1.5.8 Chapter 8 – Discussion of Results

An explanation of how the research questions are answered is indicated in Chapter 8. The results of work-sampling study are individually discussed first. Then, one by one, these are compared and contrasted with the results of the questionnaires survey, the FDS and the Markov process.

1.5.9 Chapter 9 – Conclusion and Recommendations

This final chapter draws conclusions from the previous chapters and demonstrates that the aims and objectives proposed earlier in this thesis have been achieved. Recommendations concerning future research are provided.

1.6 Summary

Chapter 1 has introduced rationale of this research and has identified the aims, objectives and hypothesis of the study. In addition, the scope, limitations and overview of the thesis structure of this study have also been clarified in the chapter.

CHAPTER 2

AN OVERVIEW OFPRODUCTIVITY

2.1 Introduction

Productivity is a concept that everyone is familiar with and wants to improve, but understanding that concept and knowing how to improve productivity is a complex subject in practice. This is particularly true in a construction organisation. The purpose of this chapter is to provide an overview of productivity. A variety of productivity definitions are provided first, followed by a classification of productivity. After that, the general steps of carrying out a productivity study are explained, then a number of reasons are given to highlight the importance of productivity. Finally, the relationship between management and productivity is identified.

2.2 Definition

The boardest definition of productivity is the ratio of output of goods and/or services to inputs of general resources, for example, labour, capital, materials, which can be expressed as follows:

$$\text{Productivity} = \frac{\text{Output}}{\text{Inputs}}$$

According to this mathematical expression, productivity can be improved either by increasing output using the same amount of inputs or by the decreasing inputs while keeping the original volume of output. On the other hand, productivity decreases when output remains constant and the inputs increase or output decreases and the inputs remain constant. In the construction industry, reduction of rework is an example of increasing productivity by decreasing inputs, which are labour and materials. However, many authors have offered different definitions of the term productivity, some examples of which are given below (in descending date order):

"*Productivity is the optimum utilisation of resource inputs – labour, material and plant – in achieving an output acceptable in relation to some standard* (Djebarni and Eltigani, 1996)."

"*Productivity =f(output, input)* (Godoy-Mejia, 1993)."

"*Productivity is defined as output divided by available operative time, where available time is total paid time less unavoidable delays such as weather and meal breaks* (Cheetham, 1987).

"*Productivity is best expressed as global site output divided by available time* (Horner *et al.*, 1987)."

"*Productivity is usually defined in terms of the efficiency of the use of inputs within the productive process* (Lowe, 1987)."

"*Productivity, defined as output per employee hour* (Cardell, 1986)."

"*Productivity may be defined as a measure of the effective use of resources* (McLeish, 1983)."

"*Productivity is a measure of the economic efficiency with which a firm converts inputs of men, machines, materials and management expertise into output* (Fleming, 1971)."

"*Productivity is the quotient obtained by dividing output by one of the factors of production. In this way it is possible to speak of the productivity of capital, investment, or raw materials according to whether output is being considered in relation to capital, investment or raw materials, etc.* (OEEC, 1950)."

In addition, Strandell (1982) identified that *productivity* has at least two meanings. The first meaning involves gains in labour productivity, which come about through additional investments in the capital stock, i.e., the amount of machinery and equipment that are utilised in association with each worker. The second meaning relates to gains in total productivity, which refers not just to labour productivity, but also to the productivity of capital, land, and other investments that are used as inputs to production. For example, when investments lead to incorporation of the latest technological advances into the stock of capital, both labour productivity and total productivity increase, and this is obviously an ideal situation. The combination of these two factors is the base that is most commonly used in all leading indicators, and it is referred to as "Productivity."

The term "productivity", nevertheless, is usually confused with the term "production." It is not necessarily true, as many people understand, that the more the production, the more the productivity. Therefore, it is worthwhile to specify the meaning of the latter term, production. In general, *production* can be defined as the process or activity of producing goods and/or services. In addition, there are three more terms, which are efficiency, effectiveness and performance, that should be clarified.

Firstly, *efficiency* means doing things right and focusing on doing better against a standard output expected. Secondly, *effectiveness* is the degree of objective achievement. Consequently, it is clear that productivity is different from production, and is a combination of both efficiency and effectiveness, as efficiency is concerned with resource utilisation while effectiveness is concerned with performance.

Performance, finally, includes four main elements, namely, productivity, safety, timeliness, and quality (Oglesby *et al.*, 1989). Therefore, productivity is a facet of performance, but is not equivalent to performance. Many workers perform strenuously, but have a low productivity, due to ineffective methods. The productivity may be high, nevertheless, with low performance, due to automatic machinery, which paces the work (Drewin, 1982).

2.3 Classification of Productivity

Bishop (1975) wrote that any study of productivity must accurately define the circumstances to which it applies if the results are to be comprehensible to those not directly concerned with the study and that it must be comparable with other studies. This may explain why productivity is defined differently by various authors. However, Sumanth (1984) pointed out that if one closely examines various definitions, three basic types of productivity appear to emerge.

2.3.1 Partial Productivity

Partial productivity is the ratio of output to one class of input. The most common productivity ratio is labour productivity, expressed as output per man-hour. Another important measure of productivity is output per unit of capital (Fashoyin, 1983).

2.3.1.1 Labour Productivity

Lowe (1986) provided a typical measure of labour productivity as:

$$\text{Average labour productivity} = \frac{\text{Output}}{\text{Number of employees}}$$

2.3.1.2 Capital Productivity

Hawkins and Pearce (1971) defined capital productivity in terms of a percentage return on capital invested, either using a traditional method such as Average Rate of Return or a discounted cash flow method such as the Internal Rate of Return method.

$$\text{Average capital productivity} = \frac{\text{Profit}}{\text{Capital invested}}$$

2.3.2 Total Factor Productivity

Total factor productivity is the ratio of growth rate of real product to the sum of all associated (i.e. labour, capital, materials and equipment) tangible inputs (Sumanth, 1984).

$$\text{Total factor productivity} = \frac{\text{Total output} - \text{Materials and services purchased}}{\text{All associated inputs}}$$

2.3.3 Total Productivity

As the terms implies, total productivity is the ratio of total output to the sum of all input factors, which reflects the joint impact of all the inputs in production of output.

$$\text{Total productivity} = \frac{\text{Total output}}{\text{Total inputs}}$$

Labour productivity and capital productivity are widely used as measures of economic efficiency and have, at least, the advantage of simplicity, although their weakness is that neither includes the total productive process and they do not properly deal with the impact of technological change and factor substitution (Weber and Lippiatt, 1983). On the other hand, the concept of total factor productivity arose in response to these problems (Kendrick, 1956), but, unfortunately, the usual aggregation of labour and capital services, by summing quantities at constant prices, is often in error. Similarly, the output aggregation of consumption and investment goods using the same technique also results in an overstatement in the initial rate of total factor productivity growth (Cardell, 1986).

Despite the many advantages of utilising capital productivity or total factor productivity as a basis for comparison and assessment of the efficiency of the productive process, average labour productivity, as expressed above, is widely used in the construction industry (Lowe, 1987; Noor, 1998). This is understandable since construction is a labour intensive industry. However, there is no single, “static” measure that will precisely describe productivity. Not only are there difficulties of measurement, but there are also conceptual problems (Hines, 1976).

2.4 Productivity Study Steps

Bishop (1975) believed that any study of productivity must accurately define the circumstances to which it applies if the results are to be comprehensible to those not directly concerned with the study and that it must be comparable with other studies. No activity is wholly independent of its environment. Productivity measurement is never absolute; it is relative to the circumstances that pertain. Bishop, moreover, introduced three general steps for undertaking a productivity study.

Step 1: The first step in any productivity study is to specify the domain of the study and to define the main factors that bear upon it. For example, is the activity being studied independently of other activities? Is the available work independent of the rate of work? And so on, quite apart from the obvious features, which include an accurate description of the task, the materials, the method and the standards required.

Step 2: The second step is to select a method of measurement. This includes not only the technique to be applied, for example, work-sampling, extraction from records, but also the intervals to which observations relate. These two factors are a matter for careful choice depending upon the activity, its elapsed time and its variability.

Every productivity study should include data collected at the highest level of generality, which can be used to verify analyses of sub-activities on whatever scale. In other words, all studies must determine the tempo, manning and output of the activity as a whole, even though these could be derived as the sum of the sub-activities. In addition, it is necessary to know the total output and the total resources; these provide a crude but reliable measure of productivity against which the plausibility of other data may be assessed; similarly, for each main operation, the essential data are the output, the total resources committed to obtain that output and the elapsed time.

Step 3: Finally, in each case, data must not be treated as valid, unless the situations in which they were obtained are identified, the variability estimated and the method of observation known. All data should be treated with caution. The prime use of productivity studies is not for absolute comparisons, but for relative comparisons to yield insights, which can better inform management of the ease by which productivity can be increased. Properly interpreted productivity studies can inform management, provide insight, and point the way to better use of resources.

McTague (1989), nevertheless, pointed out that most productivity programs have failed because (i) they have been viewed as a short-term "fix"; (ii) there has been little honest commitment to organisational goals; (iii) the organisational culture and leadership have often not supported such a commitment to these goals; and (iv) because of excessive reliance on techniques and methods without a corresponding reliance on beliefs and values.

2.5 Why Productivity is Important?

Drucker (1991) stated that for the last 120 years, productivity in making and moving things – in manufacturing, farming, mining, construction, and transportation – has risen in developed countries at an annual rate of 3% to 4%, a 45-fold expansion overall. On this explosive growth rest all the gains these nations and their citizens have enjoyed: vast increases in disposable income and purchasing power; ever-wider access to education and health care; and the availability of leisure time, something known only to aristocrats and the "idle rich" before 1914, when everyone else worked at least 3,000 hours a year (Today even the Japanese work no more than about 2,000 hours).

Low productivity growth, on the opposite side, may be the single most important factor in determining the national economic well being. Without growth in productivity, struggles over income shares lead directly to inflation (Malkiel, 1979). Therefore, Cardell (1986) believed that the importance of productivity could not be overstated. When productivity increases, the value of money goes up and the country moves forward. A decrease in productivity, especially a protracted downward slide, costs a great deal. A lag in productivity growth means less business, more unemployment and a lower standard of living.

Hussain (1979) believed that it would not be exaggeration to state that construction is the key to development; and productivity is the key to construction. As a construction industry usually contributes between 4-10% to Gross Domestic Product (GDP), what Hussain said sounds reasonable, since a construction industry can stimulate the growth of other industrial sectors, and its productivity can improve quality of life and living standards. Consequently, any productivity improvement in the industry could make a significant financial saving. Examples of the economic contribution that a construction industry makes to its country are shown below:

2.5.1.1. Hong Kong

In Hong Kong, total expenditure on building and construction constitutes about 40% of gross fixed capital formation. Productivity improvement of the industry is important because of its size and the nature of its product as a productive resource (Chau and Walker, 1988).

2.5.1.2. Indonesia

In Indonesia, the construction industry accounts for 5.5% of the GDP. Although the industry contributes less to the country's economy than do other service industries or manufacturing, it has greatly influenced the country's economic growth (Kaming *et al.*, 1997a).

2.5.1.3. Malaysia

The construction industry in Malaysia is among the most active and fast growing industries. It accounts for 4.7% of the GDP. There were indications of the contribution growing to 5.2% in 1990 with the 337,000 job opportunities created in 1984 rising to 413,000 by that year (Yong, 1984).

2.5.1.4. Nigeria

Okpala and Aniekwu (1988) stated that the importance of the construction industry on national life is further illustrated by the fact that in Nigeria, a total of $4.48 billion of government funds was earmarked to be spent on building/civil construction alone during the fourth National Development Plan period of five years. Within the same period, private sector expenditure on building construction was estimated to be $2.96 billion.

2.5.1.5. Saudi Arabia

The construction industry in Saudi Arabia employs 15% of the total labour workforce and uses 14% of the total energy consumption in the country. It contributes about 20% to the total non-oil gross domestic product. In addition, the industry was the greatest recipient of government spending during the first (1970-1975), the second (1975-1980) and the third (1980-1985) National Development Plans, with 49.6%, 32% and 49.8% of total government expenditure, respectively (Assaf and Al-Khalil, 1995).

2.5.1.6. Singapore

Lim and Alum (1995) identified that the construction industry in Singapore contributes 6% of the country's GDP and it employs 7.5% of the total workforce. The industry has exhibited strong growth in the last few years. The GDP growth rate in the construction sector increased from 1.5% in 1989 to 21% in 1991. The 1991 figure was three times the national average GDP growth rate of 6.7% for that year. The construction contracts awarded in 1991 had a value of S$7,900M and, in the same year, Singapore construction secured S$950M worth of contracts overseas.

2.5.1.7. Thailand

The construction industry in Thailand contributed between 3% and 8% of the GDP between 1993 and 1997; unfortunately, due to the economic regression during the last five years, contribution to GDP of the construction industry has decreased to 3%. In respect of the workforce, the construction industry employs 1.28 million out of 33.00 million available workers, in other words, 3.88% of operatives in Thailand, of which 80-90% are males, are working in the construction industry (Makulsawatudom and Emsley, 2001a).

2.5.1.8. Turkey

The construction industry has a strategic role in the Turkish economy, employing approximately 4% of the total labour force and contributing 6% to the country's GDP and also representing the largest body of fixed capital in the country. It has become a major prospect and provides for a number of tangible benefits for the national economy especially with construction contracting services abroad since the late 1970's (Sozen and Giritli, 1987).

2.5.1.9. USA

Historically, annual construction business has comprised over 10% of the GDP (Anon, 1981), which holds a prominent position in the USA economy, not only in terms of its direct contributions to the gross national product and to employment, but also through its provision of physical facilities, which satisfy a wide variety of social, economic, and technical needs (Koch and Moavenzadeh, 1979). Therefore, a healthy, dynamic construction industry is a key to the quality of life and physical well being there (ASCE roundtable, 1983). Low productivity wastes 15%-40% of every construction payroll dollar. Since construction has an annual volume of about $115 billion and the labour factor is about 40% of the total in place cost, Americans are spending between $12-$16 billion for nothing (Anon, 1972).

2.5.1.10. UK

Horner (1992) provided a good example of how important productivity is in the UK construction industry. He wrote that more than one million people are employed in the UK construction industry. Assuming conservatively that each costs £10,000 p.a. to employ, a 10% increase in labour productivity represents a national annual saving of £1000m.

2.6 Management and Productivity

As construction consumes a very large percentage of human resources, high construction productivity is very important (Hussain, 1979). However, labour is rarely responsible for a job being late or too costly (Anon, 1974). Management practices, in fact, are a significant factor behind declining productivity in the industry (Anon, 1981). It is management's responsibility to provide the workforce with the necessary tools, equipment, material, and information to do the job in a workmanlike manner (Maloney, 1983). The failure of management to plan and maintain an orderly sequence of work, to provide sufficient resources, access to the work area and to maintain uncongested work areas constrains productivity (Thomas *et al.*, 1990). To effectively eliminate downgrading incidents, improvements must begin at management level. Planning, organising, leading and controlling are the management functions, which must be properly executed to improve productivity (Handa and Rivers, 1983). Non-productive time, in addition, can be reduced by as much as 10%-15% through good management (Strandell, 1982).

Horner *et al.*, (1987), consequently, specified that the degree of management control has a strong positive effect on productivity. To improve productivity, management must remove any constraints hampering crews in the performance of their tasks (Howell, 1981). If management can identify and rectify factors that the craftsmen feel affect their ability to be productive, there is a strong likelihood that worker motivation and individual productivity can be improved (Borcherding *et al.*, 1980). However, management must understand what productivity is, how improvements can be achieved, and how it can be monitored and measured (Whitman, 1990). In any case, productivity improvement cannot be achieved without management recognition of the causes of the problem (Stall, 1983). Lemon and Christian (1991) concluded that every construction project can be improved. Improvement, however, requires that management know what to improve and how to improve it.

NEDO (1989) explained that improving productivity is concerned with doing more work at less cost. In a labour-intensive activity such as construction, where labour is typically the largest cost component (Picard, 1991), if man-hours can be reduced (or more work done in the same hours), the cost of supervision, plant, tools, consumable materials and temporary facilities will also be reduced. If work can be completed in a shorter period of time, not only will temporary facilities and plant hire costs be reduced, but plant owners will also get their plant operating sooner and productively.

Therefore, these matters were the inspiration for the author's first pilot study, which was the identification of the factors affecting construction productivity in Thailand. A structured questionnaire survey, with project managers, foremen and craftsmen working in the industry as the target groups, was selected to be the main research strategy, and the results will be shown in chapter 5.

2.7 Summary

At the beginning of this chapter, a number of definitions of productivity have been provided, then its classification has been specified. Productivity study steps, the reason why productivity is important and the relationship between management and productivity have been explained at the end of chapter 2.

CHAPTER 3

WORK-SAMPLING AND FOREMAN DELAY SURVEYS

3.1 Introduction

Chapter 3 describes the implementations of work-sampling and foreman delay surveys (FDS). Firstly, the relationship between work study and work-sampling is clarified. Secondly, there is an introduction to work-sampling, then thirdly, the fundamentals of statistical analysis, such as the general idea of sampling, the normal distribution are explained. Fourthly, the implementation of work-sampling and how this research can improve the present steps of work-sampling study, are specified. Finally, this chapter explains the overview and implementation of FDS.

3.2 The Scope of Work Study

The British Standard Glossary of terms in Work Study BS 3138 (1969) defines work study as a measurement service based on those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts, and which lead to systematic investigation of all the resources and factors which affect the efficiency and economy of the situation being reviewed, in order to effect improvement.

Accordingly, work study has two main aspects, *method study* and *work measurement*, which are closely related. Figure 3.1 depicts the structure of the subject. *Method study* encompasses a number of techniques that are concerned with the critical review of the ways in which work is done, or is proposed to be done, which provides systems of analysis to develop improvements. Applications of the methodology can assist in project planning, design of temporary works, distributing plant and other resources at the work place, and replacing and progressing production. Its objectives are to reduce the cost of work and to make it easier to carry out and to make it become more effective.

Work measurement sometimes called *time study*, is the measurement of the time required to perform a specific task, under specified conditions, on the basis that it is carried out by a qualified worker, so that an output standard of production for a worker and/or machine may be established. Such information is required in the estimating process, in setting financial incentives, as part of the data used in method study and can also be used to monitor actual production performance against the standard expected.

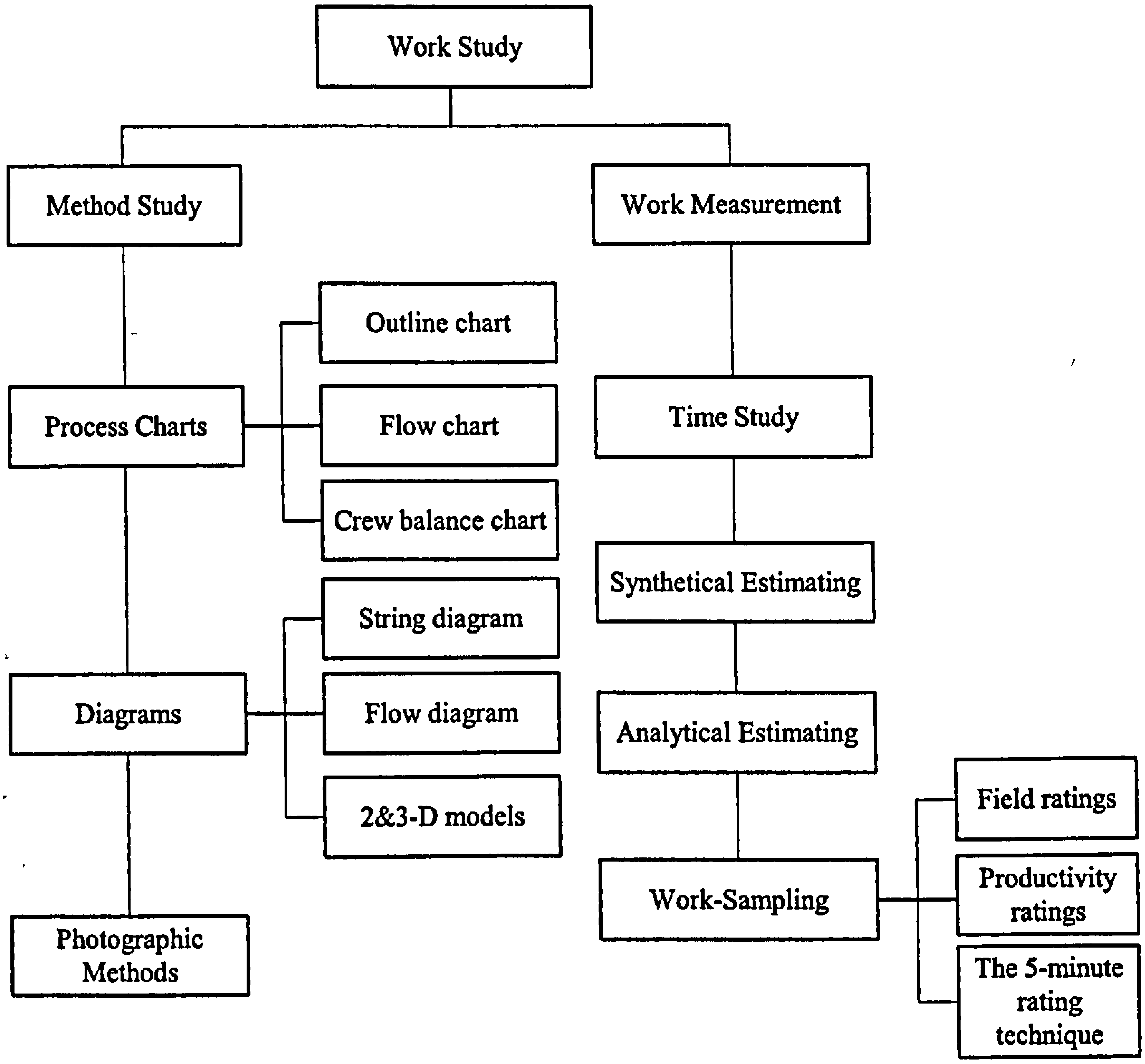

Figure 3.1 Outline of work study

Each one of these board divisions of work study can be applied to problem solving without reference to the other, although the best results are obtained most often by a carefully planned combination of the two. Method study, a creative process, when properly applied, should result in higher productivity through the improved layout of the production facility, a better and safer environment of work, the reduction of fatigue, improved quality of work, and better plant and equipment design. All of these factors should contribute to the more economical utilisation of productive facilities. Work measurement facilitates improved planning and control of production and costs, reduced costs of resources by providing established yardsticks that allow ready comparison of alternative job methods, and improved estimating of the cost of work; it also provides a sound basis for incentive schemes and scheduling processes.

Harris and McCaffer (1980) said that both methods, method study and work measurement, are increasingly finding favour in the construction industry. However, problems have arisen in applying the techniques, due to the temporary nature of most construction projects and the associated need to perform almost unique tasks in each project. As a result, there are often difficulties in acquiring data, which can readily and reliably be used in future planning, and control. Construction operations, in addition, are subject to many variables such as adverse weather, bad ground conditions, dispersed locations, high labour turnover, subcontract works on site, design divorced from construction, etc., which compound the problem of recording the facts.

Because of the nature of construction work, Pilcher (1992) suggested that not all work study techniques are as appropriate for use as those applied in engineering production. Emphasis can be placed on such techniques as work-sampling, which is very useful in providing a rapid indication of the utilisation of labour and mechanical equipment. It also may provide a guide as to the critical areas for further and more detailed investigation, particularly those areas that may yield the greatest savings. Flow process charts and crew balance charts are other techniques that can yield good results and are appropriate to many construction activities.

3.2.1 Method Study

Method study is the recording of work procedures in order to effect improvements. Ultimately the application of this technique leads to better planning and control and the improved use of manpower, plant and materials (Emsley and Harris, 1993). The exact procedure for carrying out a method study on-site varies depending on the purpose of the study and the technique adopted, but there are seven basic steps, which are summarised below (Oxley and Poskitt, 1996; Harris and McCaffer, 1995; Pilcher, 1992):

1. *Select the work to be studied*

   The criterion in deciding whether to carry out a method study exercise is judging the benefits to be expected compared to the cost and effort in implementing it. Clearly, the greater the potential cost savings in work, the higher is likely to be the priority for the selection of that work for study. In this step, it is also important to specify the problem boundaries and to ensure that there is a clear understanding by management as to exactly what problem is being investigated.

2. *Identify the recording methods*

   In many occasions, it is necessary to apply more than 1 recording technique in order to obtain complete data. Recording methods consists of three main groups. These are:

   2.1. Charts

   - ➢ Outline process chart - principal operations and inspections.
   - ➢ Flow process chart - activities of people, material or equipment.
   - ➢ Crew balance chart - activities of people and/or machines on a common time scale.

   2.2. Diagrams

- Flow and string diagrams - paths of movement of people, materials or equipment.
- 2&3-D model - layout of work-place or plant.

2.3. Photographic method - high speed, short-cycle operations.

3. *Record all relevant facts*

Collecting the facts as well as recording them is part of this stage in the procedure. An incomplete story can be extremely misleading, so it is essential to obtain all the facts concerning the work under examination. If it is possible to obtain the facts by measurement and in numerical form then this is to be preferred. Situations illustrating applications of the recording methods can be consulted in a typical construction management textbooks like Olomolaiye *et al.*, 1998; Oxley and Poskitt, 1996; Harris and McCaffer, 1995; Pilcher, 1992. Graphical recording methods should be used whenever possible.

4. *Analyse the recorded facts*

Careful study of the sampling statistics, diagrams or charts is the starting point in the design of a more efficient model. The process of analysis requires a critical examination of each recorded operation in the form of a question and answer technique as shown in Table 3.1.

Table 3.1 The questioning technique

Primary questions		Secondary questions	Alternatives
What...?	Why...?	Could it be...?	Should it be...?
purpose is achieved?	is that necessary?	what else?	what?
place is occupied?	that place?	where else?	where?
sequence is followed?	that time?	when else?	when?
person is involved?	that person?	who else?	who?
means are used?	that way?	how else?	how?

5. *Develop the new method*

In carrying out the examination phase, improved methods or new methods will be revealed. Development will almost inevitably necessitate the testing of new ideas. Pilot schemes can be implemented where conditions permit. Then, the best method from the alternatives should be submitted to management for approval.

6. *Install the new method*

   After the improved method has been designed, existing work practices must be replaced and persuasion and discussion with those personnel both directly and indirectly involved will be most important if the new method is to be accepted. Early participation in the study by those affected is likely to smooth the path of installation, or some form of financial incentive may be necessary as an encouragement, but in a well-prepared scheme one would usually expect these costs to be recovered by the increase in productivity.

7. *Maintain the new method*

   This consists of checking that the new method is adhered to by regular inspection on site or by watching output records, which will monitor and compare the results with the expectations and can be revised further if necessary.

3.2.2 Work Measurement

BS 3138 (1979) defines work measurement as the application of techniques designed to establish the time for a qualified worker to carry out a specific job at a defined level of performance. The aims of the technique are to provide the standard time, eliminate ineffective elements of work, and thus supply basic, essential data for management. The applications of work measurement, however, are extensive and can be used in:

1. Determining suitable staffing levels on construction activities;
2. Setting standards of machine utilisation and labour performance;
3. Providing the basis for sound financial incentive targets. For example, a bricklayer gang, which costs £15 a day, accomplishes 300 bricks (5p per brick, or £1 for 20 bricks). Thus, incentive can be set at £1 for each 25 additional bricks laid;

4. Providing a basis for cost control by fixing standard performance targets. For example, in the above example, if the bricklaying gang fails to lay 300 bricks a day, then the management can introduce a cost control measure;
5. Determining the most economic method from alternative methods; and
6. As an integral part of on-site method study.

It is impossible to completely separate work measurement from method study, except, probably, in describing the various techniques that are used in carrying out each of them. In the construction field the full use of work measurement is limited to a relatively small number of situations, since circumstances change so radically from task to task. One of the major difficulties of applying many of the work measurement techniques to construction sites stems from the fact that it is not always easy to define the small elements of the work that is to be studied. This frequently necessitates the study of larger and hence coarser elements of work, and is therefore a broad brush approach rather than a large number of short, detailed measurements of time. Furthermore, the difficulty is accentuated by the widely varying skills and expertise of the craftsmen and the ever-changing conditions under which they work. It is also affected by the ways in which an operative's fatigue can influence a study and the speed at which a craftsman can work.

Pilcher (1992) said in spite of these difficulties, many techniques of work measurement have been used successfully on construction sites, though their application has tended to follow fluctuating patterns of fashion rather than being consistent. An understanding of the principles of work measurement, nevertheless, is important, so as to condition a disciplined approach to thinking about estimating the cost, the planning, and the scheduling of production problems. The work measurement techniques commonly used in the construction industry are time study, synthetical estimating, analytical estimating and work-sampling.

3.2.2.1 Time Study

Time study, sometimes called *stopwatch studies*, is a principal technique of work measurement, which is concerned with data collection in the form of recording times and rates of working in order to establish the standard times and/or standard production outputs for carrying out a specified job at a defined level of performance. The purpose of time studies is to record the incremental times of the various tasks or steps that make up an operation. Such a detailed record will show exactly how long each step of an operation took. The results may be in conflict with how the job was planned, how the foreman or superintendent thought it was being done, how the plans and specifications required that it be done, or even how a reasonable person would have done it.

In brief, the study can be done by, first, timing and rating each element of work, and, accordingly, the basic times are calculable ($\text{Basic time} = \frac{\text{Observed time} \times \text{Observed rating}}{\text{Standard rating}}$). Rating is the numerical value or symbol used to denote the rate of working (Currie, 1964), which skill, speed and effectiveness must be taken into account when assessing the rate at which a person is working. Additionally, it is suggested that the breakpoints between elements of work should be readily distinguishable. Then, by allocating relaxation and contingency allowances to the basic time, the standard time is made available. Relaxation allowances consider personal needs, conditions, effort, posture, attention and monotony, whereas contingency allowances tend to cover many of the small items that cannot be covered by a specific allowance and the level can sometimes reach 100% or more depending on the job conditions (Olomolaiye *et al.*, 1998). Thus:

Standard time = Basic time + Relaxation allowance + Contingency allowance

Limitation of time studies and trends

There are several inherent constraints that prevent time study being regularly applied in construction operations, which are:

1. Reliable data can only be collected from experienced work study practitioners who are very scare in the construction industry.

2. The number of workers studied by one observer is limited (no more than five per observer), which requires employment of several observers, making the study expensive.

3. When activity break points are not clearly identifiable, there can be differences of opinion as to when one phase is completed and another started. Such errors can be significant, particularly if several observers are involved and data are compared and combined.

4. The information obtained by time studies is limited to the times recorded and the facts that there can be interdependencies among components, and the exact reasons for taking longer or shorter elemental times. These will increase the variability and reduce accuracy.

5. The data can not be assembled quickly, especially in civil engineering, where the variables on-site complicate the interpretation of information and the relaxation and contingency allowances needed often considerably exceed the required basic time.

3.2.2.2 Synthetical Estimating

Many jobs in construction work are not continuously repetitive, however there are many elemental activities such as spreading and vibrating concrete, which have a part or parts in common with to other operations, even though the total operation may be different. For example, concreting specifications in different projects may require different skip sizes at different heights on different structural elements, but all concreting consists of spreading and vibrating activities.

In order to take advantage of this characteristic it is necessary to have available a list of data relating to the elements involved. It then becomes feasible to arrive at the work content by a process of synthesis of the operations within the range covered. In addition, standard times can be estimated for the jobs that do not exist. In other words, the principle of synthesis is to build up time standards for an operation from previously carried out time studies, which are not necessarily from those of an identical nature. Details of synthetical estimating have been clearly illustrated and can be consulted in Price (1991).

The standard time for a new operation using synthetic data can be established by determining the method by which the operation is to be carried out and making a list of the work elements involved. Then, the appropriate basic time, relaxation and contingency allowances must be added in the same way as described for time study. Clearly, the smaller the size of the elements, both in the breakdown of the new operation and in the synthetics library, the easier it becomes to build up the time for the new operation.

3.2.2.3 Analytical Estimating

If the standard times of one or more of the elements in the new operation are not known because a study of that work has not previously been carried out, it may be necessary to make an estimate of the elemental times for missing synthetics. The development of standard times in this way is called *analytical estimating*. Usually handbooks, such as those published by manufacturers of earthmoving equipment or estimating manuals, similar historical data, or proper judgement by an experienced foreman, can be used to assist in this process.

3.2.2.4 Work-Sampling

As work-sampling is chosen to be the major work measurement tool for this study, this technique will be discussed in detail in the next three sections.

3.3 Introduction to Work-Sampling

Work-sampling is a statistical sampling technique employed to determine the proportion of delays or other classifications of activity present in the total work cycle (Karger and Bayha, 1966). A work-sampling study consists of a large number of observations taken either randomly or at set intervals. The study records each worker's activities, which include such categories as direct work, travelling, receiving instruction, etc. From the proportions of observations in each category, inferences are drawn concerning the total work activity during the survey.

Table 3.2 Advantages and disadvantages of work-sampling

Advantages	Disadvantages
❖ The study can be interrupted and restarted anytime without seriously affecting the result.	❖ It does not give quick answers, since the results of the sample may take days to process.
❖ It produces results of known reliability and accuracy.	❖ It must be done properly in order to be effective.
❖ It enables management to obtain an overall appraisal of operations conveniently and economically.	❖ This technique does not usually rate the work; it is not possible to assess the productivity or manning levels required.
❖ The person most capable of directing improvement may also be the person who gathers the information.	❖ Improvement methods or basic information necessary for productivity improvement are not provided.
❖ It does not impose any great strain on the observer, since attention is necessary on only one thing at a time, the individual takes snap readings; and between readings attention can be relaxed.	
❖ Those under observation are not interrupted or disturbed in their work and no great strain is imposed upon them.	
❖ It can be tailor-made to fit a given situation, either the whole site or a specific crew.	
❖ It is a relatively inexpensive, comparatively timely and simple, but effective way of obtaining valuable information on construction site activity, which can be easily understood by the whole site team.	
❖ The inaccuracies caused by fatigue and boredom on production studies are eliminated.	
❖ Errors of judgment are reduced by using quantitative information.	
❖ It does not require observers with special skill and training.	
❖ Various different jobs or a large number of machines and/or people can be covered in a single work sampling study.	
❖ There is less bias due to worker reaction to the study, as the maintenance of an abnormal pace over the longer period of observation is less likely than with a relatively short period time.	
❖ It can be used in order to detect areas that may subsequently respond to a study in greater detail using other techniques.	

The success of work-sampling relies heavily on the randomness of observations and number of observations taken. First, "*randomness*" in the statistical sampling sense means the condition that any given instant of time has an equal likelihood of selection as the time for observation as any other instant, that is there is no apparent order to the times of observation, and thus that one time of observation is independent of all other times of observation. Second, the theory of work-sampling requires that sufficient observations are taken to satisfy the statistical limits of accuracy. The exact degree of reliability of a work-sampling study can be regulated very simply by varying the number of observations made. In general, the more number of observations made, the more degree of reliability of a study. However, the reliability required of a particular study is dependent upon the end use to which the study will be put. Just like other productivity measurement techniques, work-sampling has both advantages and disadvantages, as described in Table 3.2.

3.3.1 Appropriateness of Work-Sampling Application to the Construction Industry

Work-sampling is generally suitable for investigating work of a non-repetitive or irregularly occurring nature (Heiland and Richardson, 1957, Richardson, 1976; Tsai, 1996). It has been found useful for measuring work where manual work is performed (Barnes and Andrews, 1955), and in particular for assessing the level of activity on complex non-repetitive jobs (NEDO, 1989). In addition, Dale (1976) emphasised that this type of study, basically a fact-finding preliminary to management action, is most appropriate for initial attempts to bring under management control every type of non-repetitive work to be measured. Supported by Picard (1991) who said that work-sampling is proven to be a most cost-effective and practical tool on construction projects, according to his extensive experience, Peer (1986) identified that work-sampling had been shown to be highly effective in building operations.

Furthermore, this type of study can measure the level of activity for work being carried out on site and can be extended to measure the level of productivity (Baxendale, 1987). Consequently, work-sampling is particularly appropriate to construction operations, and is chosen as the major productivity measurement technique for this research, supplemented with Foreman Delay Surveys (FDS).

3.3.2 Classification of Work-Sampling

Work-sampling includes a variety of different approaches to suit different situations and to give an insight into differing aspects of work. Three variations discussed here are field ratings, productivity ratings, and the 5-minute rating technique.

3.3.2.1 Field Ratings

Field rating, also called *field count*, is the simplest of work-sampling techniques and is used to measure the level of activity of a large workforce. The principle of field rating is that at the selected random times, each craftsman is observed and instantaneously classified into two categories as either working or not working, active or inactive, effective time or ineffective time, and so on. The general operating rules for implementing a field rating study are:

1. A field rating study requires an individual full time observer who must understand the reasons for making the count and should be drilled in the correct procedure.
2. Two mechanical counters mounted on a clipboard should be employed. One counter records the active personnel and the other those who are inactive.
3. If all of the relevant personnel cannot be covered then an attempt should be made to observe at least 75% of the operatives.
4. The rating should be taken at the first instant of observation, and should not be rationalised, for example, the activity a craftsman has just completed or is about to start should be disregarded.
5. The data should be taken at random intervals around the site during normal working hours. However, for the most realistic results, the study should not commence immediately work starts, either at the commencement of the day or after a meal break, unless the survey is

concerned with highlighting the general timekeeping standards for the project.

6. Activities classified as working should include participating in active physical work, carrying material, operating a piece of equipment or receiving instructions, and those classified as the idle should include waiting for another to finish work, relaxation, talking, walking empty handed and so on.
7. No counts should be discarded. Two counts are more representative than one.

After the observations have been carried out in this way, the results of the count will then be the total number of operatives observed and the total number of operatives observed working. The percentage working is the number working divided by the total observed, which is the *working index*. Thus:

$$\text{Working index} = \frac{\text{Total number classified working} \times 100\%}{\text{Total number of craftsmen observed}}$$

If this overall index is less than 60%, job activity is often considered dissatisfactory and further investigation is needed (Oglesby *et al.*, 1989). In addition, as a rule of thumb, it may be stated that 100 observations may identify situations that are seriously awry, but at least 400 observations (the source of this number will be described in the next chapter) are required to obtain statistically valid results. Figure 3.2 provides an example of a field rating report. A field rating study can be applied with any number of craftsmen. Where a large project is observed, a few tours will provide the required number. If a single gang is observed many tours may be required to secure the necessary number of observations.

Field Rating Summary Report						
Observation time	No. observed working	No. observed idle	Total no. of craftsman observed	Percentage craftsman observed	Total no. of craftsman	Percentage craftsman working
8.40	64	32	96	96	100	64
9.15	70	25	95	95	100	70
9.50	66	26	92	92	100	66
10.20	68	24	92	92	100	68
Total	268	107	375	-	-	67

Figure 3.2 A sample report of a field rating study

3.3.2.2 Productivity Ratings

Productivity ratings are a further step of sophistication beyond the two-classification field rating discussed above. Oglesby *et al.* (1989) said that this technique needs careful definition of the individual activities of effective, contributory and ineffective work, or idle time. There is no right way to categorise the multitude of activities for productivity-rating purposes. Rather it is necessary only to make clear the activities or conditions that are to be measured and how they are to be classified. One general breakdown that can be used in productivity ratings for almost all types of construction work is as follows:

3.3.2.2.1 Effective Work

Effective work is defined as work that directly contributes to a physical addition to the unit of construction, such as the necessary disassembly of a unit that must be modified and movements essential to the process that are carried out in the immediate area where the work is being done.

3.3.2.2.2 Contributory Work

Contributory work is that which cannot obviously be identified immediately with a particular unit of construction, but without which the work that is the subject of the investigation could not proceed. Examples are building a scaffold to serve as a work platform, heating and preparing mastic asphalt before applying tanking to concrete walls, returning an empty truck to be filled, or moving within the area of the work station, etc.

3.3.2.2.3 Ineffective Work or Idle Time

Ineffective work includes all categories of inactivity. An ineffective worker may be active in the sense of walking empty-handed or carrying anything more than 35 feet from the work station, taking a coffee break and so on, and is doing so without directly contributing to the physical addition of the unit under construction. Rework also falls into this category.

Table 3.3 gives a sample of productivity ratings developed by a large prestigious firm that has used them to assess relative productivity for many years. Its data clearly show the differences in ratings to be expected among craftsmen whose tasks are highly repetitive such as bricklayers or painters and others like electricians and pipe fitters.

Labour utilisation factors can be calculated with the results of a work-sampling study. Where a productivity rating study has been carried out there arises the question of the extent to which essential contributory work should be included in the calculations. A compromise concerning the essential contributory work leads to a formula acknowledging its existence, but only in part:

$$\text{Labour utilisation factor} = \frac{(\text{Effective work}) + \frac{1}{4}(\text{Contributory work})}{\text{Total number of observations}}$$

Table 3.3 Productivity ratings for several construction trades

Source Oglesby *et al.* (1989, p. 179)

Trade or craft	Percent of total time in category		
	Effective	Contributory	Ineffective
Bricklayer	42	33	25
Carpenter	29	38	33
Cement finisher	37	41	22
Electrician	28	35	37
Instrument installer	30	30	40
Insulator	45	28	27
Ironworker	31	36	33
Labourer	44	26	30
Millwright	34	36	30
Equipment operator	38	22	40
Painter	46	26	28
Rigger	27	57	16
Sheet metal	38	33	29
Pipe fitter	27	36	37
Teamster	45	16	39
Average	36	33	31

3.3.2.3 The 5-minute Rating Technique

This technique was originated by Oglesby *et al.* (1989), who suggested that the 5-minute rating technique is a quick and less exact appraisal of activity than that of the field ratings method. Even so, it is an effective method for making a general work evaluation. The purposes of the technique are to create awareness on the part of management of delay in a job and to indicate its order of magnitude; measure the effectiveness of a crew; and indicate where more thorough, detailed observations or planning could result in savings.

Date 7/7/88
Job Erecting pre-cast panels
Contractor N+E Corp.
Supt ______ Foreman ______

Time	Ironworker	Ironworker	Carpenter	Carpenter	Carpenter	Welder	
10.13	✓						Crew waiting for panel to be hoisted
10.14	✓	✓	✓	✓	✓		Landing panel, welder waiting to tack rebar
10.15	✓	✓	✓	✓	✓		
10.16		✓	✓	✓	✓		Install upper bolts for braces
10.17		✓		✓	✓		Install braces
10.18			✓	✓	✓		Align panels
10.19			✓	✓	✓		
10.20			✓	✓	✓		
10.21	✓	✓	✓				Unhook crane
10.22	✓	✓	✓				
10.23						✓	Welder tacks rebar, crew waits for next panel to be hoisted
10.24						✓	
10.25						✓	
	5	6	8	7	7	3	

Total man units 78 Effective 36 Effectiveness 46%

Figure 3.3 Example of the 5-minute rating technique applied to pre-cast panel erection – 12 minute cycle

Source Adapted from Oglesby *et al.* (1989, p. 182)

To undertake a 5-minute rating, the observers with a watch and a form for recording observations, as illustrated in Figure 3.3, must place themselves in a position where they can observe the whole crew without being conspicuous. As a result, the craftsmen being observed will not be aware and will not react to the presence of the observers. For small crews working in close proximity to one another, all are observed at the same time. Large crews can be mentally divided into sub-groups for ease of observation. Each craftsman in every particular group is then observed during a consecutive block of time from 30 seconds to several minutes and the ratio of effective to the total observed time is noted. If the effective time noted in any individual block of time exceeds 50% of the period of observation, then the rating for that particular block is classified as effective. On the other hand, if the effective time is less than 50%, the appropriate block is specified as ineffective. The sum of effective times for every particular period and for the crew divided by the total time of observation will then give an effectiveness ratio, which when multiplied by 100, gives an effectiveness percentage for the whole crew.

Alternatively, rather than work on a minute-by-minute basis, the observer waits until a specific task has been completed and then rates the craftsmen according to whether the majority of their time was effective or ineffective, and notes in the study sheet the appropriate minute blocks. After the study has been completed, the ratio of effective to total time is computed on a man minute basis, as shown in the Figure 3.3.

The name of this technique comes from a rule of thumb that the minimum observation time, expressed in minutes, should be equal to the number of operatives in the crew and no crew should be observed for less than 5 minutes. Thus, 4 craftsmen should be observed for at least 5 minutes, or 10 men should be observed for a minimum of 10 minutes. A longer period is sometimes necessary to satisfy observers that they have recorded the actual situation. An adequate number of rounds of observations is four times a day, two in the morning and the other two in the afternoon.

3.4 Principles Statistical Concepts of Work-Sampling

3.4.1 General Idea of Sampling

Work-sampling is based on the laws of probability, which is that a sample[1] taken at random from a large group tends to have the same pattern of distribution as the large group or the population[2]. If the sample is large enough the characteristics of the sample will differ but little from the characteristics of the population. Obtaining and analysing only a part of the population is known as "sampling."

In a daily life, everyone experiences sampling, whether one realises it or not. For example, buying apples in Sainsbury's, one actually takes a chance that those on the

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[1] A sample is a collection of observations representing only a portion of the population (Lapin, 1997).

[2] A population is a collection (or set) of data that describes some event or happening of interest to you (Sincich, 1989).

top box are representative of all the others one cannot see. When buying anything such as a digital camera, a pack of toilet paper, a DVD, a light bulb, or any other item, one is drawing a sample of one and one expects that one item to be representative of all other similar looking or similarly described items. As a result, where repeated purchases of the same thing are made, like light bulbs from the same manufacturer, one is accumulating a comparatively large sample as time goes on, and has, probably, not found any appreciable difference from item to item. However, each successive item is really a sample of a tremendous quantity of similar items. The following examples provide a better understanding of sampling and the law of probability.

3.4.1.1 Coin Tossing

If a coin is tossed there are two possibilities, which are heads or tails. Consequently, there is a 50% chance that the coin turns heads and a 50% chance that the coin turns tails or, in other words, for 100 tosses on average 50 heads and 50 tails should appear. However, actually, 46-54 or 52-48 or 51-49 or any other ratio might occur. Yet the true probability of heads and tails is 50-50! If one tries this, it will be discovered that the chance of getting the 50-50 ratio increases with the number of tosses. The ratio will be closer to 50-50 with 500 tosses than with 100 tosses, still closer with 1,000 tosses and even closer with 2,000 tosses.

3.4.1.2 Bead Sampling

A bowl contains 1,000 beads, 900 white and 100 black beads and a sampling paddle (see Figure 3.4). If the beads are thoroughly mixed and one bead is selected at random, the chances are 1 to 10 that it will be a black one, as 100 of the 1,000 beads are black. The sampling paddle just withdrawn from the box has 100 depressions, which contain from this sampling 8 black and 92 white beads. If this sample represents the estimate of the percentage of black beads, then an estimate of 8 is obtained. Yet, again, the true percentage of black beads is 10! Please note that this example will be used to demonstrate all statistical applications in this chapter.

3.4.1.3 Systematic Error and Random Error

According to the two examples specified above, one might notice that what occurs from sampling does not represent the true percentage. For example, the true percentage of black beads is 10%, but sampling indicated 8%. The extent to which these percentages may differ from the actual is determined by two basic sources of errors, namely systematic error and random error.

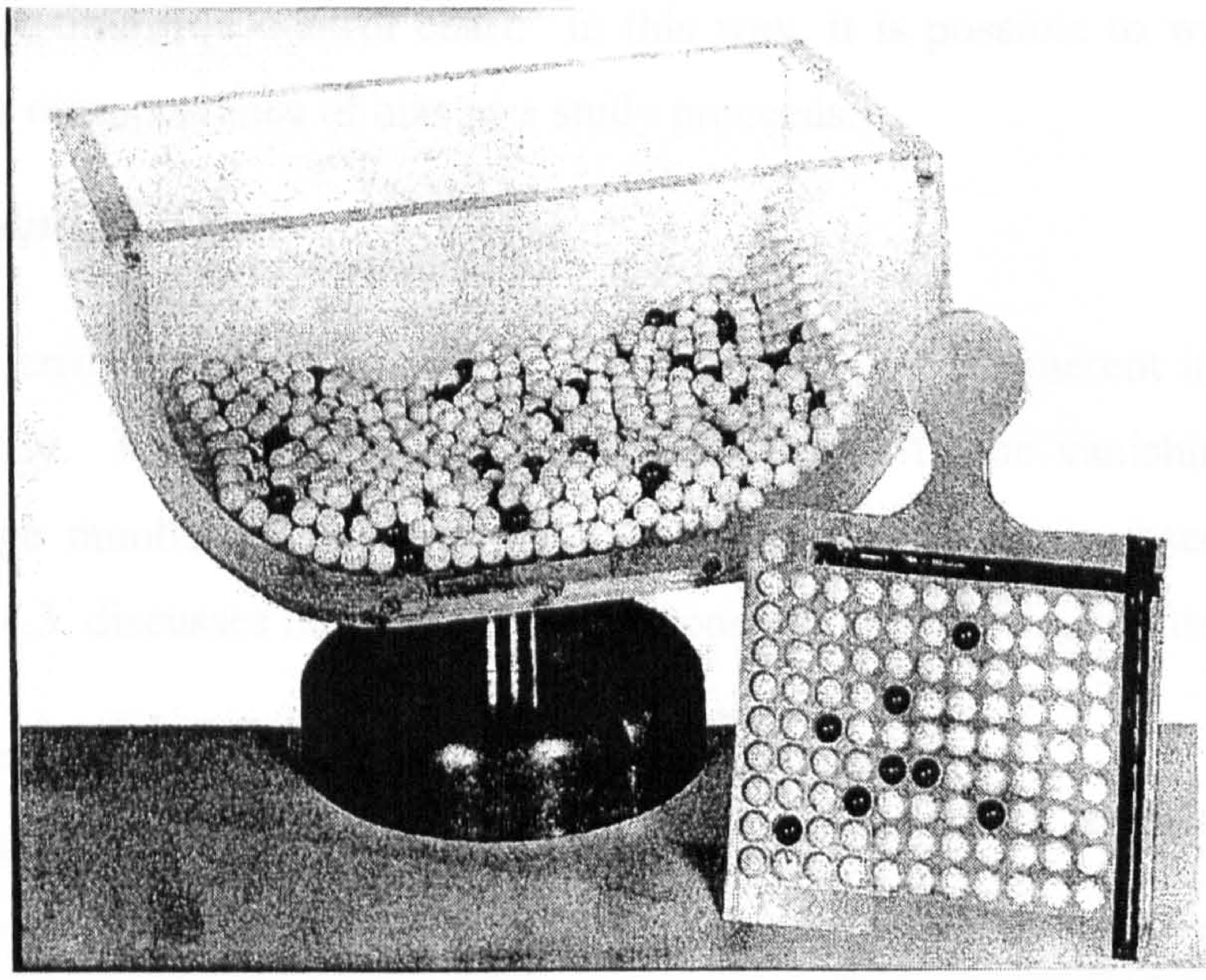


Figure 3.4 Bead sampling container and sampling paddle

Source: Hansen, B. L. (1960, p. 43)

3.4.1.3.1 Systematic Error

A systematic error may occur, for example, in the case of a craftsman having a cycle to his work, which begins every hour on the hour and the craftsman works continuously for 50 minutes, then the last 10 minutes he always goes to the toilet. If work-sampling observations always were taken at half past the hour, the craftsman would always be recorded as "working or effective time." Similarly, if observations always were taken at five to the hour, the craftsman would always be recorded as "personal allowances or unproductive time."

In both instances, a systematic error is induced by lack of randomisation of observations. Likewise, in other situations if it became known that the observer always made his round of observations at, say, a quarter past the hour, those being observed might make it a point to be busy at the time of observation. While, in the latter case, education and a proper introduction might minimise the error, it still is axiomatic that randomisation of times is essential in most cases to reduce systematic errors in observations. Fortunately, systematic error can be detected by plotting results against time in a control chart. In this way, it is possible to watch for the emergence or disappearance of bias as a study proceeds.

3.4.1.3.2 Random Error

This kind of error occurs as a result of chance causes and is inherent in any work-sampling study. Random error can be reduced almost to the vanishing point by taking a large number of observations and is reduced as more observations are obtained. (3.4.3. discusses number of observations required for a particular study).

Table 3.4 Percentages of black beads from 20 samplings
Source: Adapted from Hansen, B. L. (1960, p. 43)

Sample No.	No. of Black Beads	Sample Size	% of Black Beads	Cumulative % Black Beads
1	8	100	8	8.00
2	11	100	11	9.50
3	9	100	9	9.33
4	8	100	8	9.00
5	9	100	9	9.00
6	10	100	10	9.17
7	14	100	14	9.86
8	10	100	9	9.75
9	11	100	11	9.89
10	8	100	8	9.70
11	10	100	10	9.79
12	6	100	6	9.48
13	12	100	12	9.68
14	9	100	9	9.63
15	7	100	7	9.46
16	13	100	13	9.69
17	7	100	7	9.53
18	12	100	12	9.67
19	11	100	11	9.74
20	10	100	10	9.75
Total	195	2000		

3.4.2 The Normal Distribution Curve

The normal distribution curve refers to the shape of a well-known frequency distribution, which is of importance in work-sampling because it represents graphically the probability of the occurrence of certain chance phenomena. However, its derivation is not important here, but its application and use are very worthy of exploration.

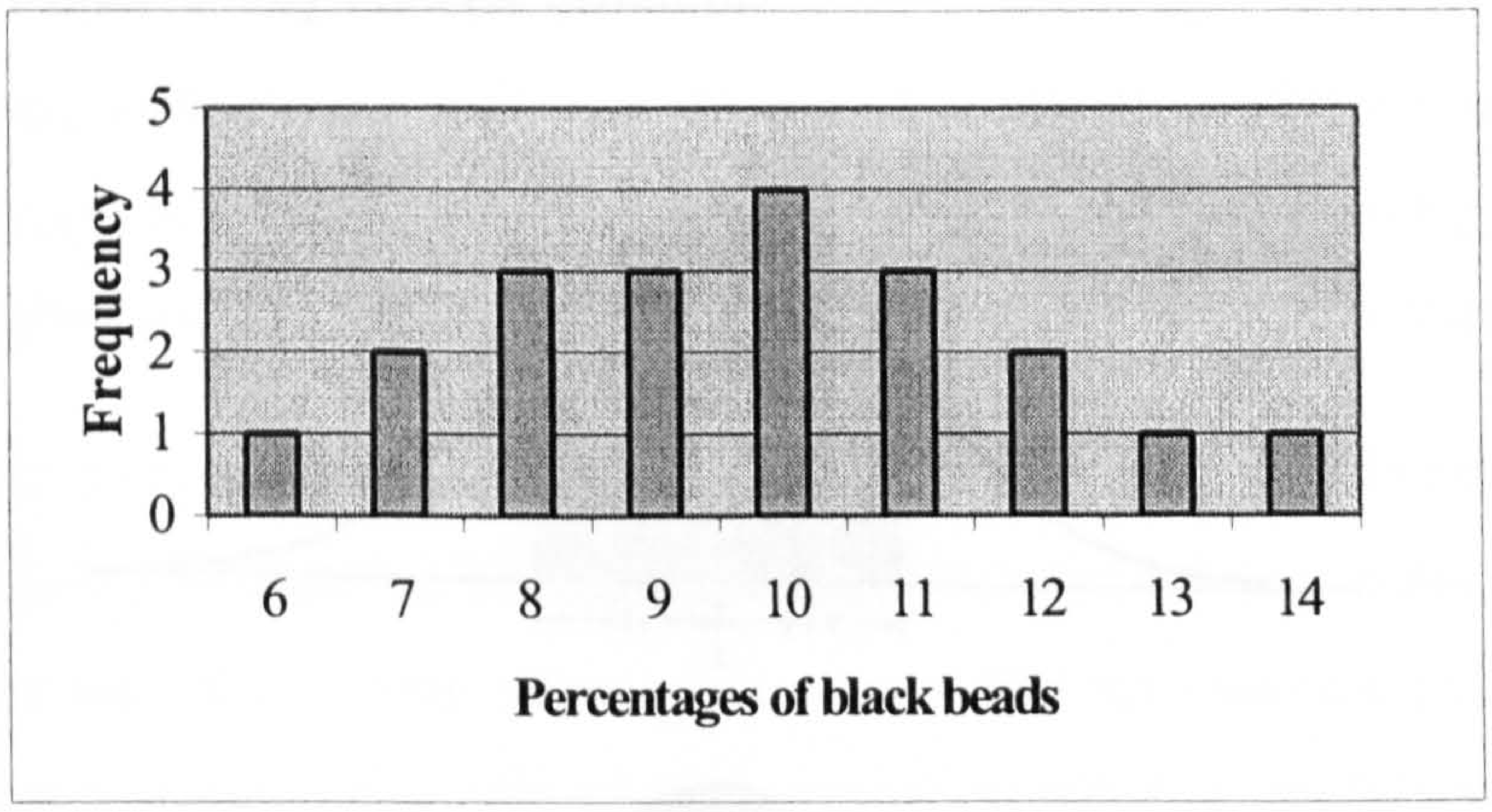


Figure 3.5 Frequency distribution for the percentages of black beads from 20 samplings

If a further 19 samples of 100 each were taken from the bowl in Figure 3.5 (see Table 3.4) and the tally of percentages from 20 samplings were plotted from the least to the most, the resulting curve would approximate to a normal curve. See Figure 3.5 Frequency distribution for the percentages of black beads from 20 samplings.

Referring to Figure 3.5, there does seem to be a pattern. If the sampling were repeated again and again, the tally marks would have a tendency to build more in the centre than at the extremes. This peaking tendency occurs in data taken from many different sources, for example, test grades of students, compressive strength of concrete, public opinion polls, etc. In fact, it occurs so often in nature that the theoretical distribution, which describes this peaking distribution, is called the "*normal distribution curve*." Figure 3.6 A common normal curve distribution exhibits a normal curve.

Table 3.5 shows the fraction part of the area under the normal curve between the mean ordinance and the ordinates at various distances from the mean (measured in multiples of σ). It is worthwhile to note here that the more multiple of σ (sigma or also called standard deviation), the less the difference in the area under the curve. For example, the area difference between one and two sigma (one sigma difference) is 27.18%, but the area different between two sigma and three sigma, again one sigma difference, is 4.28% and even less when compared between three sigma and four sigma, which is only 0.264% different.

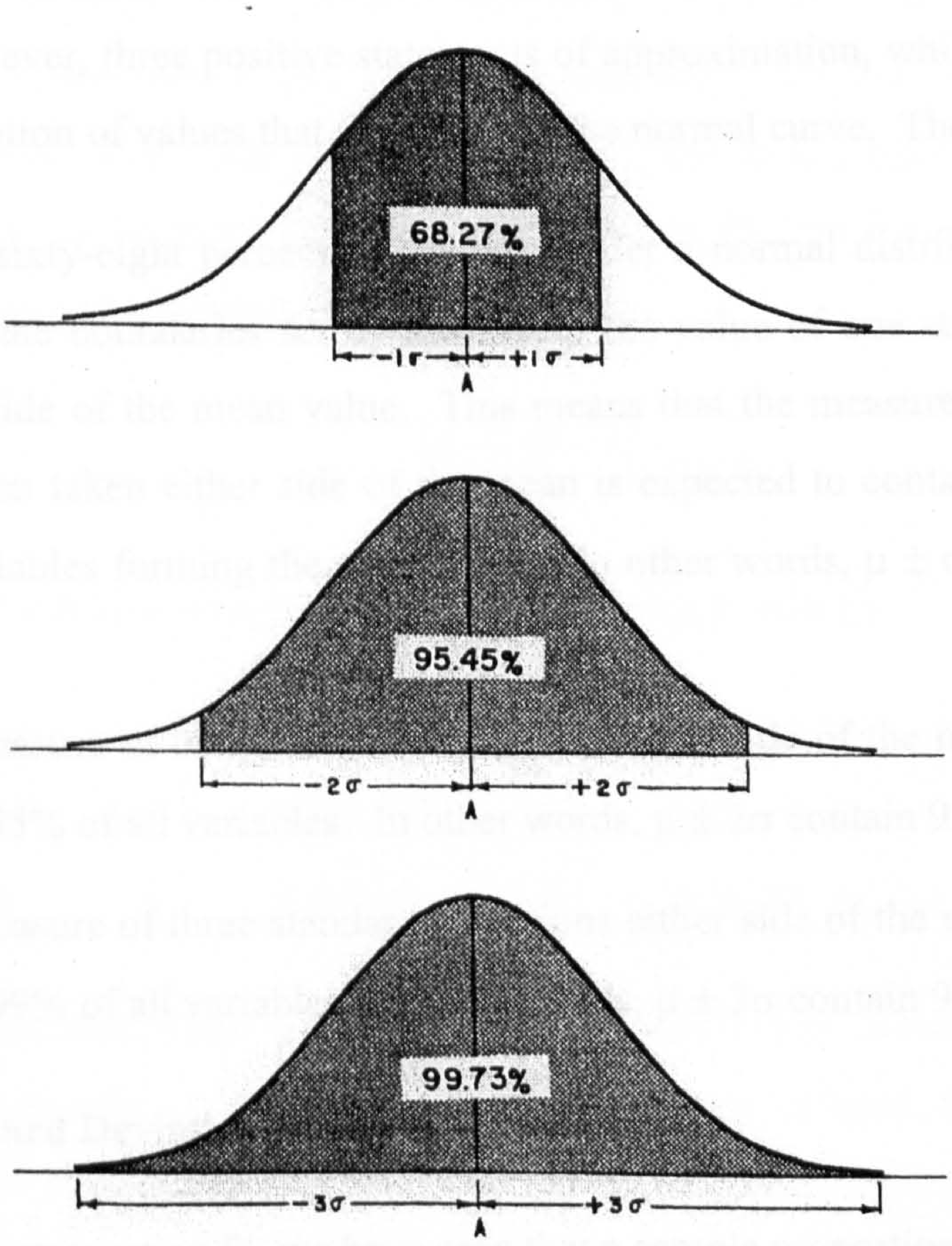


Figure 3.6 A common normal curve

Source Barnes (1956, p. 9)

Table 3.5 Normal distribution areas

Multiple of sigma (σ)	0.5	1.5	2.5	3.5	4.5
% of area under the curve	38.29	86.64	98.76	99.95	99.9993
Multiple of sigma (σ)	1.0	2.0	3.0	4.0	5.0
% of area under the curve	68.27	95.45	99.73	99.994	99.99994

3.4.2.1 Properties of the Curve

By inspection of the normal curve picture (Figure 3.6) it can be seen that the two tails of the distribution do not touch the axis, or line, along which the values are located. In theory, the curve extends in both directions indefinitely, never touching. Furthermore, the normal curve is a continuous function and not a grouped or discrete one.

The normal curve is significant because of the relationship of the area under the curve between ordinates at various distances on either side of the mean ordinate. There are, however, three positive statements of approximation, which will hold true for any distribution of values that approximate the normal curve. They are:

1. About sixty-eight percent of the area under a normal distribution curve lies within the boundaries set by measuring the value of one standard deviation either side of the mean value. This means that the measure of one standard deviation taken either side of the mean is expected to contain about 68% of the variables forming the distribution. In other words, $\mu \pm \sigma$ contain 68% of values.
2. The measure of two standard deviations either side of the mean will contain about 95% of all variables. In other words, $\mu \pm 2\sigma$ contain 95% of values.
3. The measure of three standard deviations either side of the mean will contain about 99% of all variables. In other words, $\mu \pm 3\sigma$ contain 99% of values.

3.4.2.2 Standard Deviation and Confidence Level

Given any true proportion P′, we have seen that a sample proportion P = P′ would not always occur, that is, P (for sample size *n*) would not always be exactly P′. The problem in establishing a confidence limit is simply the question: "How far from P′ may a sample P depart from P′?" Nevertheless, as a sample of sufficient size will approximate to the shape of its parent distribution, so will the value of its calculated standard deviation approximate to the standard deviation of the parent distribution.

Standard deviation of P for any given sample size *n* can be calculated from the formula below:

$$\sigma = \sqrt{\frac{P(100-P)}{n}} \qquad \text{................(1)}$$

where; σ = standard deviation of a percentage
P = average percentage
n = sample size

Let us take an example from the bead sampling. After the first sampling of 100 beads, 8 black beads were found, so we can estimate P′ for this category no more precisely than 8%. The vagaries of sampling will lead us to suspect that successive values of P may not be exactly 8%, but how far from 8% could they be expected to go? The following demonstrates the calculation:

$$\sigma = \sqrt{\frac{8 \times (100-8)}{100}} = 2.71$$

As a result, we will now have the interval that the true P′ will lie:

$\bar{x} \pm \sigma$ = 8 ± 2.71 = 5.29-10.71 or 5-11
$\bar{x} \pm 2\sigma$ = 8 ± 5.42 = 2.58-13.42 or 2-14
$\bar{x} \pm 3\sigma$ = 8 ± 8.13 = 0-16.13 or 0-17

These limits, however, seem to offer very small reliability as to the estimation of P′. This follows naturally, since we have only one sample in hand, so we should not expect great precision. Fortunately, 19 more sample were taken, with the results shown in Table 3.4. Now P = 9.75% (195÷2000 = 9.75%)

$$\sigma = \sqrt{\frac{9.75 \times (100-9.75)}{100}} = 3$$

Then, we will now have the number of samples inside limits:

$x \pm \sigma$ = 9.75 ± 3 = 6.75-12.75 or 7-12 Calculated 14 Actual 17 (see Figure 3.5)

$x \pm 2\sigma = 9.75 \pm 6 = 3.75\text{-}15.75$ or 4-15 Calculated 19 Actual 20 (see Figure 3.5)

$x \pm 3\sigma = 9.75 \pm 9 = 0.75\text{-}18.75$ or 1-18 Calculated 20 Actual 20 (see Figure 3.5)

Using the grand average of the data, 9.75%, as an estimate of the true percentage (assuming that we do not know that it is 10) and interpreting the statements above in different form, the sample results calculated previously comply with these statements:

1. We can conclude that 68% of all values will lie between 7 and 12;
2. We could conclude that 95% of distributions will be between 4 and 15; and
3. We can conclude that 99% of all values will fall between 1 and 18.

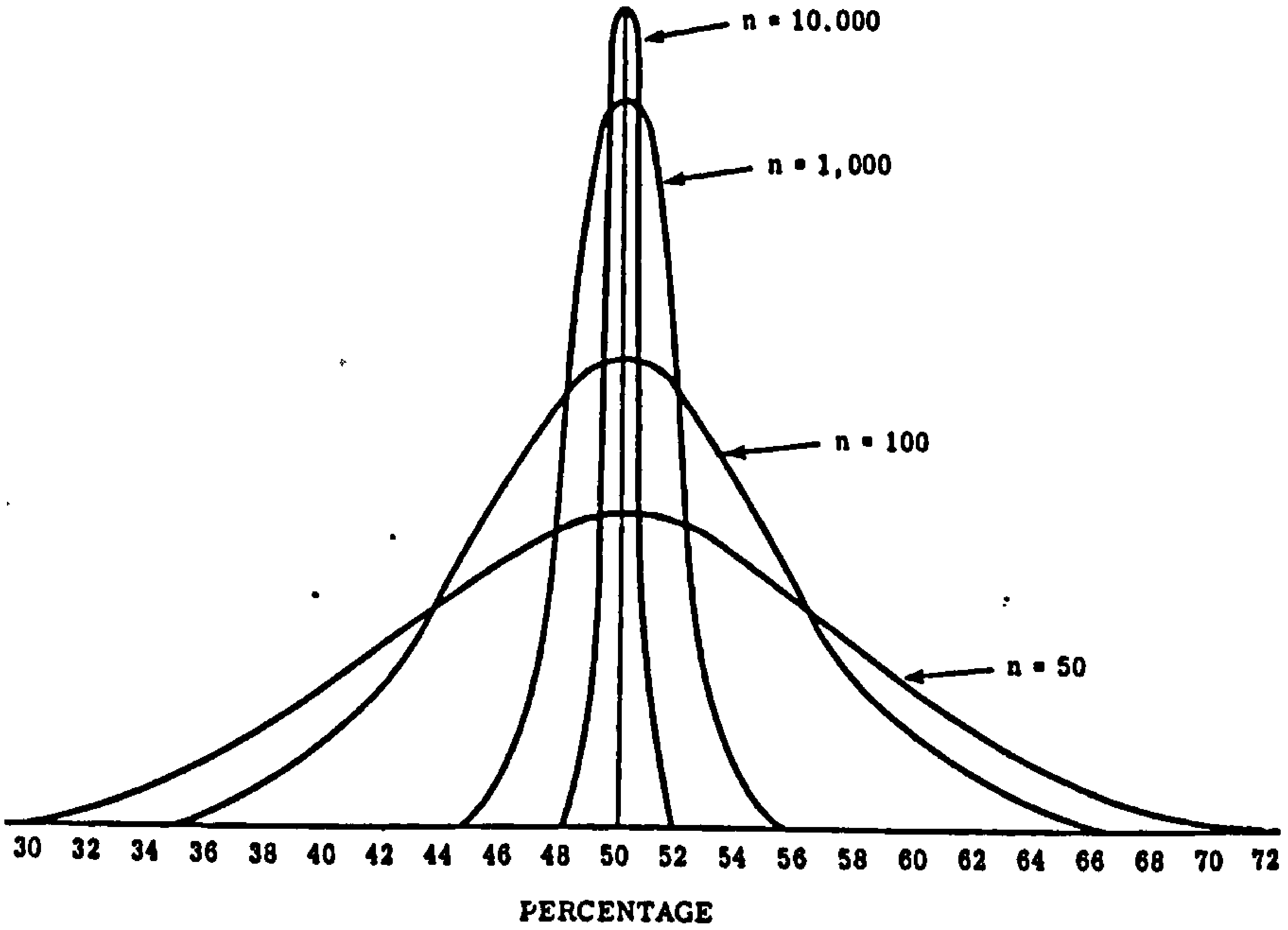


Figure 3.7 Comparison of distribution of different sample sizes
Source Hansen (1960, p. 48)

Note that, in the formula for standard deviation, the sample size has a great effect on the size of standard deviation. In fact, it is the most important variable. Figure 3.7 shows the comparative distribution of samples of 50, 100, 1,000 and 10,000 taken from a population with a true value of 50%. This can be easily proved by solving the formula with the different sample sizes. However, Figure 3.7 provides dramatic evidence of the importance of sample size.

According to equation (1), we can apply the equation in order to calculate the confidence level; a 95% confidence level is widely accepted as a reasonable limit (Barnes, 1956; Currie, 1975; Hansen, 1960; Heiland and Richardson, 1957; Lapin, 1997; Montgomery *et al.*, 1996). The equation for general use is then:

$$L = Z\sqrt{\frac{P(100-P)}{N}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where; L = Limit of error (%)

Z = value obtained from statistical tables depending upon the level of confidence required for the estimate (usually taken as 1, which corresponds to 68% confidence; 2, which corresponds to 95% confidence; 3, which corresponds to 99% confidence)

N = number of observations achieved

3.4.3 Calculation of Required Number of Observations

As pointed out, the larger the number of samples, the closer the result to the actual situation. However, the more samples that are taken, the more the time and costs required. Therefore, the optimum point is where the end use of the results and the accuracy of the study required meet. In order to determine the required number of observations for a particular study, three statistical terms: confidence limit, limit of error and proportion of the sample having (or failing to have) the characteristic that is being observed, must be specified. The first two terms are purely statistical, while the last is a physical condition and is noteworthy only because it affects the relationship between sample size and the values of the other two factors.

3.4.3.1 Confidence Limit

Confidence limit has to do with the dependability of the result. Thus, to say that the confidence limit is 95% is to say that purely as a matter of chance, the answer can be relied on 95% of the time or, conversely, that the answer may be wrong 5% of the time (one time in 20 determinations). The confidence limit is very often chosen according to the purpose of the sample: When human life is involved, the tolerable limit for acceptance may be 1 in 1 million, i.e., a confidence limit of 99.9999 percent. When sampling concrete blocks, on the other hand, to be wrong 1 time in 20, i.e., to have a confidence limit of 95% is acceptable. The higher the confidence limit, the less the chance of being wrong and the larger the number of observations or samples required. Therefore, if 100% confidence limit is to be obtained, every individual item must be inspected.

3.4.3.2 Limit of Error

Limit of error expresses the accuracy of the estimated result. It is the percentage variation on either side of the value obtained by sampling within which the results of true value can be expected to fall, given a prescribed confidence limit (limit of error will be discussed in more detail in 3.4.4).

3.4.3.3 Category Proportion

The proportion of the sample that is expected to have a given characteristic is a physical matter. It is the portion of the sample that is expected to have the characteristic being measured; it affects (mathematically) the size of the sample required to meet the pre-established confidence limit and limit of error. For example, if the grand average of percentage of the black beads is 9.75%, the category of black beads versus white beads would be 9.75% versus 90.25%, respectively.

Having identified those three statistical terms, the required number of observations for a particular study can be calculated from the equation below:

$$N = \frac{Z^2 P(100 - P)}{L^2} \qquad \text{.................(3)}$$

where; N = number of observations required

Z = value obtained from statistical tables depending upon the level of confidence required for the estimate (usually taken as 1, which corresponds to 68%

confidence; 2, which corresponds to 95% confidence and 3, which corresponds to 99% confidence)

P = average percentage of activity observed (usually assessed from preliminary study)

L = limit of error required (%)

If a power shovel is expected to be productive about 45% of the total working time and it is required to confirm this to ±3% of total time with 95% level of confidence then:

$$N = \frac{2^2 \times 45 \times (100 - 45)}{3^2} = 1100$$

Barnes (1956) wrote that it is advisable to recalculate N at regular intervals in order to improve the estimate of the number of observations to be taken. Suppose after the work-sampling study was carried out and 100 observations had been taken, a new calculation was made in order to check the original value for N. Assume that the result that the shovel was working is now 40% and, as a result, not working was 60%. This new information would enable us to recalculate the number of observations required.

$$N = \frac{2^2 \times 40 \times (100 - 40)}{3^2} = 1067$$

As the new number of observations required is down to 1,067 from the original 1,100, a more conservative approach is suggested; to maintain taking 1,100 observations. This is because some observations obtained may not be valid (to be discussed in 5.5 Control Chart), and, as a result, the accuracy of the study specified may not be achieved. In other words, in order to secure the level of accuracy required for a study, it is better to add 5% to the number of observations calculated.

As noted, within the given values of confidence level and limit of error, the category proportion determines the size of the sample to be examined. A smaller sample, therefore, is required as the category proportion falls away from the 50%-50% split in either direction. Table 3.6 illustrates that for proportional categories of 40%-60%, the sample size is about 4% smaller; and that for 30%-70%, 20%-80% and 10%-90%, the sample size are approximately 16, 34 and 64% smaller, respectively. A category proportion of 15%-85% (i.e., 35% from the 50-50 split) requires only half as many items in a sample as with a 50-50 split for the same confidence level and limit of error.

Table 3.6 Relationships among confidence limits, category proportions and number of observations

Category proportion percent	Number of observations required									
	95% level of confidence					99% level of confidence				
	Limit of error (%)					Limit of error (%)				
	1	3	5	7	10	1	3	5	7	10
1,99	891	44	16	8	4	891	99	36	18	9
2,98	784	87	31	16	8	1764	196	71	36	18
3,97	1164	129	47	24	12	2619	291	105	53	26
4,96	1536	171	61	31	15	3456	384	138	71	35
5,95	1900	211	76	39	19	4275	475	171	87	43
10,90	3600	400	144	73	36	8100	900	324	165	81
15,85	5100	567	204	104	51	11475	1275	459	234	115
20,80	6400	711	256	131	64	14400	1600	576	294	144
25,75	7500	833	300	153	75	16875	1875	675	344	169
30,70	8400	933	336	171	84	18900	2100	756	386	189
35,65	9100	1011	364	186	91	20475	2275	819	418	205
40,60	9600	1067	384	196	96	21600	2400	864	441	216
45,55	9900	1100	396	202	99	22275	2475	891	455	223
50,50	10000	1111	400	204	100	22500	2500	900	459	225

3.4.4 Accuracy of Work-Sampling Measurement

After the study has been completed, it is normally required to determine the accuracy of each of the estimates of different categories, in order to certify that the results are within the desired accuracy. This information can be obtained from equation (2), for the example discussed previously:

$$L = \sqrt{\frac{9.75-(100-9.75)}{2000}} = 0.66\%$$

As a result, we will now have confidence level of the three intervals:

$$\bar{x} \pm L \quad = \quad 9.75\% \pm 0.66\% \quad = \quad 9.09\%\text{-}10.41\%$$

$\bar{x} \pm 2L = 9.75\% \pm 1.32\% = 8.43\%\text{-}11.07\%$

$\bar{x} \pm 3L = 9.75\% \pm 1.98\% = 7.77\%\text{-}11.73\%$

Again, using the grand average of the data, 9.75%, as an estimate of the true percentage (assuming that we do not know that it is 10) and interpreting the statements above in a different form, the sample results calculated previously comply with these statements:

1. We can conclude with 68% confidence that the true percentage will lie between 9.09% and 10.41%;
2. We can conclude with 95% confidence that the interval 8.43% to 11.07% will include the true value;
3. We can conclude with 99% confidence that the true percentage will fall between 7.77% and 11.73%.

3.4.5 Control Charts and Audit Control

3.4.5.1 Control Charts

The control chart in work-sampling enables the analyst to inspect the data obtained by plotting the daily or cumulative results of the sampling study on the chart and to show graphically whether or not the process is in control. A typical control chart is shown in Figure 3.8, which is a graphical display of a quality characteristic, that has been measured or computed from a sample, versus the sample number or time.

According to Figure 3.8, the chart contains a centre line (CL) that represents the average value of the quality characteristic corresponding to the in-control state. Two other horizontal lines, called the upper control limit (UCL) and the lower control limit (LCL), are also shown on the chart. These control limits are chosen so that if the process is in control, nearly all of the sample points will fall between them. The sample points on the control chart are usually connected with straight-line segments, so that it is easier to visualise how the sequence of points has evolved over time. Furthermore, the three sigma (±3σ) limit is ordinarily used in determining the upper and lower control limits. This means that there are only three chances in 1,000 that a point will fall outside the limits due to a chance cause (Mears, 1995).

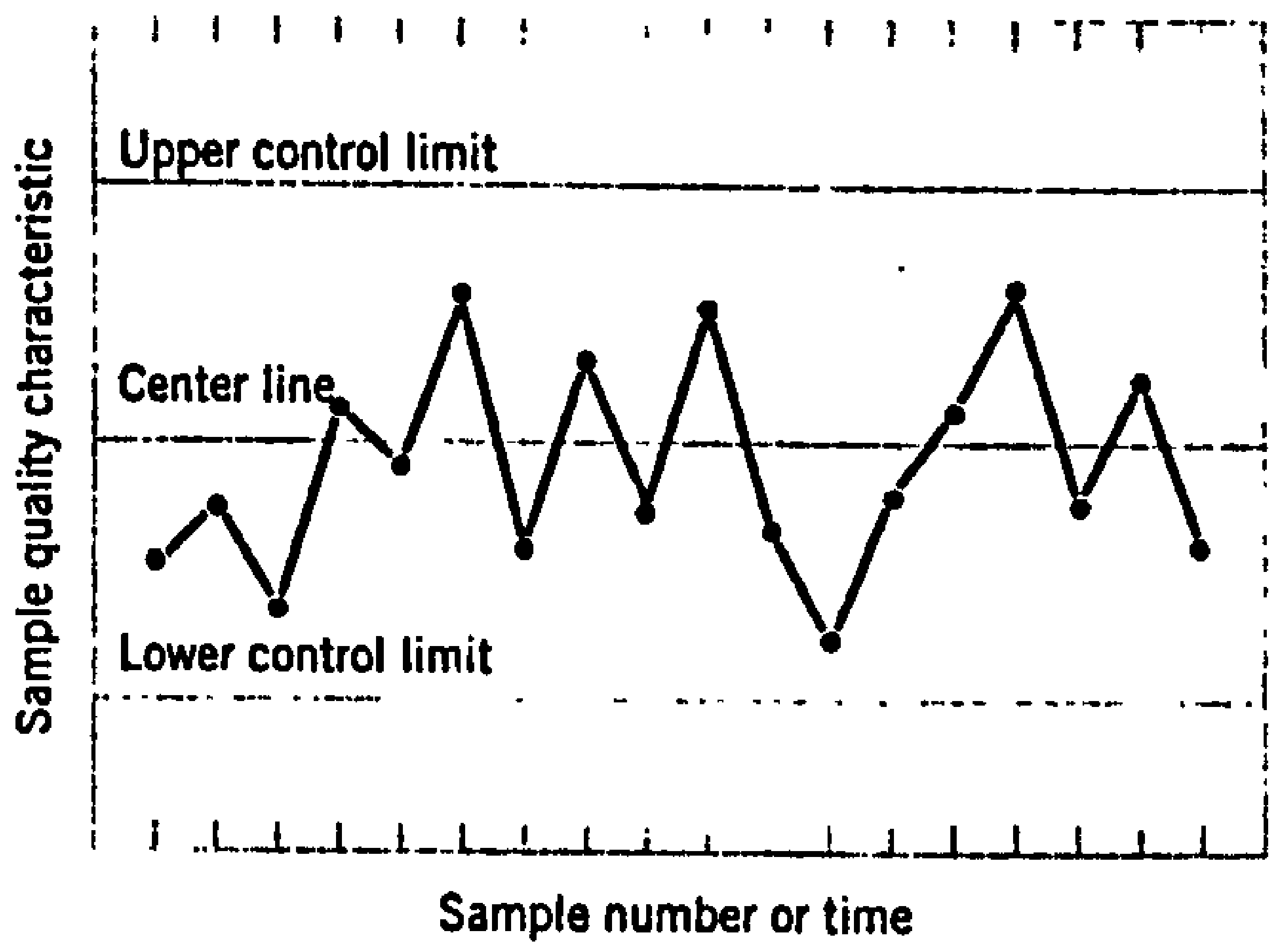


Figure 3.8 A typical control chart
Source: Montgomery, D. C. *et al.* (1996, p. 430)

In general, as long as the points plot within the control limits, the process is assumed to be in control and no action is necessary. However, a point that plots outside the control limits is interpreted as evidence that the process is out of control and investigation and corrective action are required to find and eliminate the assignable cause or causes responsible for this behaviour.

In addition, as there are 3 in 1,000 chances that a point will fall outside the limits, it can be safely assumed that when a point falls outside the limits there is a reason for it. For example, rain might stop craftsmen from working, so the sampling data taken in that period might show excessive idle time. This would be an assignable cause for the data being out of control for that particular period. Since this is an unusual occurrence, the data taken during the period of the rain would not be counted and the results of the study would be determined using the remainder of the data. This is the reason why the author suggested adding 5% to the number of observations obtained from equation (3).

In work-sampling, there are two main types of control charts usually involved, which are the *p* chart and the *c* chart (Heiland and Richardson, 1957). The applications of these charts are explained below.

3.4.5.1.1 Constructing the p chart

The *p* chart may be called the "chart for category proportions or control chart for fraction nonconforming," and is used to plot percentages found in a single category, or group of categories, in successive samples. This is the basic type of chart for analysis of results. A *p* chart is typically drawn at limit of $\bar{p} \pm 3\sigma_p$, with approximately 99% of the data lying within the lower control limit (LCL) and upper control limit (UCL) (Mears, 1995). Consequently, the control chart can be defined as follows:

$$UCL = \bar{p} + 3\sigma_p = \bar{p} + 3\sqrt{\frac{\bar{p}(100-\bar{p})}{n}}$$

$$CL = \bar{p} \qquad \text{..........(5)}$$

$$LCL = \bar{p} - 3\sigma_p = \bar{p} - 3\sqrt{\frac{\bar{p}(100-\bar{p})}{n}}$$

where; $\bar{p}$ = average percentage of a particular category or group of categories

n = number of samples in an observation round or number of observations per time interval

Table 3.7 Work-sampling results of craftsmen of a large site

Day of study	Total no. of observations	No. of observations "craftsmen idle"	Percentage of day "craftsmen idle"
1	100	21	21
2	100	30	30
3	100	36	36
4	100	24	24
5	100	18	18
6	100	27	27
7	100	69	69
8	100	27	27
9	100	24	24
10	100	27	27
11	100	27	27
12	100	24	24
	1200	354	

The results of a work-sampling study of the idle time for craftsmen of a large site are shown in Table 3.7. One hundred observations were made each day for a period of twelve consecutive working days. As the data show the craftsmen were idle for as little as 18% of day 9 and as high as 69% on day 13.

N = total number of observations = 1,200

n = number of daily observations = 1200 ÷ 12 = 100

p = average percentage of idle time = 354 ÷ 1200 = 29.5%

The formula for determining the control limits for $\bar{p}$ is:

$$\bar{p} = 29.5 \pm 3\sqrt{\frac{29.5\text{x}70.5}{100}} = 29.5 \pm 13.68$$

Therefore, we have UCL = 43.18, CL = 29.50, LCL = 15.82, which are exhibited in Figure 3.9.

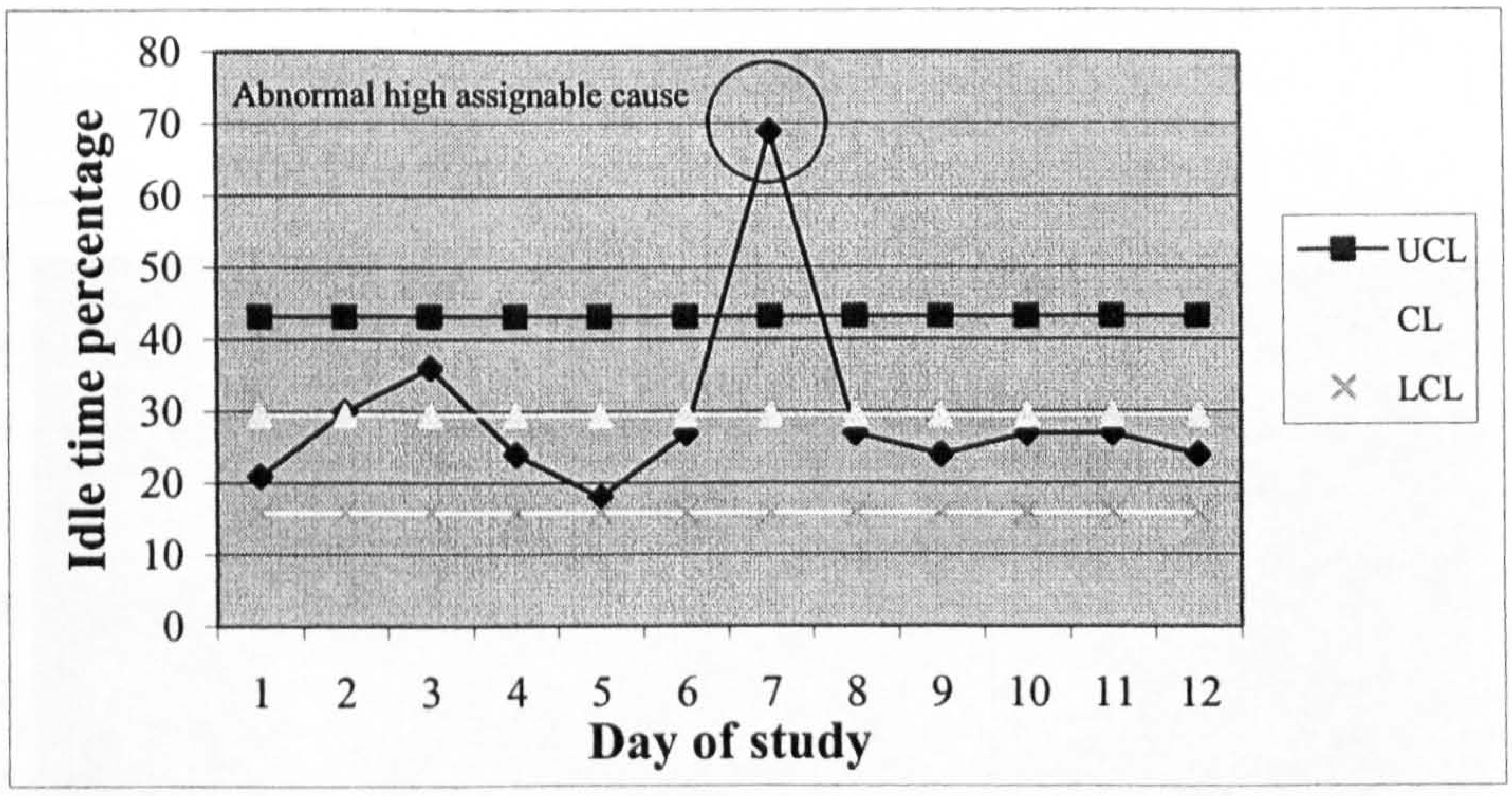


Figure 3.9 *p* chart for idle time of the craftsmen

The control chart in Figure 3.9 shows that all samples, apart from one (day 7), are in control. If the cause of unusual idle time percentage is assignable and is not cyclical, for example, it was raining the whole afternoon on that day, this sample could be discarded. If the cause, however, is assignable, but cyclical, like ready-mixed concrete delay delivery, the sample is required to be kept for computation of the next standard (section 3.4.5.2. will discuss patterns which indicate that a process is out of control).

3.4.5.1.2 Constructing the c chart

The *c* chart may be called the "chart for observations (or rounds of observation) per selected time interval." This chart is used after a study is well under way, in order to ensure randomness in the observation times and may be defined in two ways, which is observation rounds per time interval and observations per time interval. Just like the *p* chart, the chart is drawn on the same assumption that about 99% of the data will lie between the UCL and the LCL. The *c* chart can be defined as below.

$$\begin{aligned} \mathrm{UCL} &= \bar{c} + 3\sqrt{\bar{c}} \\ \mathrm{CL} &= \bar{c} \qquad \qquad ....(4) \\ \mathrm{LCL} &= \bar{c} - 3\sqrt{\bar{c}} \end{aligned}$$

where; $\bar{c}$ = an average number of observations round per interval

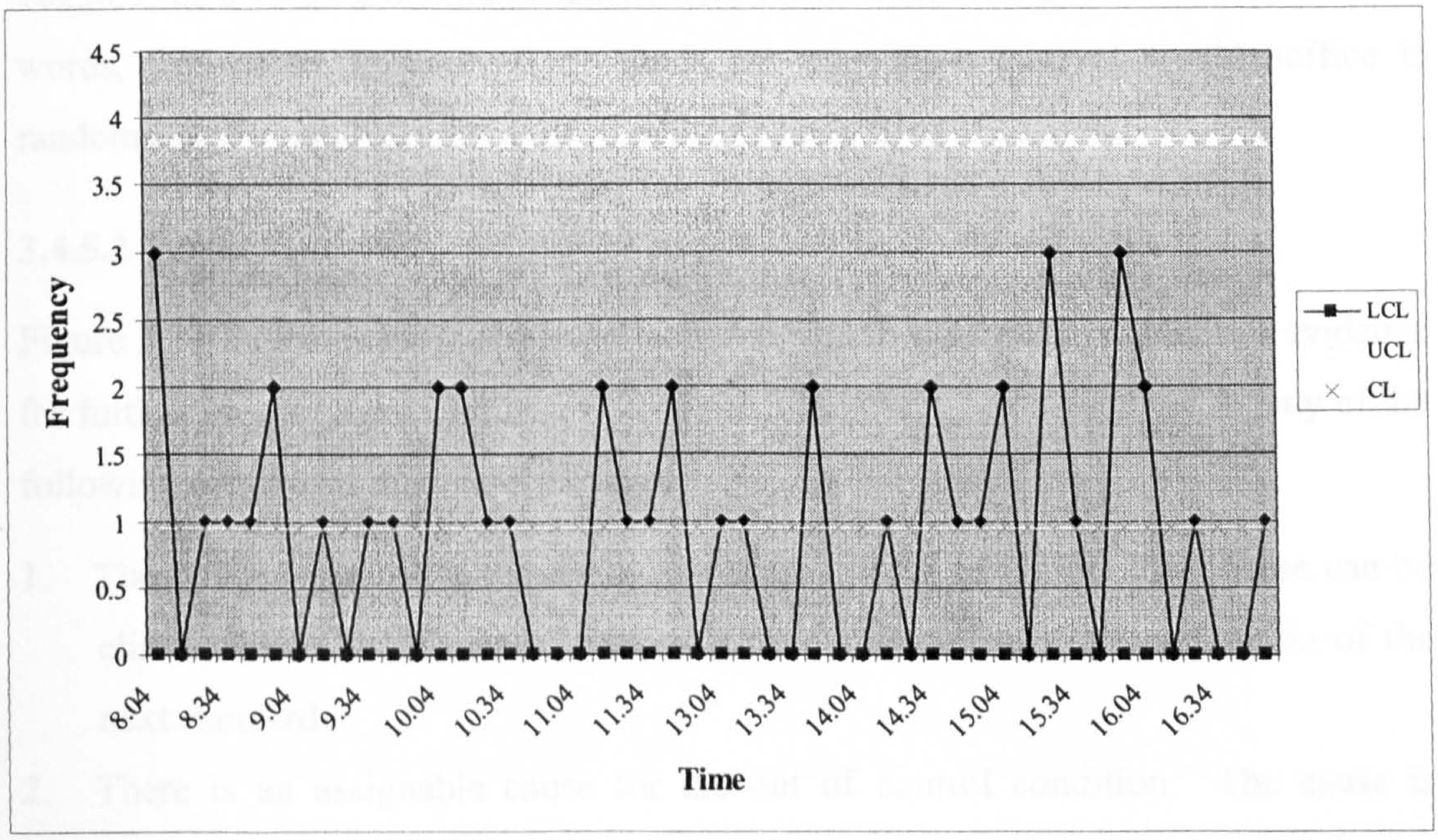


Figure 3.10 *c* chart for observation per 10-minute interval for 45 observation rounds

Miller, I. and Freund, J.E. (1977) explained that c charts are based on the Poisson distribution and that, in the Poisson distribution, the mean and the variance are the same. The standard deviation (sigma) is the square root of the variance and so that is why it is the mean $\bar{c}$ *plus/minus 3 times the square of sigma, as the square root of sigma represents the standard deviation.*

For Figure 3.10, the total number of rounds of observations was 45 and total number of craftsman observed was 10 each round, equalling 450 craftsmen observed. Using 48 intervals of 10 minutes each (to give 480 minutes = 8 hours working day), $\bar{c}$ based on rounds of observations is 0.94 (45÷48 = 0.94). The limit lines for $\bar{c} = 0.94$ are:

$$\bar{c} = 0.94 \pm 3\sqrt{0.94} = 0.94 \pm 2.91$$

Consequently, we have UCL = 3.85, CL = 0.94, LCL = 0, as exhibited in Figure 3.10. By inspection of these limits, it can be seen that if random times for rounds of observations are made and 10 craftsmen are observed per round, from 10x0.00 to 10x3.85, or 0 to 39 craftsman-observations per interval would be allowed. In other words, from 0 to 4 observation rounds per 10-minute interval would suffice if randomness for the distribution of rounds of observation is desired.

3.4.5.2 Audit Control

Figure 3.11 indicates basic abnormal patterns, which may be considered as evidence for further investigation. Hansen (1960) specified that upon investigation, any of the following conditions may be discovered:

1. There is an assignable cause for the out of control condition. The cause can be eliminated. Out of control data may be eliminated in the computation of the next standard.
2. There is an assignable cause for the out of control condition. The cause is cyclical, causing recurrence of the condition. It cannot be eliminated. Out of control data should be included in the computation of the next standard.

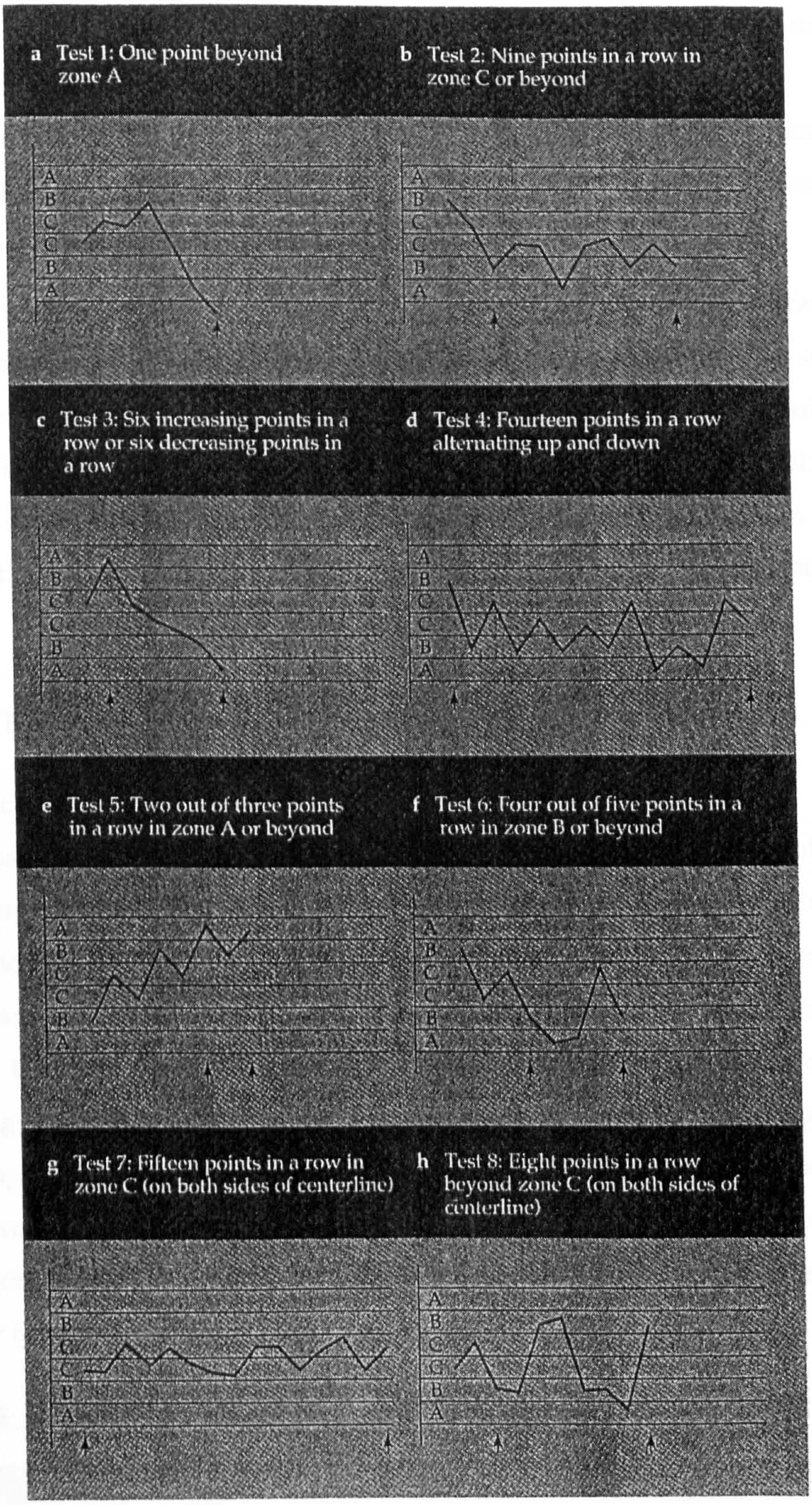


Figure 3.11 Examples of patterns indicating process out of control (C = ±σ, B = ±2σ and A = ±3σ)

Source: Keller and Warrack (1997, p. 967)

3. There is no assignable cause for the out of control condition. Assume that it is a chance variation and include it in the computation of the next standard.
4. The cause for the out of control condition can be attributed to faulty data collection or observation methods. Eliminate out of control data in the computation of the next standard.

There is a tendency to rush to investigate out of control evidence on the unfavourable side and cheer and leave alone the same type of evidence on the favourable side. It is nice to be optimistic, but, from a purely objective standpoint, any out of control condition is worthy of investigation. If a plot does fall on the favourable side, it should be investigated to see whether the data collection and observation methods are correct and, if they are, to see if the favourable evidence can be duplicated in the future.

3.4.6 Hypothesis Test

The application of work-sampling for this study will have two sections. The first section has the main objective of perceiving the current productivity problems of a participating site and then specifying ways to improve productivity. The second section, then, will detect if there is any productivity improvement, with regards to the response action from the first section. Consequently, it would be ideal if there is any indicator to confirm that there is significant productivity improvement, when comparing the productivity rate of the two sections. Fortunately, Montgomery (1996) suggested that this may be done by testing the hypothesis that the fraction nonconforming in the second section differs from the fraction nonconforming in the first section. Table 3.8 shows the alternative hypothesis and rejection criterion for a particular hypothesis test.

Table 3.8 Alternative hypothesis and rejection criterion

Alternative Hypotheses	Rejection Criterion
H_1: $p_1 \neq p_2$	$Z_0 < Z_{\alpha/2}$ or $Z_0 < -Z_{\alpha/2}$
H_1: $p_1 > p_2$	$Z_0 > Z_\alpha$
H_1: $p_1 < p_2$	$Z_0 < -Z_\alpha$

Nevertheless, the hypothesis for this investigation are:

H_0: $p_1 = p_2$

H_1: $p_1 > p_2$

Then, the test statistic for the above hypothesis is (Montgomery, 1996):

$$Z_0 = \frac{\bar{p}_1 - \bar{p}_2}{\sqrt{\bar{p}(100-\bar{p})\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \qquad \text{...............(6)}$$

where; p_1 = the average ineffective time of the first section (%)

p_2 = the average ineffective time of the second section (%)

$$\bar{p} = \frac{n_1\bar{p}_1 + n_2\bar{p}_2}{n_1 + n_2}$$

For example, a first work-sampling study initiated on a construction site specified that idle time was 52%, and some productivity problems were revealed. As a result, the management reacted and responded to the problems, in order to alleviate them. After that, the second work-sampling was carried out to reflect the effectiveness of those actions, where 46% idle time was reported. In addition, for both occasions of the study, 400 observations were taken. The management would like to know if they could have 95% level of confidence that their idle time had decreased.

The hypothesis test can be done as follows:

1. The parameters of interest are p_1 and p_2, the proportion of idle time.
2. H_0: $p_1 = p_2$
3. H_1: $p_1 > p_2$
4. $\alpha = 0.05$ (95% confidence level)
5. Reject H_0: $p_1 = p_2$ if $Z_0 > Z_{0.05} = 1.65$
6. The test statistic is:

$$\bar{p} = \frac{n_1\bar{p}_1 + n_2\bar{p}_2}{n_1 + n_2} = \frac{(400x52)+(400x46)}{400+400} = 51$$

$$Z_0 = \frac{\bar{p}_1 - \bar{p}_2}{\sqrt{\bar{p}(1-\bar{p})\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} = \frac{52-46}{\sqrt{51x(100-51)\left(\frac{1}{400}+\frac{1}{400}\right)}} = 1.70$$

Conclusion: Since $Z_0 = 1.70 > Z_{0.05} = 1.65$, we reject the null hypothesis (H_0). There is strong evidence to support the claim that the idle time of the site has been decreased. In other words, the management can say with 95% level of confidence that the productive time of the site has increased from 48% to 54%.

3.5 The Implementation of Work-Sampling

3.5.1 Literature Review of Applications of Work-Sampling in the Construction Industry

Stevens (1976) developed special recording forms, which can be read directly into an optical reader, to speed up the work of the analysis of sampling of labour expended on site for various categories of work recorded by up to 1,000 samples daily. The reader transcribes the hand-marked forms into punched paper tape suitable for direct presentation to a computer. His article also briefly explains the practical aspects of the work-sampling technique and concentrates on the snags that occurred when using these forms in the field and how these may be overcome. Furthermore, the author identified the type of information obtained from the analysis and explains how this is presented by the computer.

Borcherding (1978) examined factors that influence the productivity of craftsmen and foremen on large construction projects, through a written questionnaire. However, a section of his paper indicated an overall average effective work percentage for United State power plant construction as being 32% and he further gave a list of effective time percentages for different trades, which are depicted in Table 3.9.

Table 3.9 Lists of the percentage of effective time for different crafts

Source: Adapted from Borcherding (1978, p. 252)

Trades	% of effective time	Trades	% of effective time
Teamsters	44%	Welders	28%
Carpenters	42%	Pipefitters	28%
Labourers	41%	Electricians	28%
Oper. Engineers	39%	Boilermakers	27%
Millwrights	32%	Insulators	26%
Ironworkers	31%		

The author, furthermore, believed that 45%-55% effective time or better is usually achieved on commercial buildings and other less complex projects, although 100% productive work is not possible, and he revealed the percentage of effective time of various projects in Austin, Texas, that are shown in Table 3.10.

Table 3.10 Percentage of effective work of projects in Austin, Texas, from 1972-1977

Source: Adapted from Borcherding (1978, p. 252)

Projects	%	Projects	%
Three Span Bridge Project	48%	University Building (Graduate Education)	41%
University Building (Swimming Pool)	47%	University Building (Drama Addition)	44%
University Building (Graduate Library)	45%	University Building (Law School Addition)	50%
University Building (Fine Arts Complex)	50%	University Building (Chemistry Addition)	48%
State Bar Association Building	58%	Bank Building	43%
Apartment Complex	35%	Elevated Interstate Highway	40%
Parking Garage	41%	Custom Residence	38%
Hospital Addition	45%	Mariott Hotel	53%
Hospital Addition	46%	Sewerage Treatment Plant	40%

Horner *et al.* (1987) quantified the relationship between productivity and the factors, which affect it in order to optimise productivity. The measurement techniques employed are direct measurement and work-sampling. A brief detail of work-sampling application was described where, on 6 sites, the number of men working and not working was recorded on hand-held counters at random intervals, with at least 1750 observations being taken, which allows 95% confidence and an accuracy of ±2%.

Handa and Abdalla (1989) concentrated on demonstrating the correlation between the work-sampling percentages, unit rate productivities and the learning rates of global activities through the development of productivity projection models (for each data set of work-sampling, a maximum number of 400 observations were recorded for 95% confidence and ±5% degree of accuracy). Thus, it is possible to quantify productivity and learning rates directly through the simple technique of work-sampling. The authors concluded that the productivity models can be a powerful management tool and should be applied to the construction industry.

Thomas and Holland (1980) carried out a comparison of eight work-sampling programs to illustrate some general pitfalls of the studies implemented on large construction projects and found that many work-sampling programs fail to meet management expectations because activities categories, data collection techniques, intervals between studies and data analysis procedures are incompatible with the program objectives. Consequently, the authors emphasised that each of these aspects must be designed around the objectives of the study and the desired results that management hopes to achieve with the information gathered. Additionally, they recommended collecting data by concentrating on specific crews.

Thomas (1981) carried out a work-sampling study at the Forked River Nuclear Generating Station and came up with a number of conclusions. This author believed that work-sampling could be used effectively to isolate problem areas, but cost, schedule savings, or both, will result only when the systems concept is accepted and applied vigorously. Although Thomas introduced two approaches for data collection procedures, which are the tour approach and the crew approach, he recommended the crew approach, as it offers the following benefits:

1. The crew approach permits the study to be focused on only those critical or near critical activities, which are considered to be important to the construction schedule.
2. All crewmembers can be accounted for by establishing a no contact category.
3. Because unique categories are established by studying the work patterns of each crew, it is possible to provide much more descriptive data.
4. Because the work analyst is located in the immediate work vicinity on a continuous basis, the observer is able to develop a perception of the difficulties encountered by the craftsman. Thus, the observer can serve in a capacity other than just a number collector.

Thomas *et al.* (1982) identified guidelines and principles for planning and implementing a work-sampling program and suggested these steps should be done as a joint venture between owner, contractor, construction manager and labour. The authors classified work-sampling application into three major groups, planning philosophy, data collection and data analysis. According to their experiences, four major principles should guide the manager in planning and implementing a work-sampling study, which are:

1. The program must be carefully planned and implemented. Establishing objectives is perhaps the most important step. The design of the program, like the selection of sampling categories, should be a reflection of the management's objectives.

2. The program must be closely monitored and revised to reflect changes in the physical characteristics of the project or changes in the needs of management.

3. There must be a strong element of leadership accompanied by a good understanding of the limitations of work-sampling. The study leader must always be cognisant of the program objectives.

4. The success of the program will be measured by the extent to which problems are isolated and corrected.

These authors, moreover, revealed some awareness of how to prevent the demise of the program. They are:

1. All parties should be informed well in advance of the impending study.

2. Sloppy or secretive data collection must be avoided; observers should be open and communicative with the craftsmen and supervisors.

3. In data analysis, the presence of errors should always be recognised. Playing a numbers game with the data will only lead to the downfall of the program. Perhaps the most difficult aspect of data analysis is the implementation of meaningful results.

4. It should be recognised that the contractor will normally be responsible for any changes and his involvement must be sought at an early stage.

Thomas and Daily (1983) described and compared three methods of measuring the performance of a five-man ironworker crew placing reinforcement, namely; work-sampling, group timing technique and five-minute rating. By gathering data from a time-lapse film, the three methods can be compared for the same operation. Work-sampling is shown to provide the level of direct work and important information about the characteristics of delays. Considerable time is lost because of waiting for materials and for instructions.

The group timing technique provides production data that is very different from work-sampling. It is suggested that this technique can be used to validate estimating data regarding cycle times. It is also shown how a crew balance index can be determined which will allow the manager to evaluate if the crew size is appropriate for the way the work is being performed. The five-minute rating seems to be a quick estimator of the delay time of a crew, however its reliability is not as good as that of the other two techniques. The advantage of the five-minute rating is its simplicity and ease of application.

Thomas *et al.* (1984) presented theoretical aspects to evaluate the adequacy of work-sampling as a surrogate productivity measure. A 10-week study is described in which work-sampling data were gathered simultaneously with earned value information for a 10-man, small-bore pipefitter crew. The authors believe that if earned value data are available, work-sampling data are unnecessary, nevertheless, in the long run, work-sampling is a simpler, more efficient data collection system, as long as its limitations are recognised. Then, they concluded that work-sampling can be used as a reliable estimator of construction productivity provided the definition of direct work is narrowly defined.

Liou and Borcherding (1986) collected 45 work-sampling data points from 11 nuclear power projects and 4 fossil fuel power projects and the results confirmed that, firstly, work-sampling is a good indicator of labour productivity, and, secondly, work-sampling information is useful, as a predictor in the productivity projection model.

Olomolaiye *et al.* (1987) used work-sampling techniques on 7 construction sites in Nigeria to determine how the working day was being utilised by craftsmen in bricklaying, joinery and steel fixing trades. Unproductive time was found to be 40% for both bricklaying and joinery and 39% for steel fixing trades. This article focused only on two categories, absence time and attendance time, with definition of each category provided.

A performance measurement tool called "CALIBRE" was developed by Building Research Establishment (BRE, 2004). This tool employs an observer to observe the site at regular intervals to record the task being carried out by each craftsman. The purpose is to reduce the ineffective utilisation of labour and materials (Cain, 2004). Accordingly, it seems that CALIBRE and work-sampling have the same approach, where data are collected at a designated interval. However, it is obvious that CALIBRE require more extensive data than work-sampling, as it collects data on labour and material usage.

Drosell (1980) and Stull (1982) specified the successful implementation of the technique on a $3-billion nuclear power plant that Mississippi Power & Light Co. (MP&L) was building near Vicksburg, USA. The plant was constructed by the San Francisco-based Bechtel Power Corporation.

Before the program was started, a consultant retained by MP&L had found, based on work-sampling, that the direct work component on the project was below 30%. In order to carry out a work-sampling study, Bechtel and the utility set up a nine member production engineering team that represented both the owner and the contractor. This group carried out work-sampling studies at the job site to ascertain waiting time and other non-productive activities. Working with observations and input from craftsmen, superintendents and field engineers, the group analysed the crew's activity to pin down underlying causes of delays.

Bechtel anticipated $5 million in savings by the end of 1979 as the result of the program starting on the power plant earlier in the year. After the investigations were carried out for 2 years, the percentage of direct work, as measured on the job, had almost doubled, when compared with below 30% in 1978, which provided Bechtel with a significant saving.

Rogge and Tucker (1982) evaluated the usefulness of foreman delay surveys (FDS) for performance measurement and productivity improvement at a nuclear plant construction site, in comparison with concurrent production rates and work-sampling technique and concluded that:

1. Work-sampling indicated general decreases in "waiting," while FDS reported general decreases in delays.

2. A FDS is easier, more economical to implement and less threatening to the workforce than a work-sampling program. However, a work-sampling study provides more detail and complete information. Both systems accomplish productivity improvement through the generation of problem lists, and implementation of solutions.

3. Both work-sampling and FDS are effective tools and should be employed. Their applications are different; thus it is possible to utilise both on the same site.

Benjamin (1987) compared the results of continuous work-sampling studies made during the construction of the Callaway and Wolf Creek nuclear power plants with the results of similar studies made at other nuclear plants and with industry averages of direct craft activity and concluded that:

1. It is impossible, in general, to compare the work-sampling results of one plant with those of another because the categories are differently defined. In addition, although they may be using the same categories, different observers will have different biases.

2. As there are differences in plants at various stages of completion, comparisons of the work-sampling results of one plant with those of another are meaningless.

3. It is not possible to compare direct craft activity at one stage of completion with that at another stage of completion, since there are changes in the nature and complexity of the work as the job progresses.

4. The ways work-sampling observations are analysed and reported does not provide job management with the information needed to detect and correct productivity problems. Reports are not timely and analysis is superficial.
5. The results of work-sampling do not have the statistical validity generally claimed, as the technique as it is applied in the field violates the assumptions upon which it is based.

Heinze (1984) emphasised practical applications of work-sampling and clarified the actual design and execution of the program such as observer selection, activity categories, computer application and analysis of study results. This author specified that the program must be carefully planned for specific objective. Observers should be encouraged to openly communicate with the craftsmen and their supervisors. The selection of sampling categories must be compatible with the program objectives. Sampling must be collected during the entire day (or shift). The time of commencement, duration and path of tours must be designed for maximum randomness. Data analysis should result in the implementation of a meaningful follow-up program to create the actions for improvement.

Peer (1986) introduced an improved fix-interval work-sampling technique, which has been shown to be highly effective in most building operations, based on the author's extensive experience of the application of the different work measurement techniques. The technique entails economy in writing work during recording and compilation. The whole working process is recorded in chart form, thereby providing improved insight into the interrelationships of the observed facts. Skilled and unskilled labour are observed separately, and the production efficiency rating is readily incorporated, if desired.

Baxendale (1987) reviewed the derivation of work-sampling from activity sampling methodology together with the rules for taking samples. Particular interest is taken in non-repetitive activities for analysis and elimination. Case studies are given showing examples of both good and bad site organisation practice. Studies range over groundworks, superstructure, cladding and finishes. For example, categorising work for individual operatives and large gangs, is included with sampling observations made at intervals of between half a minute and two minutes.

Emsley and Harris (1993 and 1990) combined work-sampling and time study to observe the precast concrete and structural steelwork erection phases of thirteen medium sized framed buildings. In these studies, work-sampling observations were made at one-minute intervals, on both the erection gangs and the crane used in the operation, and each observation rated on a scale of 50 to 125, according to the British Standards Rating Scale. Finally, the basic operation time was established and the authors indicated that both techniques are appropriate and effective tools in determining productivity data.

Jayawardane *et al.* (1995a and b) conducted a more sophisticated approach than general work-sampling on brickwork and blockwork, by including assessing performance level, based on the standard rating scale, when observations are taken. Since, the primary objective is to establish standard times, the investigation was carried out on individual operations with a relatively small interval of one minute. The study focused on two bricklayers and one labourer and, finally, the authors concluded that work-sampling is sufficiently accurate for this purpose.

3.5.2 Critics of the Current Work-Sampling's Steps and the Improvement

In the construction industry, the steps of implementation of work-sampling have not yet been completely specified elsewhere, neither in textbooks or articles, although the technique has been widely applied and mentioned for a period of time (Jayawardane *et al.*, 1995a and b; Emsley and Harris, 1993 and 1990; Thomas, 1991; Thomas *et al.*, 1990; Handa and Abdalla, 1989; Baxendale, 1987; Benjamin, 1987; Horner *et al.*, 1987; Olomolaiye, 1987; Liou, 1986; Peer, 1986; Heinze, 1984; Thomas *et al.*, 1984; Thomas and Daily, 1983; Rogge and Tucker, 1982; Stull, 1982; Thomas *et al.* 1982; Thomas, 1981; Drosell, 1980; Thomas and Holland, 1980; Steven, 1976).

For example, although Randolph Thomas published a series of articles about work-sampling studies between 1980 and 1991, none of his papers clearly identified the steps. His publications generally divided work-sampling application into three main parts, namely; Planning philosophy, Data collection and Data analysis. These will be referred to as "Prepare work-sampling, Perform work-sampling and Evaluate and present results," respectively, later in this chapter. He provided suggestions, recommendations and explanation of pitfalls that are useful for the implementation of work-sampling, but still no particular steps to carry out this technique are provided.

Similar to the articles, a number of textbooks about construction management and construction productivity improvement (Nunnally, 1998; Olomolaiye *et al.*, 1997; Oxley and Poskitt, 1996; Harris and McCaffer, 1995; Horner and Talhouni, 1995; Pilcher, 1992; Oglesby *et al.*, 1989; NEDO, 1989; Alfeld, 1988; Geary, 1970) have not provided a clear approach of how to undertake a work-sampling study from the beginning to the end use of the results. Basically, these textbooks mainly describe data collection, but rarely describe planning philosophy and data analysis. However, when compared generally with the articles, textbooks clarify the implementation steps more clearly. Since work-sampling procedures specified in the textbooks are similar, three crucial references will be discussed below.

NEDO (1989), firstly, explained the broad idea of planning, documentation and observations. This report provides useful information for some particular steps of implementation, such as the period of the study, the study team and communication These will be referred to as "1.4 Set the study span, 1.6 Select and train personnel and 1.7 Announce the study," respectively, later in this chapter. It also provides examples of observation forms and the role of the study leader. Unfortunately, NEDO did not present the idea in a clear form of application stages.

Secondly, Harris and McCaffer (1995) briefly described eight work-sampling procedures, which are the preliminary survey, identification of the sample, classification of categories, preparation of a suitable observation sheet, informing everyone, determining the observation times, recording the data and analysing the data. The procedure specified is very clear, in respect of the application steps, however details of each individual application stage are insufficiently clarified.

Finally, Olomolaiye *et al.* (1997), who provided most details with regards to the application of a particular step, when compared with other literature, identified six stages of carrying out a work-sampling study. These stages comprise establishing the objectives, carrying out a preliminary survey, preparing suitable observation sheets, carrying out a pilot study, establishing the number of observations, and calculating the results. These steps were obviously classified, in terms of procedure, nevertheless the identified stages are not that complete.

According to the literature review regarding to the steps of implementation of work-sampling in the construction industry, the procedure can be as shown in Figure 3.12.

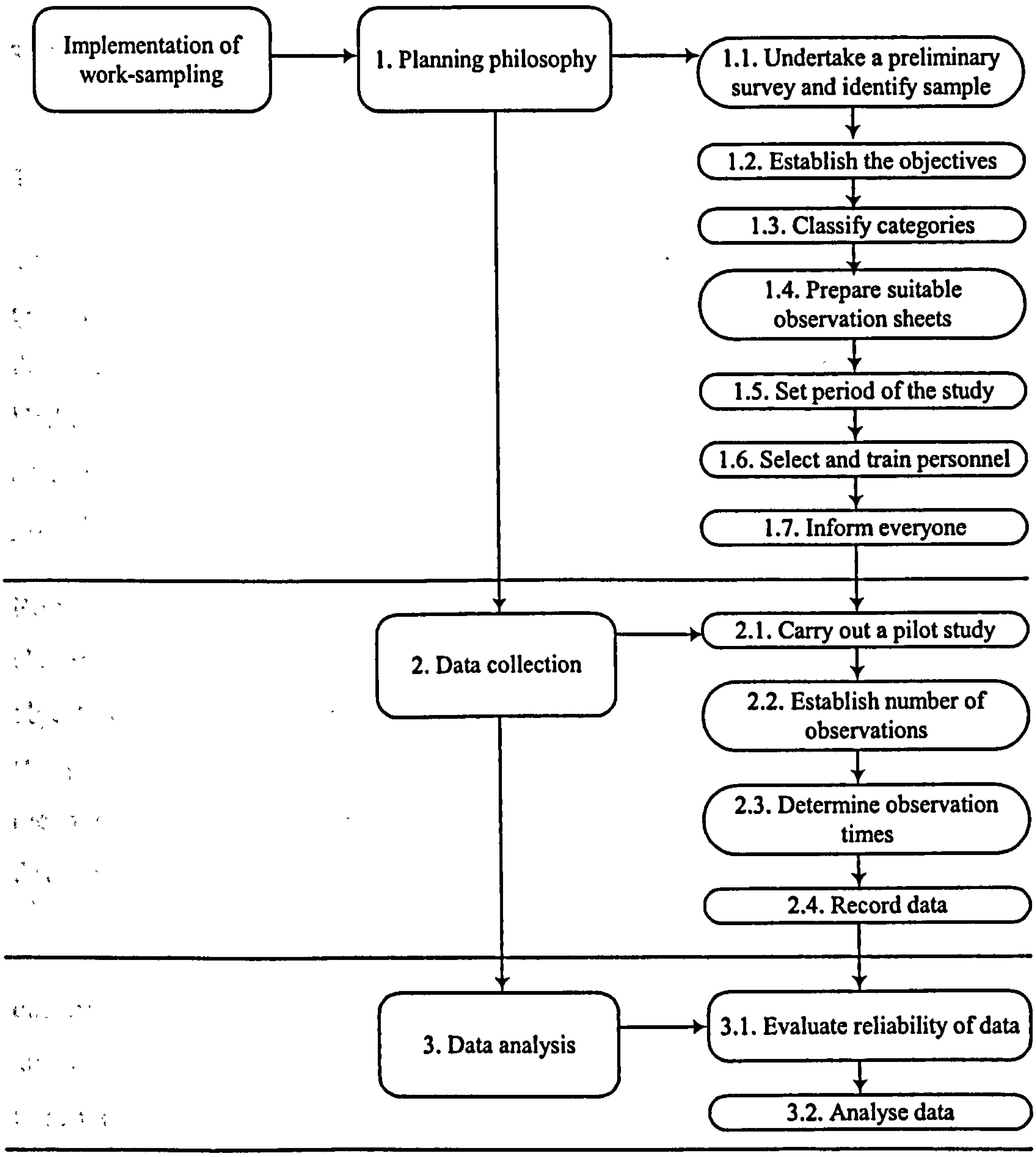


Figure 3.12 Current implementation steps of work-sampling in construction

Referring to Figure 3.12, it seems quite practical in respect of the application steps. Nevertheless, the author strongly believes that the current procedure can be improved to be more practical and more rigorous, since:

1. Validity of the data has not yet been explained;
2. More details of how to carry out every individual stage are required, so the technique can be undertaken properly, particularly in respect of the planning philosophy and data analysis;
3. The roles of the parties involved and choices of observer have not yet been clarified;
4. Sampling procedure and the rules of observation have not yet been specified.

To overcome these problems, therefore, further literature about work-sampling in general must be surveyed. The author focuses mainly on the manufacturing industry, the origin of the technique. Fortunately, Richardson (1976), Hansen (1960) and Heiland and Richarson (1956) provided the answer for most of the four problems, apart from an explanation of sampling procedure. However, Moder (1980) could provide the answer for the last question, which will be discussed below.

Richardson (1976) included twelve stages of application of work-sampling, without classifying into three main steps (i.e. planning philosophy). These steps are set the objectives, select the sample, select the measures of output that are the subject of the study, define the period of study, select the observer, formulate categories, determine the number of observations, announce the study, develop the observation times, develop the necessary forms, make a preliminary study and record the data.

Although the procedures may be organised slightly differently from those used in the construction industry (see Table 3.11), eleven steps duplicate the current procedure and the remaining one step can be reasonably added to Planning philosophy to improve the current procedure, which is to select the measures of output that are the subject of the study (this will be referred to as "1.4 Record correlated quantitative measures" later in this chapter), as this would provide evidence for improvement. Consequently, Planning philosophy now has six sub-stages (it previously had five).

Richardson, in addition, provided full practical details of all procedures specified, which also clarifies the second problem and the choice of observers in the third problem discussed above.

Hansen (1960) distinctly classified a work-sampling study into two primary groups, planning the sampling study and preparation for sampling work, with details of implementation of each step. Planning the sampling study includes defining the objectives of the study, setting the time period (study span), breaking down and defining the work and the delay elements. Meanwhile, the preparation for sampling work comprises making a preliminary estimate of the element percentage, determining the required number of observations, establishing the observation times and designing of the observation record.

Although this author clearly established only two prime steps, he described some details of human relations (e.g. keep your people informed and who should carry out the study), selling work-sampling and evaluating results, especially audit control, although, unfortunately, an explanation of how to validate the data has not been provided. However, an awareness of the importance of the validity of data, the first problem, has been raised.

Heiland and Richardson (1957) divided work-sampling implementation into three major stages, preparing work-sampling, performing work-sampling and evaluating and presenting the results of work-sampling, which included twelve steps in total. Preparing work-sampling consists of deciding the objectives, recording quantitative measures so that the results may be correlated and the selection and training of personnel. Performing work-sampling comprises classifying categories, designing the necessary forms, developing observation times and recording data. Evaluating and presenting the results of work-sampling includes evaluating the validity of the data, evaluating the reliability of the data, presenting and analysing the data and planning for future studies. There is no doubt that ten out of the twelve steps identified repeat the improved steps of implementation (see Table 3.11).

These authors, fortunately, have mentioned the validity of data that clarifies the validity of both data recorded and observation times, which can fulfil the first problem. Therefore, this step must be inserted in the last main step, data analysis. Furthermore, planning for future studies included in their procedures should also be put in the final major step, since this step will complete the loop of implementation in terms of a series of studies. As a result, the improved implementation steps of work-sampling has included another two steps in its final crucial stage, data analysis.

Like Richardson (1976), Heiland and Richardson (1957) explained the full application details of each step. However, the authors did provide more information with regard to the roles of the parties involved such as management and observer, choices of observer and rules of observation, which obviously explain the third and fourth problem, apart from the sampling procedure.

Moder (1980) discussed five strategies for the adoption of observation intervals in a variety of work-sampling situations in order to establish an appropriate observation approach for a particular study (this will be explained in 3.5.4.5 Develop observation times). The problem of sampling procedure (the fourth problem), consequently, can be now overcome. These procedures will be included in 3.5.4.5, since a particular choice of the procedure will have an effect on the development of observation times. In other words, the approach for adoption of observation intervals has to be specified before observation times can be developed.

Brisley (1952) interestingly introduced six implementation stages of work-sampling, which are to sell work-sampling, define the objectives, make an observation recording form, select the frequency of observation, estimate the number of observations and the define categories. The selling of work-sampling, which functions like an introduction of the technique to an organisation, has not yet been included, but will be added in the first main step, Planning philosophy, since without a proper introduction, the parties involved might be reluctant to accept and might question the effectiveness of a work-sampling study.

Up to now, it is remarkably clear that the four weak points of the current procedure can be completely overcome. Theoretically, at the moment, steps of implementation of work-sampling are ready for any application, however different authors have arranged them into different application stages, although the steps are identical or similar. Nevertheless, all potential steps, including their references, are demonstrated in Table 3.11. Please note that the three main steps, Planning philosophy, Data collection and Data analysis, have now been renamed as Prepare work-sampling, Perform work-sampling and Evaluate and present results, respectively.

Table 3.11 Potential steps of work-sampling implementation and their references

Potential steps*	References'				
	A	B	C	D	E
1. Prepare work-sampling					
Sell work-sampling				1	
Undertake a preliminary survey					1
Establish the objectives	1	1	1	2	2
Classify categories	6	3	5	6	3
Set the study span	4	2			5
Record correlated quantitative measures	3		2		
Select and train personnel	5		3		6
Announce the study	8		4		7
2. Perform work-sampling					
Select sample	2				1
Make preliminary study	11	4			8
Determine number of observations	7	5		5	9
Design necessary forms	10	7	6	3	4
Develop observation times	9	6	7	4	10
Record data	12		8		11
3. Evaluate and present results					
Evaluate validity of data			9		
Evaluate reliability of data			10		12
Present and analyse data			11		13
Plan for future studies			12		

*where appropriate, similar steps are grouped and/or renamed; 'number indicated in the table refers to the steps specified by that particular reference; A = Richardson (1976); B = Hansen (1960); C = Heiland and Richardson (1957); D = Brisley (1952); E = current procedures gathered from literature in construction industry.

Referring to Table 3.11, it is obvious that there is no consensus in respect of the ordering of the procedures. Therefore, the author needs to prudently investigate these steps and rearrange them in order to construct a proper working order.

Firstly, the undertaking of a preliminary survey will not be included in the improved procedure. Since the primary objective of the survey is to perceive general problems, any specific problems can be raised and discussed during the establishing of the objectives (to be discussed in 3.5.3.2), so the preliminary survey is not required. Selecting the sample, nevertheless, which is previously included within the undertaking of the preliminary survey, will be removed to the first step of Perform work-sampling, since it would be more appropriate to select the sample (craftsmen), after they have been informed about the study.

Secondly, designing the necessary forms will be reclassified from Prepare work-sampling to Perform work-sampling (immediately after determining the number of observations). As, after the preliminary study (2.2 in Figure 3.13), recategorisation may be required, it is wiser to wait until the categories have been finalised, then the forms can be designed.

A subgroup of evaluating the validity of data, is to ensure the randomness of observation times. If the randomness is invalid, the data recorded will be invalid too. The author, therefore, believes it is more practical for the randomness to be checked before their application. As a result, it is reasonable to separate the validity of observation times from evaluating the validity of the data and to put it immediately after the developing of observation times, and before recording data. Finally, the steps of work-sampling implementation are improved and shown in Figure 3.13. Whilst Figure 3.13 is presented as a linear process, in reality, it will be iterative one. Where feedback loops are shown in dotted lines, the sequence of actions will bounce back and forward to find a resolution

3.5.3 Prepare Work-Sampling

3.5.3.1 Sell Work-Sampling

Although the concept of work-sampling is simple, many managers and supervisors may need more than 5 minutes introduction to be convinced of its value. Operatives will not buy a brief explanation and may be reluctant to admit that work-sampling can give a true picture without watching the operation continuously (Brisley, 1952). Therefore, it is essential to convince management and labour of the value of work-sampling.

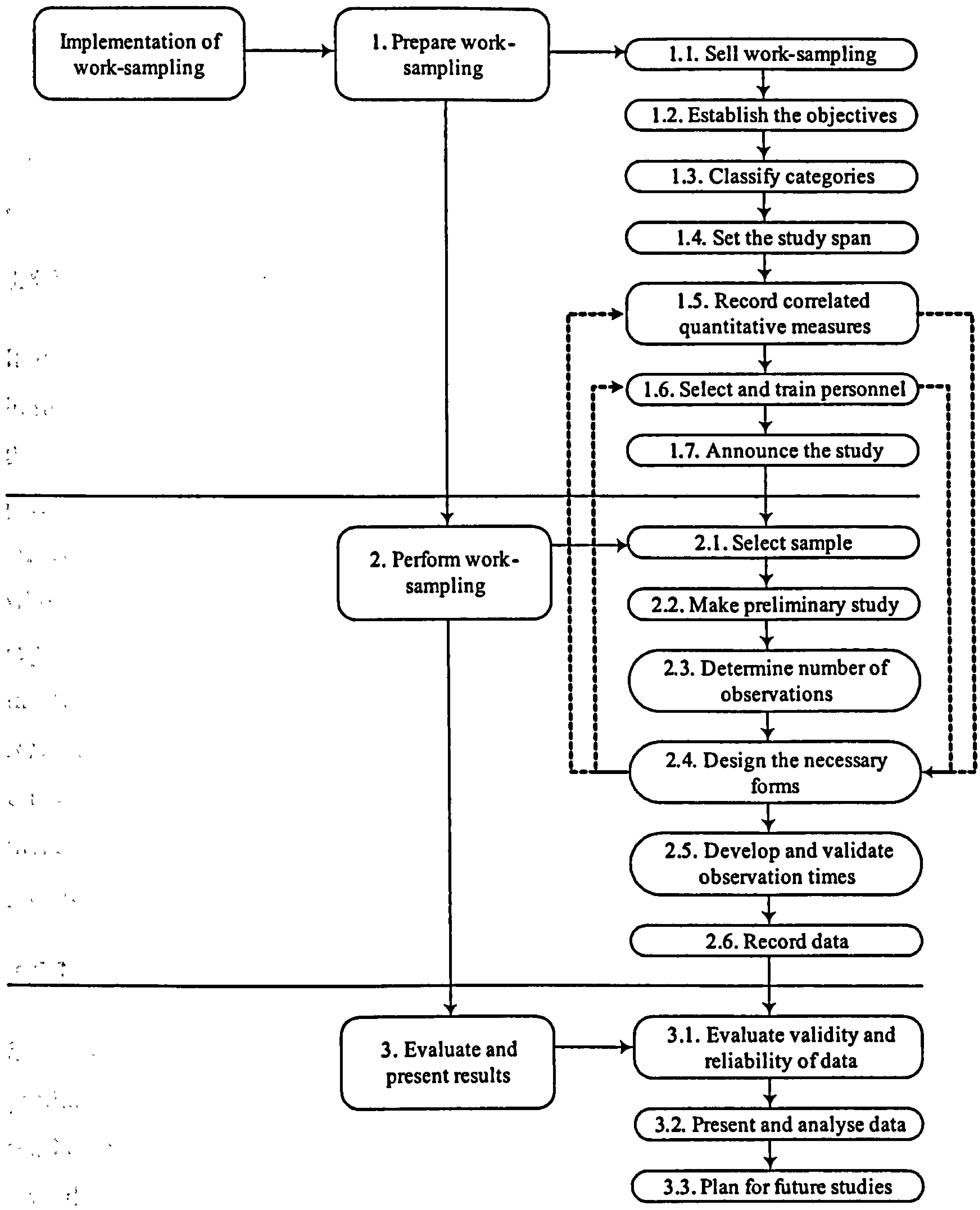


Figure 3.13 Improved steps of implementation of work-sampling

3.5.3.1.1 Convince management

Dales (1972) said that lack of experience in the use of work-sampling might lead to scepticism about its effectiveness. Consequently, it is necessary to clearly set out the method of approach, the time required, and the expected financial returns based on a proposal to management, since management will usually accept any principle if it can be demonstrated that it will produce positive results. Thomas *et al.* (1982), in addition, found it to be quite successful to show the results of previous studies, especially those where it can be illustrated that a restrictive specification or procedure has been changed to allow the contractor to improve site productivity.

3.5.3.1.2 Convince supervision

It is understandable that supervisors and middle management may feel that the introduction of the technique is a criticism of their past performance, so, probably, they are the most difficult group to convince. They should be informed, by painstaking and honest explanations, that the study has absolutely no intention of criticising, but only to bring greater security and prosperity to the organisation as a whole and to them as a part of it. Work-sampling, therefore, should be sold to supervisors and middle management on the trueness and dependability of the measurement technique – on the fact that its results are not fallacious and non-representative, that it is an impartial fact finding method, and that it will show up effectiveness as well as deficiency (Hansen, 1960). Supervisors and middle management, in addition, should be encouraged to give the work-sampling practitioner all possible help to facilitate the program.

3.5.3.1.3 Convince labour

Savery (1998) suggested that workers feel that they will bear more of the costs of any productivity improvement program. Evidently there needs to be some advertising of the benefits of improving productivity for the main producers of any productivity growth, in this case craftsmen, if they are to be convinced that productivity gains are important. The operatives will have to be assured that such changes are going to be beneficial to them and that any adverse affects will be offset by the gains. Operatives, consequently, should always be made aware that they will be studied, and also for what purpose, if their confidence and co-operation is to be gained.

There are a number of reasons for informing craftsmen. Firstly, it is not an acceptable personnel practice to avoid doing so. Secondly, surreptitious and concealed studies are sometimes explicitly prohibited in labour union contracts. Finally, as a practical matter, it would be difficult to conduct a work sampling study without the knowledge of those being observed and extremely difficult to use the results. If operatives are not informed about the study, they will discover soon enough anyway and will greatly resent not being trusted by being informed at the start (Karger and Bayha, 1996). It is claimed by many people with experience in the technique that knowledge by the workers that studies are being carried out has not unduly biased the results obtained from work sampling studies (Currie, 1965). Apart from that, the author found that some useful information, in respect of productivity problems, could be obtained from the craftsmen.

3.5.3.2 Establish the Objectives

Work-sampling is a versatile technique and can be implemented to accomplish a number of objectives. Before the study starts, however, it is important to specifically define the expectations of the study. A variety of different variations are possible in the selection of work units, the observers, the required level of accuracy, the confidence level, and the patterns of observation, so it becomes essential to identify each of these in the light of the objectives of the study. Accordingly, it is necessary, at this stage, to establish clearly the purpose of the study, for example, whether the study is for a quick appraisal of efficiency by considering effective and ineffective work as in a field count, or a detailed appraisal by dividing the data into further effective and ineffective elements. There is, consequently, no doubt that setting the objectives of a work sampling study should be considered as a crucial first step (Heinze 1984; Thomas *et al.* 1982). However, the objectives of this study are, first, to identify the time utilisation of all craftsmen, by observing 10 randomly selected craftsmen on each of 4 sites, and, second, to identify the delays and, from this information, to try to eliminate these delays in order to improve on site productivity.

3.5.3.3 Classify Categories

In work-sampling, the observers observe a precisely specified group of people or machines over a precisely specified period of time, classify this information into one of several categories of activity, and record them in the observation recording sheet.

It is extremely important that the categories must be designed to reflect the objectives of the study. In addition, it is essential to state explicitly the content of each element that is to be studied. The elements must be so selected and defined as to leave no doubt in the mind of the observers into which category they should place what they sees. In general, when developing categories, the following rules should be applied:

1. Categories should be clearly and concisely defined, in writing.
2. Categories should be capable of recognition by visual observation.
3. Categories must be chosen in the light of the objectives and end uses of the study.

There is no fixed minimum or maximum number of categories. For the initial study, different authors recommended different numbers, for example, Heiland and Richardson (1957) suggested no more than ten or twelve, meanwhile Thomas (1980) advised around twelve to fifteen. However, the author believes that, irrespective of the category numbers, as long as categories are well defined and reflect the objectives of the study, they are appropriate.

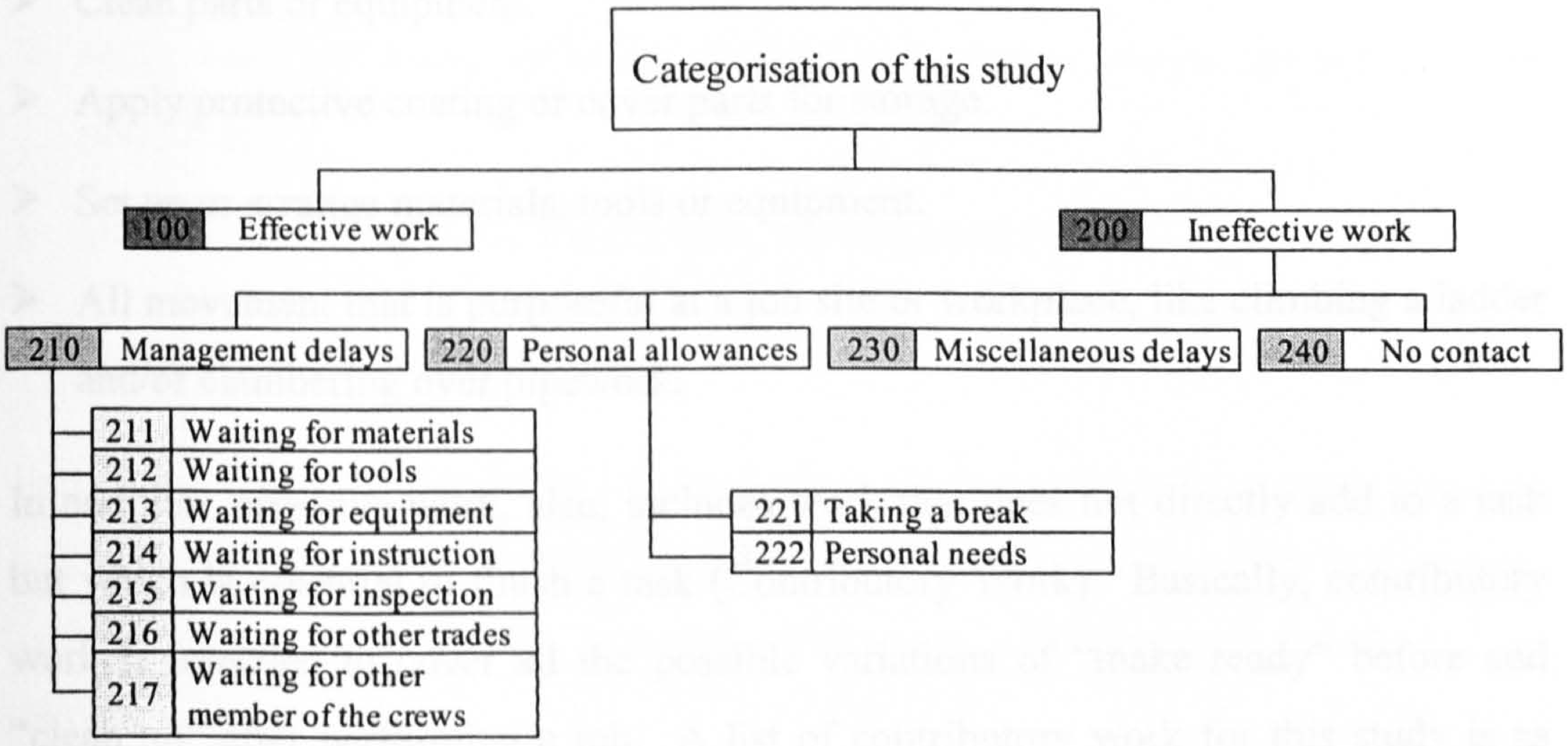


Figure 3.14 Work-sampling categories of this study

The degrees of fine categorisation have their own advantages. Broadly defined categories make the study easy to do and the reliability of each category will improve, because there will be a relatively larger number of observations per category. On the other hand, categories defined in detail provide better perception of the problems encountered, and it is easy to combine elements into boarder categories after the study has been completed, but not vice versa.

The broadest categories of work sampling for this study consist of two main groups, which are effective work and ineffective work. Figure 3.14 exhibits the categorisation of the study. The code and definitions of each category and sub-category are described as follows.

Code 100 Effective Work

Effective work is those physical actions or "do" activities that contribute directly to completing or adding to a unit being constructed. Examples of effective work are listed below:

- Do craft work.
- Handle and use material, tools or equipment within the job site.
- Gauge, inspect, or otherwise check or test work, or carry out quality checks.
- Clean parts or equipment.
- Apply protective coating or cover parts for storage.
- Set up or arrange materials, tools or equipment.
- All movement that is purposeful at a job site or workplace, like climbing a ladder and/or clambering over pipework.

In addition, effective work, also, includes work that does not directly add to a task but which is essential to finish a task (Contributory Work). Basically, contributory work is intended to cover all the possible variations of "make ready" before and "clean up" after performing a job. A list of contributory work for this study is as stated below:

Information

- Study, sketches, drawings, specifications, work procedures, guidelines, etc.

- Receive/give instruction involving communication to or by supervisors and among crew members.

Travel records all movement of craftsmen in the work area, which consists of:

- Obtaining materials in the immediate work area, including walking empty handed to fetch them.
- Obtaining tools in the immediate work area, including walking empty handed to fetch them.
- Obtaining equipment in the immediate work area, including walking empty handed to fetch it.

Prepare

- Put on protective clothing or equipment.
- Look over, or pre-inspect the job site or parts to determine what is needed and/or what is to be done.
- Make room to work, including cleaning the area in which the job is to be performed.
- Other contributory work, for example, moving scaffolding.

Code 200 Ineffective Work

Ineffective work includes being idle or doing something that is in no way necessary to complete a job. The research classified ineffective work into four major areas, namely; management delays, personal allowances, miscellaneous delays and no contact.

210 Management Delays The purpose of this category is to investigate delays, which are beyond a craftsman's control. Sub-groups of management delays are listed below:

211 Waiting for or obtaining materials outside the immediate work area, including walking empty hand to fetch them.

- Fetch raw materials from stores, shops, etc.

212 *Waiting for or obtaining tools outside the immediate work area*, including walking empty handed to fetch them.

- Fetch tools, supplies or parts from stores, shops, etc. (outside immediate work area).

213 *Waiting for or obtaining equipment outside the immediate work area*, including walking empty handed to fetch it.

- Fetch equipment from stores, shops, etc. (outside immediate work area).

214 *Waiting for instruction*

- Wait for job assignments – where?, what?, when?.
- Wait for instruction – how?, why?.

215 *Waiting for inspection*

- Wait for job approval – changes or continuations.

216 *Waiting for other trades*

- Wait for other crafts to complete their work.

217 *Waiting for other crews*

- Wait for other crews due to an unbalanced crew condition, for example, two crafts are assigned to a job, only one can work at that particular moment because of the nature of task to be performed or because of limited space.

220 ***Personal Allowances*** consist of two sub-categories:

221 *Taking a break* (i.e. fatigue recovery, mop brow, personal conversations)

222 *Personal needs* (i.e. lavatory, drinking water, smoking)

230 ***Miscellaneous Delays***

Any other delays apart from those specified above. Remarks should be noted giving the causes of the delay.

240 No Contact

- Failure to observe a worker who is assigned to a specific work location.

It is important that category classification is homogenous with the objectives of the study. It is clear that the objectives of this work-sampling program are to identify the time utilisation of craftsmen, to identify the delays and, from these, try to eliminate those delays in order to improve on site productivity. As a result, the categories are as given above, which are classified in the interest of different kinds of delay. If the objective of the study, however, is solely to identify craftsmen's time utilisation, the categories may be classified into three board groups, effective work, contributory work and ineffective work, or even into two of the boardest categories, effective work and ineffective work.

For the first case, categories are classified into three main groups, and so all sub-categories of ineffective work, for example, code 211, 212, 216 and 230 will be eliminated. However, their definitions will be retained in their head categories. Furthermore, contributory work will be separated from effective work and promoted to be another main category, with the code 200. This means, therefore, the content of each category remains constant, but the number of categories decreases, from 15 to 3. In respect of the boardest categorisation, the second case, everything is organised in exactly the same way as the previous case and the only difference is that all definitions of contributory work are included in effective work, as originally, and all codes beginning with 2 are removed. Again, the contents of the categories are the same, but effective work is more detailed and there are fewer numbers of categories. Figure 3.15 depicts this idea.

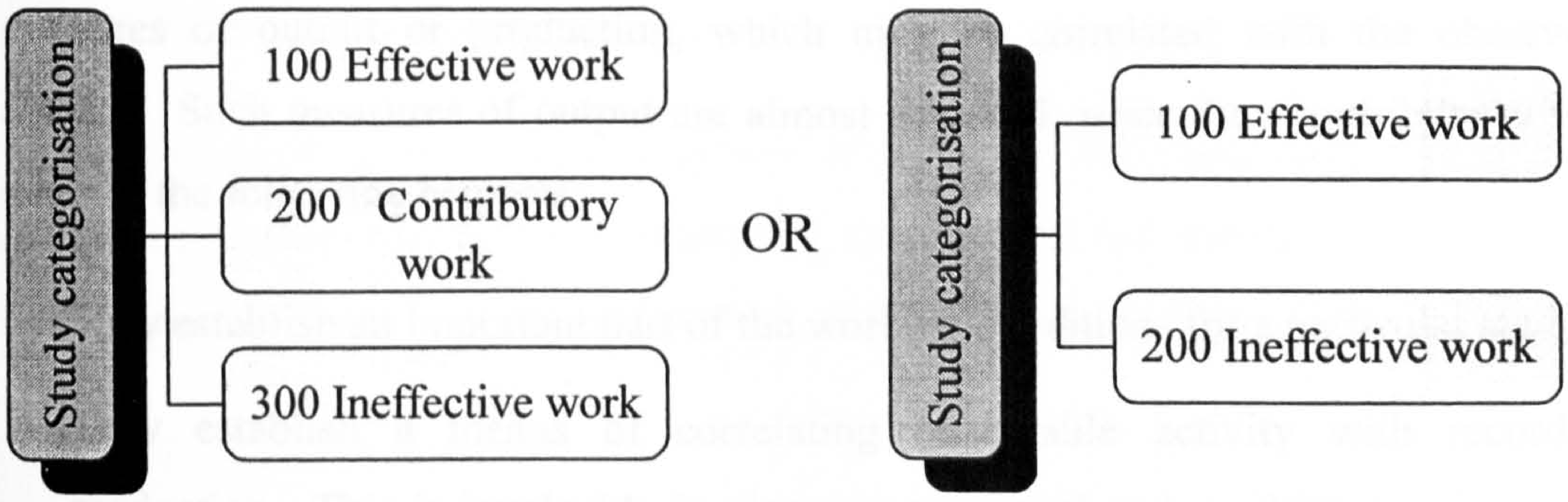


Figure 3.15 Possible categories for craftsmen's time utilisation study

3.5.3.4 Set the Study Span

The next step is to decide over what period the observations are to be collected. An advantage of work-sampling is that the required observations can be discontinued and restarted anytime without seriously affecting the results. In this way it is possible to obtain a more representative sample of the activities and delays under investigation. This advantage normally leads to a program being extended over several days or weeks. Nevertheless the time period during which the study is made should be representative of the activity and such that seasonal or cyclic effects will not bias the results.

The sample should be taken over the whole cycle, and if one cycle will not yield a large enough sample, the cycle must be doubled or some of the multiple used as required. In other words, the observation period should be a multiple of any work cycle time. It is important, furthermore, to note that observations should cover the whole of the working period. For example, in the case of an 8-hour working day, over a period of ten days, observations should be taken throughout the 8 x 10 hours of this period. As the nature of construction work is non-repetitive and not seasonal or cyclic, it is reasonable to set five consecutive working days as a study time span for the study.

3.5.3.5 Record Correlated Quantitative Measures

Work-sampling is a measure of the distribution of time or of the input to a work situation. The conditions under which the work-sampling study is taken are noted, but are not specific in detail. Therefore, it is wise to agree upon some quantitative measures of output or production, which may be correlated with the observed activity. Such measures of output are almost essential, since they contribute to the study in the following respects:

- They establish an important part of the working conditions for a particular study.
- They establish a means of correlating observable activity with recorded production. This is invaluable in planning personnel and machine requirements and for setting standards.
- They may help answer the question: "Was the period of time over which the work-sampling was done representative of the entire operation?"

Basically, no new records will be required to keep track of the output for the period during which the work-sampling is done. It may be necessary to segregate and preserve some records which otherwise might be destroyed, but this is not usual. Table 3.12 depicts some examples of the type of records used for the purpose under discussion.

Table 3.12 Example of production measurement

Source: Adapted from Heiland, E. R. and Richardson, J. W. (1957, p. 42)

Situation under Study	Measure of Production
Manufacturing department activity	Earned man-hours of production
Structural steel shop	Tons of steel fabricated
Airline passenger reservation procedure	Number and type of tickets issued
Stock-picking and shipping room	Number of orders filled
Retail-store sales departments	Dollar volume of business
Accounts payable office	Number of invoices received
Machine-shop activity	Units of production

In such cases of non-repetitive work like maintenance, supervision, materials handling, and shop clerical work, where it is too difficult or expensive to measure, it is suggested that the cost of such work units should be put into a pool called overheads or factory expenses. The cost of such work should be redistributed over the product or service produced on the basis of man-hours, labour dollars, or some other scheme (Richardson, 1976).

3.5.3.6 Select and Train Personnel

Generally speaking, there are five groups of people in an organisation who will be required to participate in a work-sampling study, these are management, the study leader, the line supervisor, the observer(s), and the personnel being studied.

3.5.3.6.1 Management

The management function is to make the basic decisions involved. These include the initial decision to make the study, the selection of the director and the observer(s), and the determination of the objectives of the study. In general, a work-sampling program needs strong management support (Thomas *et al.*, 1982). Management should make a clear statement that it regards work-sampling as a tool in gathering factual information to aid the conduct of its business, which is, certainly, a legitimate objective of management. In addition, management should set up the means to receive reports of the progress of the study. It should be prepared to accept these results and, if necessary, to take action. It makes sense, consequently, to give those making the study the proper degree of support necessary to ensure that the study itself is carried out properly, and that co-operation is obtained from all concerned.

3.5.3.6.2 Study leader

The primary requisites for the leader of the study are that the person selected should have the confidence of management and supervisors, that they should be alert, personable, and painstaking in nature, and that they should have a good background in basic mathematics, although some training in statistics may be desirable. There seems to be no rigid requirement of formal education. In brief, the job requires a person who "gets things done," and who has an open mind. The leader of the study has:

- In the overall sense, to guide and supervise the study in its planning, technical details, and execution;
- In co-operation with management, to select and train observers;
- In co-operation with supervisors and observers, to define categories of activity;

- To design all the necessary forms;
- To arrange for the necessary data tabulation and processing;
- To perform or be responsible for statistical work as required; and
- To be responsible for the proper reporting of results.

3.5.3.6.3 Line supervision

The function of the supervisor, if not acting as an observer, is to provide information as necessary to the observer(s) and study leader, to assist aid in establishing the objectives and help to explain the study to personnel. The supervisor should be kept informed of the results, and should understand that any changes to be made may depend upon the reliability of the study. It must be kept in mind that line authority and responsibility rest within the supervisor.

3.5.3.6.4 The observer(s)

The worth of work-sampling, like other work measurement systems, depends upon the validity and reliability of the basic data, which consist of the initial observations, as classified and recorded by the observers. The program, therefore, cannot succeed, unless the observers are conscientious and well instructed in their duties. Observers must be capable of distinguishing between the various types of category, which are specified on the observation sheet, and record the instant state or condition of each person or machine under study. The most important requirement is that what is observed should be faithfully recorded without bias.

Heiland and Richardson (1957) wrote that the observers can be selected from a number of positions, and should either be familiar with or be given time to become familiar with the work situation. There are four basic types of observers who may be chosen:

1. *Methods and measurement personnel*, who have already been involved in work measurement activity. This type of observer, no doubt, is a trained person, accustomed to recognising detail and to the classification of work

activity into categories. Such observers will be familiar with work measurement techniques even if they have no specific experience of work-sampling. If these personnel are available, they are the first choice for the selection of observers.

2. *Line supervision.* It is recommended that the first-line supervisors and their assistants act as observers, whenever possible (Heiland and Richardson, 1957). If the supervisor has participated in taking the observations, and if he is assured that his "throat will not be cut" as a result of this study, experience has shown that the supervisor makes a very satisfactory observer (Richardson, 1976). While doing so may require some supervisors' time, the benefits; that the supervisor is quite familiar with the work will have tremendous confidence in the results, and be able to know and explain details of the study to the workers, by far outweigh the disadvantages. To the objection that supervisors may try to influence the results favourably to themselves, this can be easily detected by testing the validity and reliability of work-sampling, which will be discussed later. In order to allow the supervisor to perform effectively, a general idea of how work-sampling works should be acquired.

3. *Specially trained observers, hired for the purpose*, or transferred into a full-time job. In some cases where measurement personnel are not available and supervisors are unable to do the observations, due to, for example, to work overload or management being dissatisfied with their performance, employing a work sampler is another option. This is particularly applicable to construction and maintenance fields, where there are a large number of operatives, the work is done over wide geographical areas and supervisors are usually too busy to do sampling.

4. *Engineers,* whether mechanical, electrical, or civil, who are already working on a construction site, are another choice. If either hiring a work sampler or training engineers, a period of time is required (maybe one or two weeks) for them to perceive the basic concept of how work-sampling works, to become familiar with the work to be studied and to recognise by

sight the craftsmen to be sampled. Therefore, this alternative is the least viable, when compared with the previous three choices discussed above.

Referring to the author's experience, in the case of the construction field, at least in Thailand, the author would recommend that an engineer(s), who is participating in the work to be studied, is the first priority observer, due to the following reasons:

- As the success of work-sampling requires strong support from management, an engineer, with fairly high power, could easily persuade the project manager and push his subordinates to have things done. Therefore, having an engineer acting as an observer, offers better opportunity for the work-sampling program to be successful than a line supervisor, since an engineer has more power and has a better communication channel to the top management.
- Basically, management knows there are productivity problems on their site However an engineer, participating as an observer, will know how serious the problems are. As a result, he could solve the problems, according to the management priorities.
- The results of the study will have less bias than those obtained by a line supervisor because the engineer believes the results have less effect on him than does the line supervisor.
- An engineer would require less training time in order to appreciate the general idea of work-sampling or the mathematics and statistics concerned than a line supervisor, as he has a better academic background.

When the observers have been specified, the following aspects should be clarified. It should be noted that in discussing the training of observers, the assumption is made that the observers are familiar with the operations to be studied and have no problems with recognising activities by category and the personnel by name.

- Explanation of the theory of sampling to provide observers with an overview of sampling.
- Discussion of the objectives and end uses of the study.

- Discussion of the definition of categories.
- Explanation of the use of the observation form.
- Discussion of the randomisation of times of observations.

3.5.3.6.5 The personnel being studied

No one likes being spied upon, whether he is a professional or of the lowest classification on the pay roll. Everyone to be studied, therefore, should be informed about the study by an informal group meeting. If possible, they should be appraised of the facts, and then the meeting should be thrown open for comments. Craftsmen, also, should be asked to work normally and should be assured that the results, in an abridged form, will be made public but that this will not affect their employment. These results should be carefully interpreted from the personnel relations point of view, but all questions should be clarified.

For this research program, the author will perform as both the leader of the study and an observer. Referring to the previous discussion, it is clear that the author is qualified to act as a study leader. Due to the time constraint of the research program, which allowed insufficient time for the author to train observers, and as the number of observations required for the studies is not too large, only 400 for each study, the author will, therefore, be the only observer for each study.

3.5.3.7 Announce the Study

A useful means of informing the operatives concerned is to write a memorandum describing the study, and giving as many of the details as may be thought necessary, for discussion by the supervisors with the people to be sampled. The purpose is to avoid misunderstandings and suspicions arising from secret or repetitious studies. This form of written statement is also useful in informing all levels of management of the fact of the study. This is not only good personnel management, but also serves as an indicator of management's interest in the work-sampling study.

3.5.4 Perform Work-Sampling

3.5.4.1 Select Sample

If the work to be studied employs a small numbers of operatives, say less than 20, it is acceptable to sample all of them. Nevertheless, if the number is over 20, which is common in the construction field, which often involves a large number of craftsmen, it is necessary to specify a sample, so as to save time and cost, while maintaining effectiveness. Sample selection must strictly rely solely on randomness, where every craftsman has an equal chance to be chosen and thus can be done in several ways. For example, writing numbers, with each representing one operative, on a piece of paper, then selecting them randomly until the required number is achieved, or using the random number command in Excel to specify the samples. In the case of the construction field, the author would recommend 10 samples (the source of this number will be discussed in 3.5.4.3).

In any case, 10 samples should represent the whole population of craftsmen. The number of representatives from each trade can be obtained from the ratio of the number of each trade to the total number of craftsmen. For example, if there are 100 craftsmen, which consist of 52 labourers, 19 fitters, 17 carpenters and 12 welders, the 10 samples should include 5 labourers, 2 fitters, 2 carpenters and 1 welder.

3.5.4.2 Make Preliminary Study

At this point, a few rounds should be made at fairly random intervals and observations taken. This is necessary because the number of observations required cannot be identified, either by alignment chart or mathematical formula, without knowledge of the element percentage. The procedure permits the magnitude of the final answer, for example, total effective time, to be either estimated from prior knowledge or based on a preliminary study of 50 to 100 samples. However, the further advantages of making a preliminary study are:

1. The result obtained is more likely to provide the correct final answer as to the number of observations required without the necessity for further entries.

2. Confidence in observer competence can be tested.
3. A final check on the suitability of the categories, the observation points and the routes could be made.
4. It allows determination of the time taken to complete a round.
5. Observers have a chance to get used to the study field before real observations are taken.
6. The people who are being observed have the opportunity to see just what is involved in a work-sampling study.
7. A preliminary study also offers the opportunity to test the measures of output upon which decisions have been made. Some of these may prove to be difficult to obtain, and others may prove to be less meaningful.

3.5.4.3 Determine the Required Number of Observations

Since all relevant statistical aspects of work sampling have been clarified previously, there will be no further discussion of the statistical principles here. This section will explain only their applications. The required number of observations can be calculated from the formula given below:

$$N = \frac{Z^2 P(100 - P)}{L^2} \qquad \text{............(3)}$$

where:

N = number of observations required

Z = value obtained from statistical tables depending upon the level of confidence required for the estimate (usually taken as 2, which corresponds to 95% confidence)

P = average percentage of activity observed (usually assessed from preliminary study)

L = limit of error required (%)

There is a general consensus among specialists (Olomolaiye *et al.*, 1997; Harris and McCaffer, 1995; NEDO, 1989; Ogesley *et al.*, 1989; Baxendale, 1985; Langford, 1982) that for work-sampling results, in construction situations, to be considered reliable, a combination of a confidence level of 95 percent and limit of error of 5 percent is sufficient. At these levels the results give a good indication of the overall effectiveness of an organisation or the individual crews that make it up. Regardless of the rating scheme, the working portion of activities usually falls into the 40 to 60 percent category. With these limits, and with the possibility that the split might be close to 50-50, it is more conservative to calculate the required number of observations based on P = 50%. Doing so will guarantee reliability of the results, since P = 50% would require the maximum observation numbers for a given level of confidence and a limit of error. Furthermore, category proportions of either 40 or 60 percent result in sample sizes only 4 percent smaller than that of 50 percent. As a result, nevertheless, the required number of observations for this study is determined below:

$$N = \frac{2^2 x50x(100-50)}{5^2} = 400$$

The required number of observations for the program is, therefore, 400 observations, which, guarantees, at least a 95% level of confidence and ±5% limit of error. However, as discussed in 5.3, this study, where appropriate, will take 450 observations. Since 450 samples will be recorded within 5 days and, at least, 8 rounds of observation a day (as discussed in 6.2.4.), say 9 rounds in the case of 450 samples required, it will be the most suitable if 10 craftsmen are observed each round (5 x 9 x 10 = 450).

Please note that the remaining 3 subgroups of Perform work-sampling (see Figure 3.12), namely; 2.4. Design the necessary forms; 2.5. Develop and validate observation times; and 2.6 Record data will be discussed in detail in 4.3.3.2.

3.5.5 Evaluate and Present Results

3.5.5.1 Evaluate Validity and Reliability of Data

When observations have been completed, the next step is to evaluate the validity and reliability of data. The validity of a test may be defined as the accuracy with which it measures that which it is intended to measure (Correll and Barnes, 1950). The validity test may be tested by comparison with some other independent measurement or criterion. In this case, comparison of effective work time with other studies like Borcherding (1978), who specified that 45%-55% or better is usually achieved, and the application of a *p* chart are used to test the program validity.

On the other hand, three aspects of the problem of statistical tests of reliability are noted as follows: (i) tests of reliability of the proportion derived from a given study; (ii) tests of homogeneity of results from a series of studies made of a given job over a time period or analysis of variations observed in such studies; and (iii) evaluation of the significance of work-sampling results as "forecasts" (Sammet and Malcolm, 1954; Malcolm and Sammet, 1954). Since work-sampling for this study is implemented only for a short time, and not for a series of studies, only a test of the reliability of the proportion derived from the studies (i) will be carried out. In addition, an evaluation of the validity of the data will also be presented.

3.5.5.1.1 Evaluation of validity of data

An almost continuous evaluation of reliability should be in progress when the study is about half complete, or after 10 rounds of observations, or 300 individual observations (based on 10 categories), which ever come first. The use of control charts is appropriate whenever a quantitative measurement of a variable can be made, and it is desirable to test this value as it behaves across time, by drawing samples at regular or irregular intervals, seeking to see either stability or change. In work-sampling, there are two main types of control charts, which are the *p* chart and the *c* chart. The application of the *c* chart is discussed previously, so only the *p* chart is explained below.

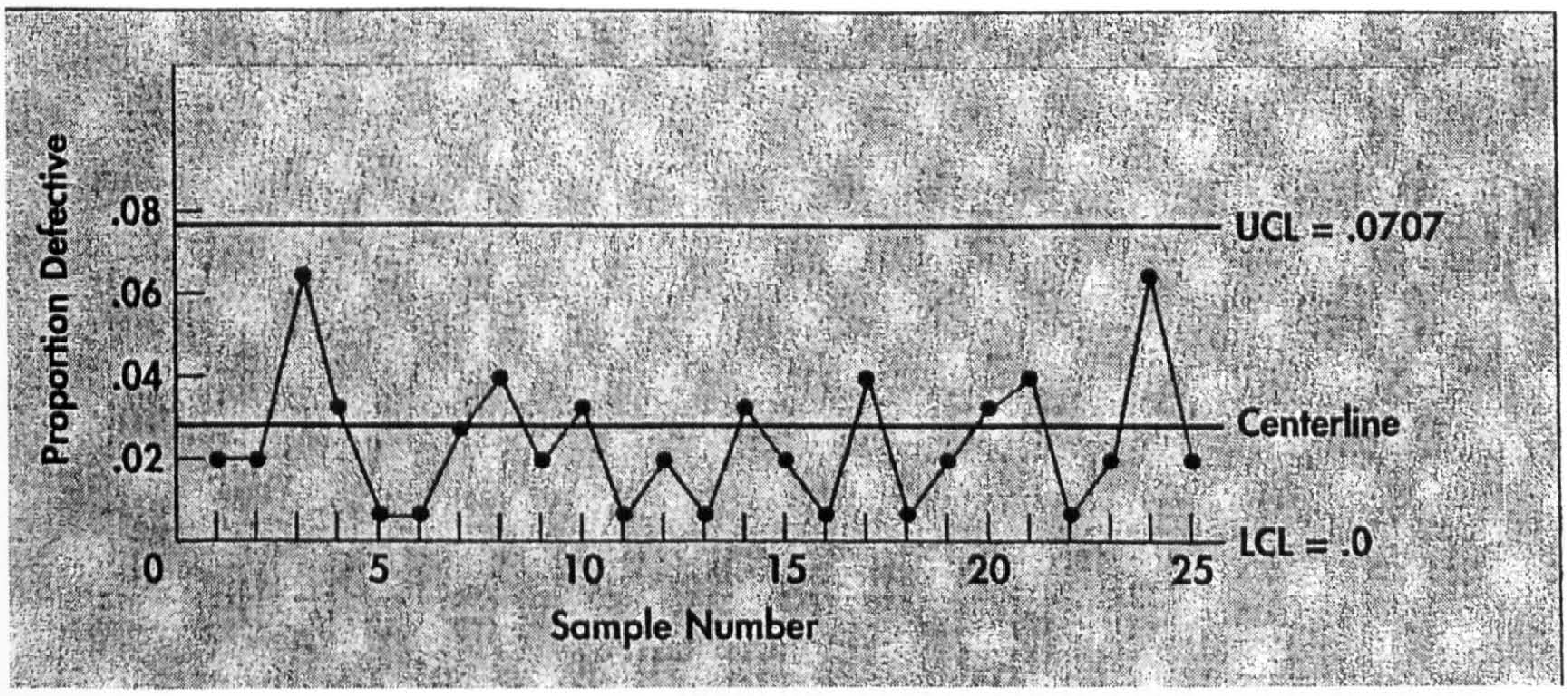


Figure 3.16 A typical *p* chart

Source: Montgomery, D. C. (1996, p. 257)

The *p* chart may be called the "chart for category proportions or control chart for fraction nonconforming," and is used to plot percentages found in a single category, or group of categories, in successive samples. This is the basic type of chart for analysis of results (see Figure 3.1616). A *p* chart is typically drawn at a limit of $\bar{p} \pm 3\sigma_p$, with approximately 99% of the data lying within the lower control limit (LCL) and upper control limit (UCL) (Mears, 1995). Consequently, the control chart can be defined as follows:

$$\begin{aligned} UCL &= \bar{p} + 3\sigma_p = \bar{p} + 3\sqrt{\frac{\bar{p}(100-\bar{p})}{n}} \\ CL &= \bar{p} \qquad \qquad \qquad \qquad ....(5) \\ LCL &= \bar{p} - 3\sigma_p = \bar{p} - 3\sqrt{\frac{\bar{p}(100-\bar{p})}{n}} \end{aligned}$$

where; $\bar{p}$ = average percentage of a particular category or group of categories

n = number of samples in an observation round

3.5.5.1.2 Evaluation of reliability of data

In work-sampling, it is always possible to make more observations to increase the reliability of data as long as doing so complies with the end uses, the objectives of the study and it is economic to do so. As these work-sampling programs require 400 observations to satisfy a minimum of 95% confidence level and ±5% limit of error, the reliability test for each proportion can be derived from:

$$L = Z\sqrt{\frac{P(100-P)}{N}} \qquad \text{...........(2)}$$

where;

L = limit of error achieved (%)

Z = value obtained from statistical tables depending upon the level of confidence required for the estimate. In this case, taken as 2, which corresponds to 95% confidence.

P = percentage of activity observed of a particular category

N = number of observations achieved

3.5.5.2 Present and Analyse Data

There are various ways in which the results of a work-sampling program can be presented. A typical graphical presentation of this research is demonstrated in Figure 3.1717. The most important rule to follow is that the results should be reported in terms of the original objectives of the study. That is, if the objective was simply to obtain a basic analysis of the activity of a particular group, this should be stated as the proportions of activity that are listed. Since the technique is relatively straightforward, the project manager, who looks at the results, will be able to draw some fairly sensible conclusions. The essential point is that the study be taken in a careful and conscientious manner, so that all may have confidence in the results themselves.

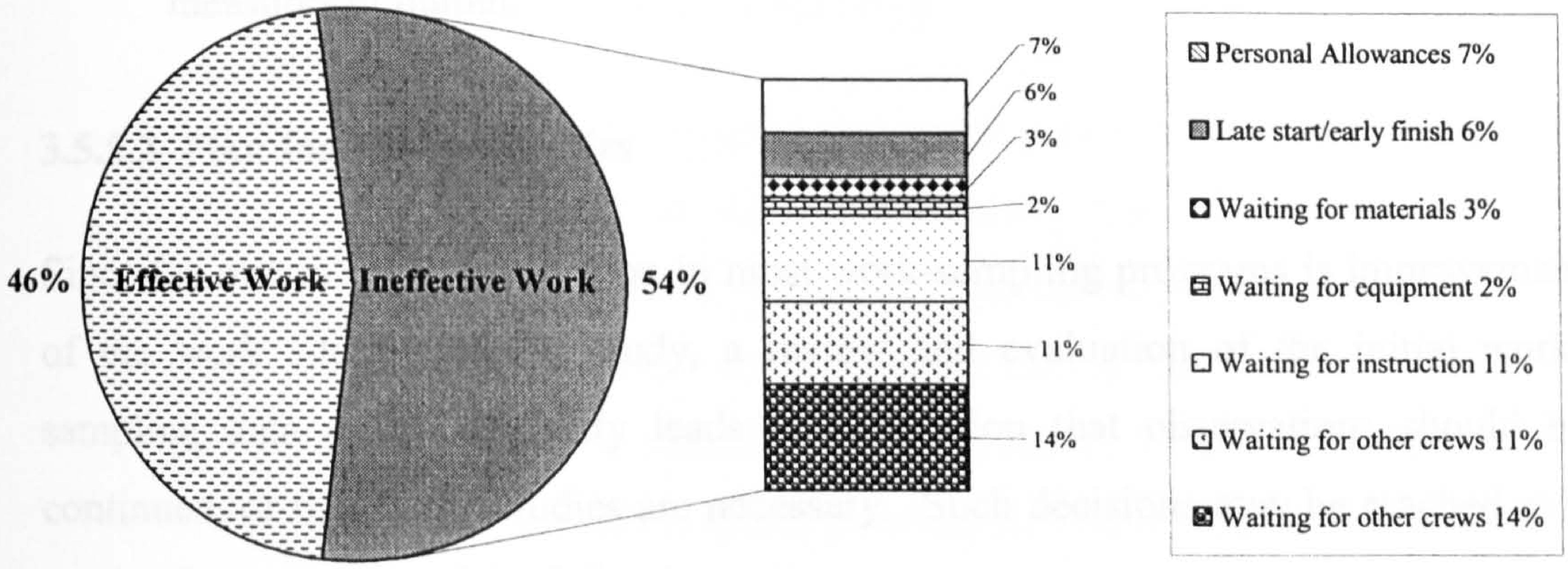


Figure 3.17 A typical graphic presentation of this study

The basic data resulting from a work-sampling study are a series of proportions or percentages of observations, which have been classified into the various categories. In general, each observation includes the notion of the following variables: (i) the person or unit of equipment observed; (ii) the time of observation; (iii) the category into which the observed activity, state, or condition is classified; (iv) the surrounding conditions, for example, an unusual stop situation. In presenting the results of a work-sampling program, the proportions or percentages may be given more meaning by the following techniques; however the purpose here is just a guideline, not an exhaustive list of the methods of data presentation:

1. Combining categories into broad classes, for example, effective work and ineffective work.
2. Expressing results directly in terms of money spent in various categories. This is particularly useful in equipment studies.
3. Charting results on a time axis, to show trends and peak-load conditions.

4. Charting or tabulating the results to show the relationship of these to measures of output.

3.5.5.3 Plan for Future Studies

Since the overriding consideration in most work-sampling programs is improvement of the work situation under study, a review and evaluation of the initial work-sampling data quite frequently leads to a decision that observations should be continued, or that future studies are necessary. Such decisions may be reached as a result of one or more of the following:

1. The supervisor has become aware of the usefulness of work-sampling as a technique for the continuous measurement of shop operations. In this case, where it is desired to continue work-sampling as an aid to supervision, the initial study must be examined carefully. It may be that the categories should be combined, that the time rate of observations should be altered, or that the degree of detail required should be changed. The criterion here should be the proven needs of the supervisor. The only precaution necessary is that, where possible, the changes should allow the first study to be used for comparison with future studies.

2. Management institutes change, and plans future studies to appraise the effect of such change. In this case, work-sampling may be discontinued for a period of time, sufficient to allow the changes made to take effect, and a separate work-sampling study is then made. When such a "check" study is made, the results are tested for the significance of the difference of $\bar{p}$ (average percentage of ineffective time), to determine whether or not the desired change has taken place. This presupposes that the change will be reflected in the proportions of time spent in specific categories. Details of performing the check study should be similar to those in the initial study, in order to make the comparison valid. Accordingly, it is clear that this work-sampling program falls into this group, as after the initial study, the study will allow two weeks for the action taken to take effect. Then, further work-sampling

will be conducted to find out if ineffective time has decreased using the same categories implemented in the initial study.

3. It may be desirable to investigate the nature and extent of yearly or other long-term cycles. In these cases, a company may be aware of certain seasonal or long-term cyclical variations in its business. For example, if the initial work-sampling study has been taken during an "average" month, it may be desired to take supplemental spot studies of a "busy" month and of a "slow" month. While this is sound practice, an even better solution might be to take a series of shorter studies, perhaps one every month. In this way a better concept of the entire cycle could be gained, and the control chart technique could be applied.

3.6 Foreman Delay Surveys (FDS)

It has been widely accepted that asking the workers themselves is one of the best means of acquiring information about productivity problems (Kaming *et al.*, 1997; Oglesby *et al.*, 1989). The implementation of foreman delay surveys (FDS) is one such method whereby productivity problems are revealed by foremen through the identification of causes and quantification of delays in the daily routine of their crewmembers.

3.6.1 Overview of foreman delay surveys

Foreman delay surveys is a method for performance measurement and for productivity improvement, which involves foremen in identifying the causes of delay on construction sites. The foreman is chosen to identify these causes because he is closest to the work, so the foreman is most directly affected by them. As a result, he should be able to specify and estimate the time losses fairly accurately.

A foreman delay survey requires that each foreman records all delays or interruptions, for example, lack of materials, tools, equipment, etc., which may or may not be beyond the foreman's control, that affect his crew members. He must note the length of each delay, the number of craftsmen affected and the causes of each disruption. At the end of each day or the next morning, the foremen need to spend about five minutes summarising this information to calculate the total number of manhours lost. The delay survey forms are collected through normal time card channels. The data obtained are summarised by trade and by delay cause. The resulting summary of costs of lost time are reviewed and discussed with all levels of site management, including the foremen who inputted the data, in order to identify productivity improvement solutions.

The program can be conducted over the entire site and involve all the foremen or on a specific section of the site where particular problems are presented. In the latter case, participating foremen are the ones concerned with those particular sections. In respect of survey duration, the operation can be carried out each day for a specific duration, for example, a two-week survey on a quarterly basis, or one week of each month, which may be either the whole length of the project or a given period within it. Table 3.13 indicates strengths and weaknesses of foreman delay surveys.

Table 3.13 Strengths and weaknesses of foreman delay surveys

Strengths	Weaknesses
❖ Data are gathered from an entire site rather than a sample of the work force, so the whole project can be monitored.	❖ Foremen's subjective judgement of how much time they actually lose may be inaccurate.
❖ Delays to particular trades and specific delays are immediately highlighted, thus allowing management's attention to be directed toward to those problem areas.	❖ Other sources of delay may arise without being noticed during gaps between surveys (FDS is usually carried out for one week of each month).
❖ Provides a mechanism for two-way communications between management and foremen and facilitates discussion of problems and means of solution, which encourages improved communications between the parties.	❖ The surveys require a short interval between data collection and management actions to handle the delays, so unless management responds quickly, foremen may come to discount the value of the program.
❖ The survey is easy and inexpensive to carry out, avoids adversarial relationships with the workforce, and can be done regularly and by untrained personnel.	❖ This technique does not provide information on the efficiency of work methods used, or of the competence of the workforce.
❖ The form requires a very short time, a few minutes, for foremen to complete.	❖ Unwillingness to report delays attributed to the foreman.
❖ The information is current and fairly accurate, as information is asked for at the end of each day.	

Referring to Table 3.133, it is extremely clear that foreman delay surveys offer obvious advantages. For example, they provide a board view of problems, they are economical and easily implemented and the information is fresh and exact, which, as a result, could outweigh their disadvantages like subjective judgement and unwillingness to report. Consequently, it is reasonable to claim that foreman delay surveys are appropriate for the construction industry, in terms of a productivity improvement tool.

3.6.2 Conducting foreman delay surveys

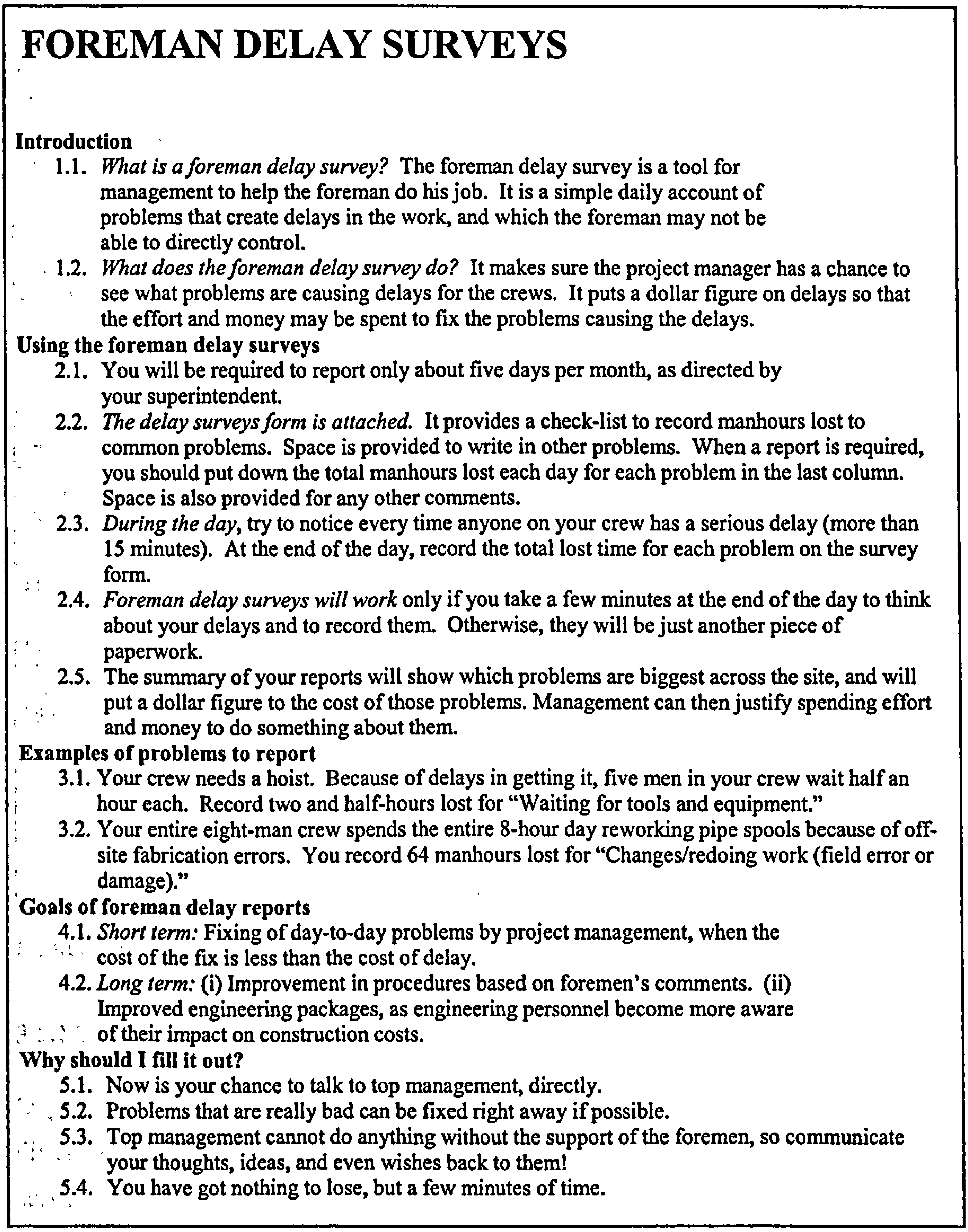
The implementation of the foreman delay surveys involves five steps including the introduction to foreman, form distribution and collection, results summarisation, feedback session, and remedial action. These steps are described as follows:

3.6.2.1 Introduction to the foreman

Foreman delay surveys, like all other data collection surveys, require an introduction session preceding their first use. Each of the foremen participating in the survey must attend this meeting, where all of them will receive a hand out consisting of a form for introducing foreman delay surveys (see Figure 3.1818) and a typical foreman delay survey daily form (see Figure 3.1919). The group meeting can last from 15-60 minutes, and should be kept to less than 10 foremen in a session in order to maintain effectiveness of the exchange of ideas and to encourage questions and discussion. In addition, all supervisors, and, if possible the project manager, should attend this session to demonstrate management commitment to the survey. In the case that the project manager cannot join this introductory meeting, formally written, strong support for the program by the management, should be issued and presented in the session. In general, nevertheless, the introduction session should:

1. clearly specify that the survey is intended to pinpoint problems outside the control of individual foreman that it is not a criticism of their past performance, and highlight the problems for the attention of those who can correct them;
2. assure job security and that there is no penalty for honest reporting that may put management in an unfavourable light (this is the reason why the project manager should be present during the meeting);

3. explain how to record the details of the delays, preferably quoting examples;
4. indicate when the form should be completed (the end of each day or the following morning), and where the form is to be distributed and collected.



FOREMAN DELAY SURVEYS

Introduction

1.1. *What is a foreman delay survey?* The foreman delay survey is a tool for management to help the foreman do his job. It is a simple daily account of problems that create delays in the work, and which the foreman may not be able to directly control.

1.2. *What does the foreman delay survey do?* It makes sure the project manager has a chance to see what problems are causing delays for the crews. It puts a dollar figure on delays so that the effort and money may be spent to fix the problems causing the delays.

Using the foreman delay surveys

2.1. You will be required to report only about five days per month, as directed by your superintendent.

2.2. *The delay surveys form is attached.* It provides a check-list to record manhours lost to common problems. Space is provided to write in other problems. When a report is required, you should put down the total manhours lost each day for each problem in the last column. Space is also provided for any other comments.

2.3. *During the day*, try to notice every time anyone on your crew has a serious delay (more than 15 minutes). At the end of the day, record the total lost time for each problem on the survey form.

2.4. *Foreman delay surveys will work* only if you take a few minutes at the end of the day to think about your delays and to record them. Otherwise, they will be just another piece of paperwork.

2.5. The summary of your reports will show which problems are biggest across the site, and will put a dollar figure to the cost of those problems. Management can then justify spending effort and money to do something about them.

Examples of problems to report

3.1. Your crew needs a hoist. Because of delays in getting it, five men in your crew wait half an hour each. Record two and half-hours lost for "Waiting for tools and equipment."

3.2. Your entire eight-man crew spends the entire 8-hour day reworking pipe spools because of off-site fabrication errors. You record 64 manhours lost for "Changes/redoing work (field error or damage)."

Goals of foreman delay reports

4.1. *Short term:* Fixing of day-to-day problems by project management, when the cost of the fix is less than the cost of delay.

4.2. *Long term:* (i) Improvement in procedures based on foremen's comments. (ii) Improved engineering packages, as engineering personnel become more aware of their impact on construction costs.

Why should I fill it out?

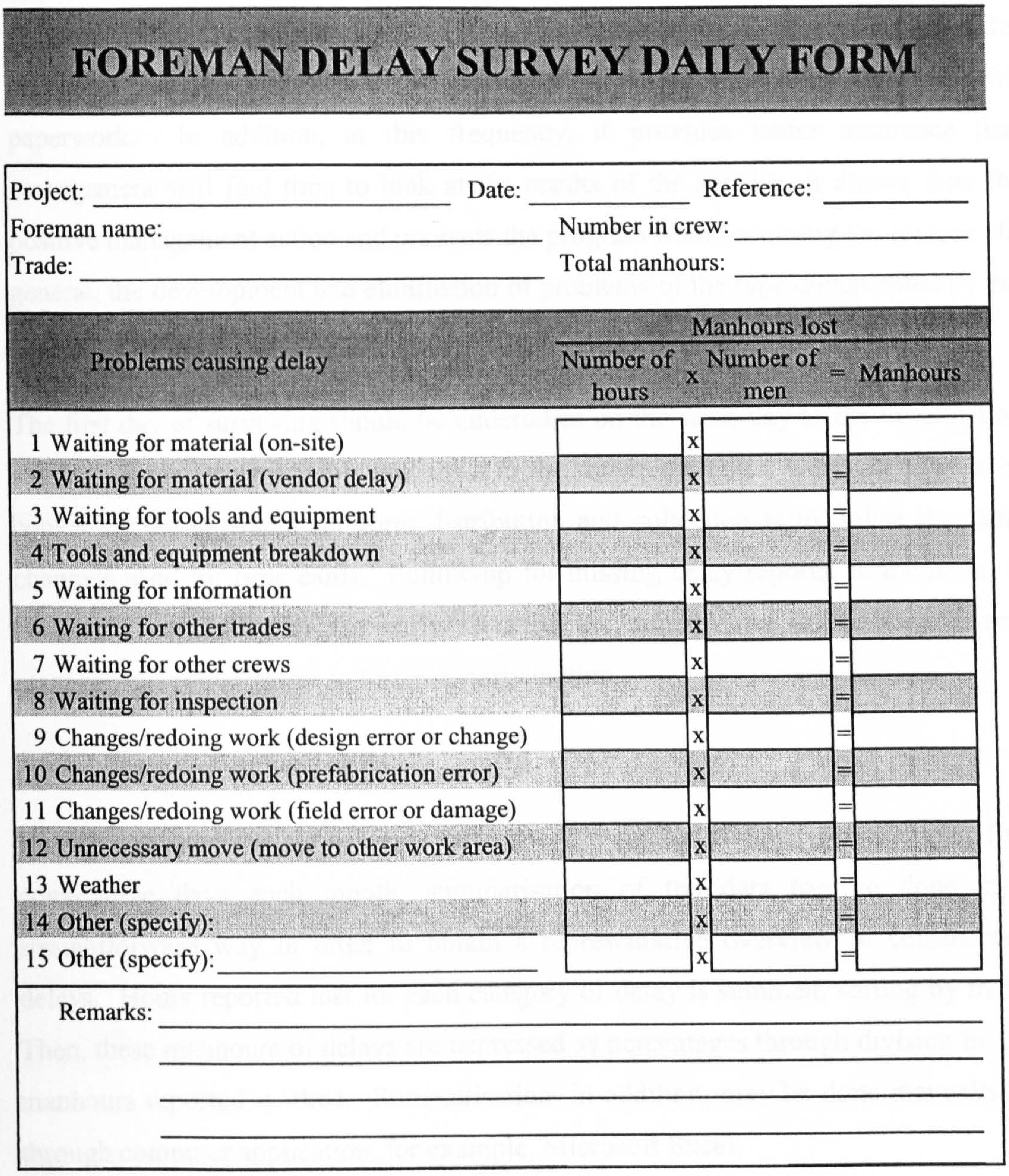
5.1. Now is your chance to talk to top management, directly.

5.2. Problems that are really bad can be fixed right away if possible.

5.3. Top management cannot do anything without the support of the foremen, so communicate your thoughts, ideas, and even wishes back to them!

5.4. You have got nothing to lose, but a few minutes of time.

Figure 3.18 Handout for an explanation of foreman delay surveys (Adapted from Tucker *et al.*, 1982)



FOREMAN DELAY SURVEY DAILY FORM

Project: ____________ Date: ________ Reference: ________
Foreman name: ____________ Number in crew: ________
Trade: ____________ Total manhours: ________

Problems causing delay	Manhours lost				
	Number of hours	x	Number of men	=	Manhours
1 Waiting for material (on-site)		x		=	
2 Waiting for material (vendor delay)		x		=	
3 Waiting for tools and equipment		x		=	
4 Tools and equipment breakdown		x		=	
5 Waiting for information		x		=	
6 Waiting for other trades		x		=	
7 Waiting for other crews		x		=	
8 Waiting for inspection		x		=	
9 Changes/redoing work (design error or change)		x		=	
10 Changes/redoing work (prefabrication error)		x		=	
11 Changes/redoing work (field error or damage)		x		=	
12 Unnecessary move (move to other work area)		x		=	
13 Weather		x		=	
14 Other (specify): ____________		x		=	
15 Other (specify): ____________		x		=	

Remarks: ____________

Figure 3.19 Foreman delay survey daily form

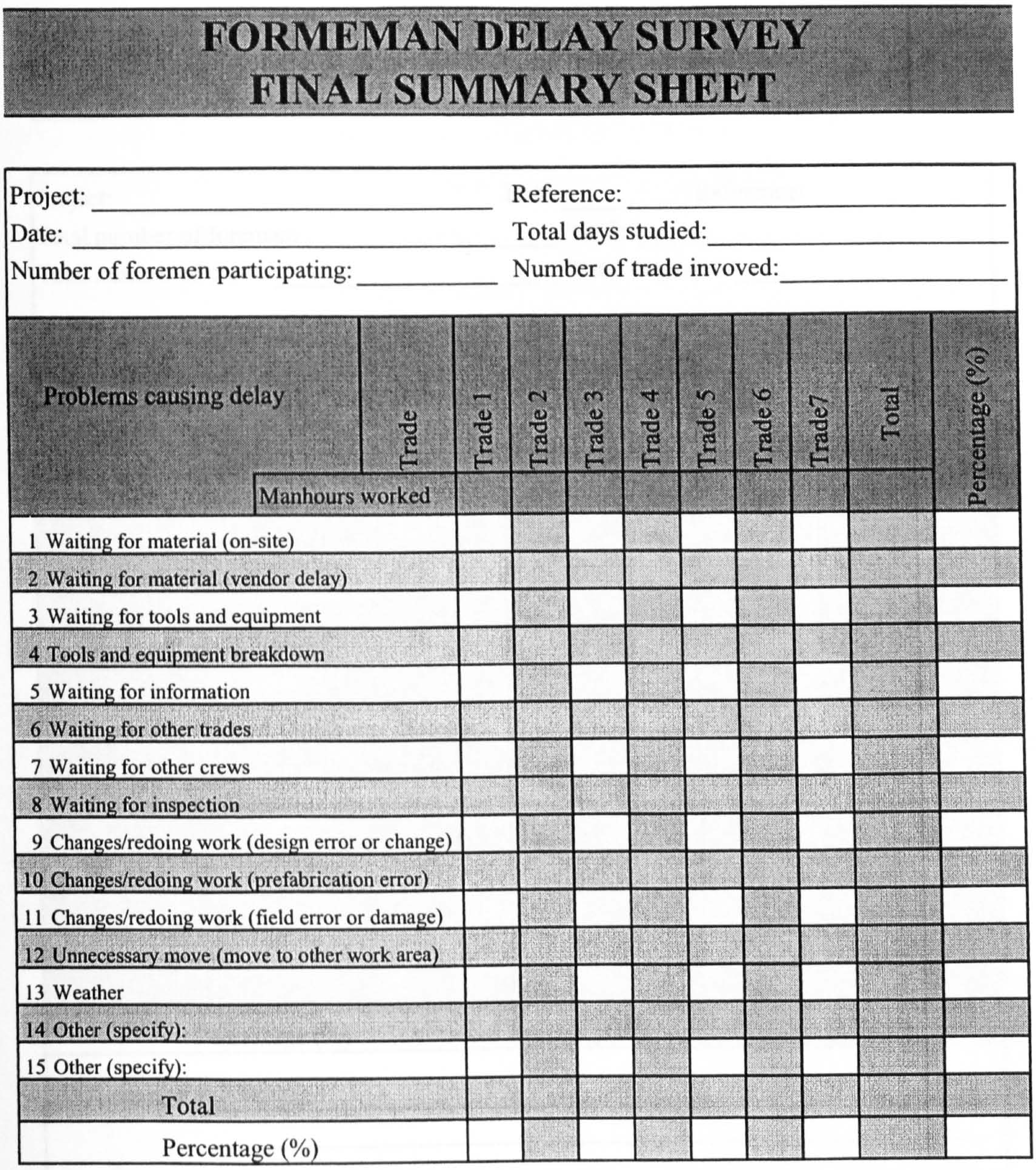
3.6.2.2 Form distribution and collection

Depending on the circumstances, foreman delay surveys can be implemented at a different range of frequencies and duration of survey periods, for example, daily survey and weekly surveying throughout the project, a two-week survey on a quarterly basis, or as needed, such as to measure a change in productivity before and after holidays. However, the most frequently used approach, which is considered to be the best, concerns collection of delay surveys for one week on a monthly basis (Alfeld, 1988). This approach is thought to present an adequate representation of the problems being experienced on a site, without overburdening the foremen with paperwork. In addition, at this frequency, it provides better assurance that management will find time to look at the results of the surveys, it allows time for positive management action and prevents the program from becoming too routine. In general, the development and elimination of problems of the type documented by the surveys is not so rapid that monthly surveys will not reasonably track them.

The first day of surveying should be undertaken on the same day as the introduction session, as the information is still fresh in the foremen's mind. Generally, the most convenient arrangement for form distribution and collection is to utilise the same channels used for time cards. Follow-up for missing delay reports, furthermore, is necessary, especially in the early days of the surveys, as doing so confirms management commitment to foreman participation.

3.6.2.3 Results summarisation

Having collected the survey data for a specific period of time, for example, five consecutive days each month, summarisation of the data can be done in a straightforward way in order to obtain a representative overview of construction delays. Hours reported lost for each category of delay is summed, sorting by trade. Then, these manhours of delays are expressed as percentages through division by the manhours reported worked. Summarisation, in addition, may be done manually or through computer application, for example, Microsoft Excel.

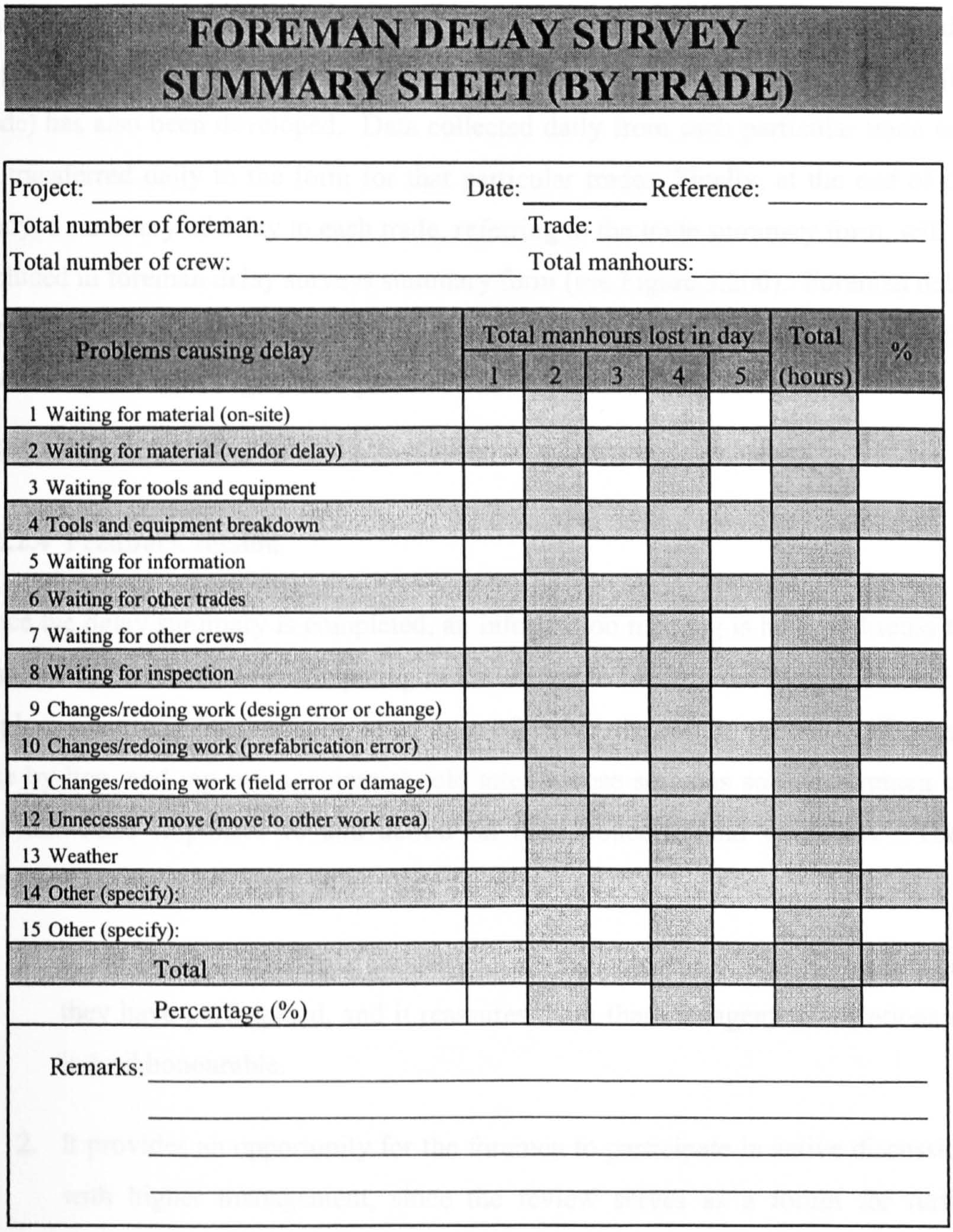


FOREMEMAN DELAY SURVEY
FINAL SUMMARY SHEET

Project: ______________________ Reference: ______________________
Date: ______________________ Total days studied: ______________________
Number of foremen participating: __________ Number of trade invoved: ______________

Problems causing delay / Trade	Trade 1	Trade 2	Trade 3	Trade 4	Trade 5	Trade 6	Trade7	Total	Percentage (%)
Manhours worked									
1 Waiting for material (on-site)									
2 Waiting for material (vendor delay)									
3 Waiting for tools and equipment									
4 Tools and equipment breakdown									
5 Waiting for information									
6 Waiting for other trades									
7 Waiting for other crews									
8 Waiting for inspection									
9 Changes/redoing work (design error or change)									
10 Changes/redoing work (prefabrication error)									
11 Changes/redoing work (field error or damage)									
12 Unnecessary move (move to other work area)									
13 Weather									
14 Other (specify):									
15 Other (specify):									
Total									
Percentage (%)									

Figure 3.20 Foreman delay survey summary form



FOREMAN DELAY SURVEY SUMMARY SHEET (BY TRADE)

Project: ____________ Date: ________ Reference: ________

Total number of foreman: ____________ Trade: ____________

Total number of crew: ____________ Total manhours: ____________

Problems causing delay	Total manhours lost in day					Total (hours)	%
	1	2	3	4	5		
1 Waiting for material (on-site)							
2 Waiting for material (vendor delay)							
3 Waiting for tools and equipment							
4 Tools and equipment breakdown							
5 Waiting for information							
6 Waiting for other trades							
7 Waiting for other crews							
8 Waiting for inspection							
9 Changes/redoing work (design error or change)							
10 Changes/redoing work (prefabrication error)							
11 Changes/redoing work (field error or damage)							
12 Unnecessary move (move to other work area)							
13 Weather							
14 Other (specify):							
15 Other (specify):							
Total							
Percentage (%)							

Remarks: ____________

Figure 3.21 Foreman delay survey summary form (by trade)

Nevertheless, whether manual or computer methods are employed, the delay summary should include both manhours lost and this value expressed as a percentage of hours worked. Values should be tabulated for each category and for each craft. Daily values will be tallied in the process of obtaining weekly values.

Figure 3.200 shows an example of foreman delay summary form. However, in order to prevent handling too much paperwork, a foreman delay survey summary form (by trade) has also been developed. Data collected daily from each particular trade will be transferred daily to the form for that particular trade. Finally, at the end of the study, a summary of delay to each trade, referring to the trade summary form, will be included in foreman delay surveys summary form (see Figure 3.200). Foreman delay survey summary form (by trade) is depicted in Figure 3.211 and Figure 3.222 demonstrates a typical graphical presentation of foreman delay surveys.

Figure 3.22 A typical graphical presentation of a foreman delay survey

3.6.2.4 Feedback session

Once the delay summary is completed, an information meeting is held to discuss the results with the foremen participating in the survey to identify the root causes and to explore solutions. Furthermore, to be most effective, the results should be discussed line by line, and top management should attend these sessions so that foremen can get first-hand responses to and action on their concerns and questions. These feedback sessions, however, offer other benefits;

1. It satisfies the foremen's curiosity to see the outcome of something in which they have participated, and it reassures them that management intentions are indeed honourable.

2. It provides an opportunity for the foremen to participate in active discussions with higher management, since the review serves as a forum for further investigation into the delay categories indicating the largest time losses. Specifics of the problems are obtained, as well as ideas for possible solutions.

3. It motivates the foremen to increase their commitment to future surveys, especially if higher management indicates that actions are being taken to solve at least some of the relatively simple problems specified by the survey.

3.6.2.5 Remedial action

This step is mandatory. Management actions taken to eliminate the problems, according to the foremen's suggestions, must be firm and positive and the whole management team must be committed to making them work. A highly visible improvement in operations implemented by management will do more than anything else to convince the foremen that the program is worthwhile and that management cares about what is done to help productivity.

3.7 Summary

Work-sampling is a subgroup of work measurement, which is a part of work study. Apart from the essential basic statistics of work-sampling, chapter 3 has identified the weakness of the current work-sampling procedures in the construction industry, before suggestions for improvement are specified. The improved implementation steps of work-sampling divide into three main parts, namely; prepare work-sampling, perform work-sampling and evaluate and present results. The appropriateness of work-sampling and FDS, including their stages of application, to the construction industry have also been clarified.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Introduction

This chapter clarifies the basic fundamentals of this research, which consist of research questions, research methodology and research variables. The purposes are, first, to identify the inspirations that made the author carry out the study, which will be discussed before hand and, second, to specify how it was undertaken, which will be explained in Research methodology. Finally, to indicate all the research variables that will be mentioned at the end of the chapter. In addition, validity testing, reliability testing and hypothesis test are explained in Chapter 4.

4.2 Research Questions

There are a number of questions, which inspired the author to undertake this research. They are:

1 What are the significant factors that affect the productivity of the construction industry in Thailand?

2 Are there any significant differences in the perceptions of project managers, foremen and craftsmen of the productivity factors?

3 From the work-sampling results, can we predict the productive time change?

4 What factors have the greatest potential to change the productive time improvement?

4.3 Research Methodology

4.3.1 Critique of Available Methodologies

4.3.1.1 Qualitative and Quantitative Research Methods

The distinction between qualitative and quantitative methods is important, although it is often overemphasised.

4.2.1.1.1 Qualitative Research Methods

Qualitative research answers such questions as 'what?', 'why?', or 'how?' (Keynote, 1989), and it is centrally concerned with the interpretation and analysis of what people do and say without making heavy use of measurement or numerical analysis as within quantitative methods. Qualitative methods are designed to explore and assess things that cannot easily be summarised numerically by using a set of *ad hoc* procedures to define, count and analyse its variables, therefore, the study of a small sample of subjects is appropriate. Interviews that use open-ended questions and descriptive observation of another culture's rituals, are both examples of qualitative research. Qualitative research proceeds with an open mind, takes all the data available into account as systematically as possible, and is guided by a carefully chosen research question rather than the impulses of the researcher, and also makes a contribution to the development of theory. Consequently, it seems to provide in-depth material, which is both flexible and rigorous. Above all, it relatively cheap (Miller and Dingwall 1997). Qualitative research is sometimes called "phenomenological" (Saunders, Lewis and Thornhill, 1997).

4.2.1.1.2 Quantitative Research Methods

Quantitative Methods are associated with the positivist assumption that the things scientists are interested in can and should be measured as accurately as possible (Priest, 1996). From this point, the adequacy and accuracy of scientific measurement instruments is a central focus of concern. This is the sense in which quantitative methods are sometimes argued to be more objective than qualitative ones.

Quantitative researchers who have been influenced by positivist philosophy argue that qualitative research results are of less value because they are too subjective (Lee, 1999). Most survey research, various kinds of personality testing and studies are examples of quantitative research that lead to the answer of the question 'how many?' (Keynote, 1989).

4.2.1.1.3 Tensions between Qualitative and Quantitative Traditions

The qualitative and quantitative traditions are too often oversimplified into "research with numbers versus research with no numbers" (Miller and Dingwall, 1997). However, McDaniel and Gates (1999, p.127) said that qualitative research does not distinguish small differences as well as large-scale quantitative research does. Cassell and Symon (1994, p.6) stated that qualitative researchers do not commonly begin with strong prototypical models to follow, where as quantitative researchers begin with a relatively clear mental model for their designs. Qualitative research is better suited for theory creation, whereas quantitative research is better suited for theory testing. (Kvale,1996). Table 4.1 compares qualitative and quantitative research on several levels, and Table 4.2 summarises the possible advantages and disadvantages of these two approaches.

Table 4.1 Qualitative versus quantitative research

Source: McDaniel and Gates (1999, p.126)

Comparison Dimension	Qualitative Research	Quantitative Research
Types of questions	Probing	Limited probing
Sample size	Small	Large
Information per respondent	Much	Varies
Administration	Requires interviewer with special skills	Fewer special skills required
Type of analysis	Subjective, interpretive	Statistical, summarisation
Hardware	Tape recorders, projection devices, video, pictures, discussion guides	Questionnaires, computers, printouts
Ability to replicate	Low	High
Training of the researcher	Psychology, sociology, social	Statistics, decision models, decision support systems, computer programming
Type of research	Exploratory	Descriptive or causal

Table 4.2 Key advantages and disadvantages of the main approaches to research design

Source: Adapted from Saunders, Lewis, and Thornhill (1997, p.74)

	Qualitative	Quantitative
Advantages	➢ Facilitates understanding of how and why ➢ Good at understanding social processes ➢ Enables researcher to be alive to changes which occur during the process	➢ Economical collection of large amount of data ➢ Clear theoretical focus for the research at the outset ➢ Easily comparable data ➢ Greater opportunity for researcher to retain control of research process
Disadvantages	➢ Researcher has to live with the uncertainty that clear patterns may not emerge ➢ Data collection can be time consuming ➢ Generally perceived as less credible by "non-researcher" ➢ Data analysis is difficult	➢ Inflexible – direction often cannot be changed once data collection has started ➢ Weak at understanding social processes ➢ Often does not discover the meanings people attach to social phenomena

4.3.1.2 Research Strategies

Robson (1993) lists the three traditional research strategies as:

- experiment;
- survey; and
- case study.

4.2.1.2.1 Experiment

The experiment is the principal natural scientific method for theory testing (Rose and Sullivan, 1996). The principle of experiment lies in the attempt to control all factors, which might affect what is being studied, in order to specify the causal relationships involved. Consequently, what is being studied must be capable of being measured.

It seems easy to plan experiments, which deal with measurable phenomena. In addition, the experiment allows conclusions to be drawn about cause and effect, if the experimental design is sound, but usually large groups are needed if many variations and ambiguities are to be controlled. Such large-scale experiments are expensive to set up and take time, although, some tests which require only a few hours can be very effective. In claiming a causal relationship, great care must be taken to ensure that all possible causes have been considered (Bell, 1993).

4.2.1.2.2 Survey

Scarbrough and Tanenbaum (1998, p.120) said that survey research is a mechanism of the kind of quantitative methods used. The survey is defined by Zikmund (1997, p.192) as a method of primary data collection based on communication with a representative sample of individuals. It allows the collection of a large amount of data from a sizeable population in a highly economical way. Based mostly on questionnaires, these data are standardised, allowing easy comparison. However, Saunders, Lewis and Thornhill (1997) stated that the questionnaire is not the only data collection device which belongs to the survey category. Structured observation, where the problem has been defined precisely enough so that the behaviours that will be observed can be specified beforehand, as can the categories that will be used to record and analyse the situation, (Gilbert and Churchill, 1992) and structured interviews, where standardised questions are put to all interviewees, (Lehmann, Gupta and Steckel, 1998) also fall into this category.

In surveys, all respondents will be asked the same questions in, as far as possible, the same circumstances. It is important to pilot question wording carefully to ensure that all questions mean the same to all respondents. Surveys can provide answers to the questions What? When? Where? and How?, but it is not easy to find out Why? (Bell, 1993) In addition, Zikmund (1997, p. 194) believed that they provide a quick, inexpensive, efficient, and accurate means of assessing information about a population and surveys are quite flexible.

4.3.1.2.3 Case Study

Miller and Dingwall (1997) wrote that case study research is a qualitative method. Robson (1993, p.40) defined a case study as the development of detailed, intensive knowledge about a single "case", or a small number of related "cases". It is best suited to the examination of why, what, and how contemporary, real-life phenomena occur, but under conditions where researchers have minimal control (Yin, 1994).

The great strength of case study research is that it allows the researcher to concentrate on a specific instance or situation and to identify the various interactive processes at work. Case studies may be carried out to follow up and to put flesh on the bones of a survey. They can precede a survey and be used as a means of identifying key issues which merit further investigation, but the majority of case studies are carried out as free-standing exercises. Unfortunately, where a single researcher is gathering all the information, selection has to be made. The researcher selects the area for study and decides which material to present in the final report. It is difficult to cross-check information and so there is always the danger of distortion. Observation and interviews are most frequently used in a case study but no method is excluded (Bell, 1993).

4.3.2 The Selection of Research Strategies

The aim of this research is to find out how appropriate work-sampling is for the construction industry in Thailand, as a productivity improvement tool. Therefore, based on the small amount of research carried out previously in the industry, the proposed data can be divided into two main parts. The first part employs a questionnaire to collect data, with the objective to appreciate the factors affecting the construction industry and the second part uses a case study to implement work-sampling studies to see how well they work. Experiments are not appropriate to this study because the point of conducting an experiment is to isolate individual factors and observe their effect in detail (Denscombe, 2000). The purpose is to discover new relationships or properties associated with the materials being investigated, or to test existing theories (Rose and Sullivan, 1996).

4.3.2.1 Questionnaire

McDaniel and Gates (1999, p.356) defined a questionnaire as a set of questions designed to generate the data necessary for accomplishing the objectives of the research project. The type of questionnaire differs according to how it is administered (see Figure 4.1). *Self-administered questionnaires* are usually completed by the respondents. Such questionnaires are either posted to respondents who return them by post after completion (*mail questionnaires*), or delivered by hand to each respondent and collected later (*delivery and collection questionnaires*). Responses to *interviewer-administered questionnaires* are recorded by the interviewer on the basis of each respondent's answers. Contacting respondents and administering questionnaires using the telephone are known as *telephone questionnaires*. The final category, *structured interviews*, refers to those questionnaires where interviewers physically meet respondents and ask the questions face to face (Gill and Johnson, 1997).

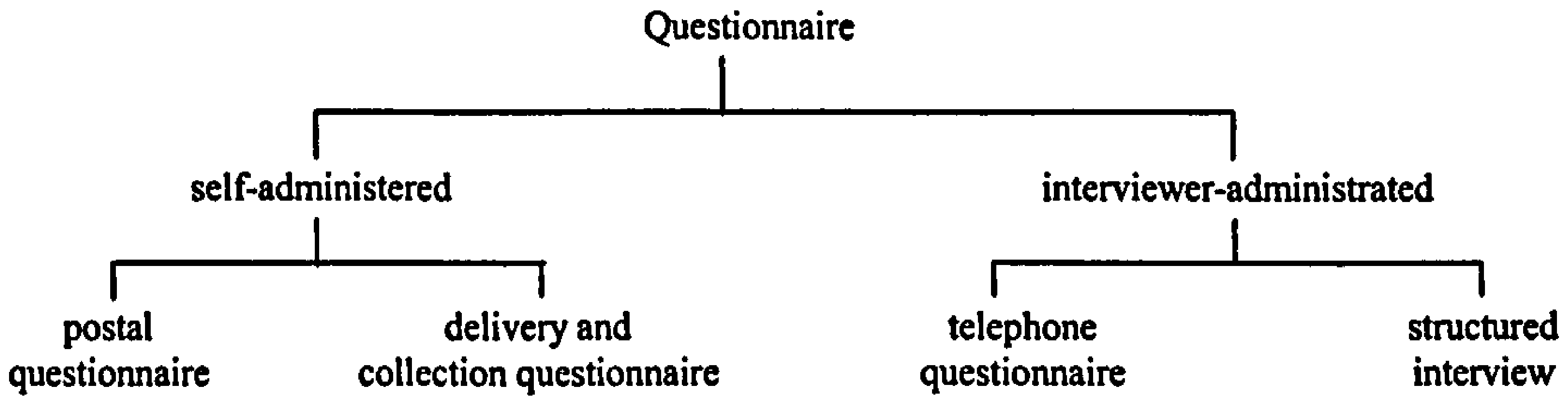


Figure 4.1 Types of questionnaire

Source: Saunders, Lewis and Thornhill (1997, p.245)

Since the author knew exactly what sort of data is required, questionnaires are a good way of collecting data, as Bell (1993, p.76) wrote that questionnaires are a good way of collecting certain types of information quickly and relatively cheaply. The type of questionnaire employed in this thesis is a delivery and collection questionnaire, supplemented with some structured interviews.

4.3.2.2 Case Study

As well as the delivery and collection questionnaire and the structured interview, another research strategy for this research is a case study. It provides an opportunity for intensive analysis of the many specific details which are often overlooked by other methods (Kumar, 1999). The case study undertaken in this thesis can be classified as a *critical case*, where the researcher has a clearly specified hypothesis, and a case is chosen on the grounds that it will allow a better understanding of the circumstances in which the hypothesis will and will not hold (Yin, 1994). Occasionally, researchers use at least two instances (Denscombe, 2000).

4.3.3 The Application of Research Strategies

4.3.3.1 Questionnaires

These research strategies were conducted in Thailand, firstly between November and December 2000 with project managers at the management level and craftsmen active at operative level, as the target groups and, secondly, between October and December 2001, with foremen, as the target group. A structured questionnaire survey was designed in English, but was translated into Thai, and was approved by experienced persons in the industry, who have qualifications at either masters degree or PhD level.

In general, the questionnaires launched to the three target groups have mostly the same content, as the first part of the questionnaire asked for general information about the participants and their organisations. In the main part of the questionnaire each foreman and craftsman were asked to rate the factors affecting construction productivity drawn from the literature on scale from 0 (no influence) to 5 (very great influence). The questionnaire to the project managers required each participant to rate the factors affecting productivity on scale from 0 (no influence) to 5 (very great influence) and to rate each factor in respect of its potential for productivity improvement on a scale from 0 (no potential) to 4 (very high potential). In addition, respondents were welcome to add and rate factors that they believed to have an effect on construction productivity, apart from those included in the questionnaire.

A total of 40, 95 and 220 questionnaires were distributed to project managers, foremen and craftsmen, respectively. Most project manager respondents were contacted through personal recommendation, resulting in a high return rate, of 34 out of 40 (85%). From the 95 questionnaires distributed to foreman, 57 (60%) were returned. The respondents consisted of 3 major trades (18 fitters, 12 steel erectors and 16 welders) with 11 from other trades (such as crane riggers and scaffolders). The craftsman questionnaires were not distributed directly to the craftsmen, but given to the project managers on five sites, who passed them to their craftsmen at an appropriate time. Finally, 128 questionnaires, equal to a response rate of 58.18%, classified into six groups of respondents (19 masons, 27 fitters, 26 carpenters, 20 steel fixers, 28 general labourers, and 8 welders), were completed.

Project managers, foremen and craftsmen were considered as distinct groups of respondents and were asked to rate factors affecting the productivity of the construction industry in Thailand. The questionnaires were structured to find the answer to Research questions no. 1 and 2.

4.3.3.2 Case Study

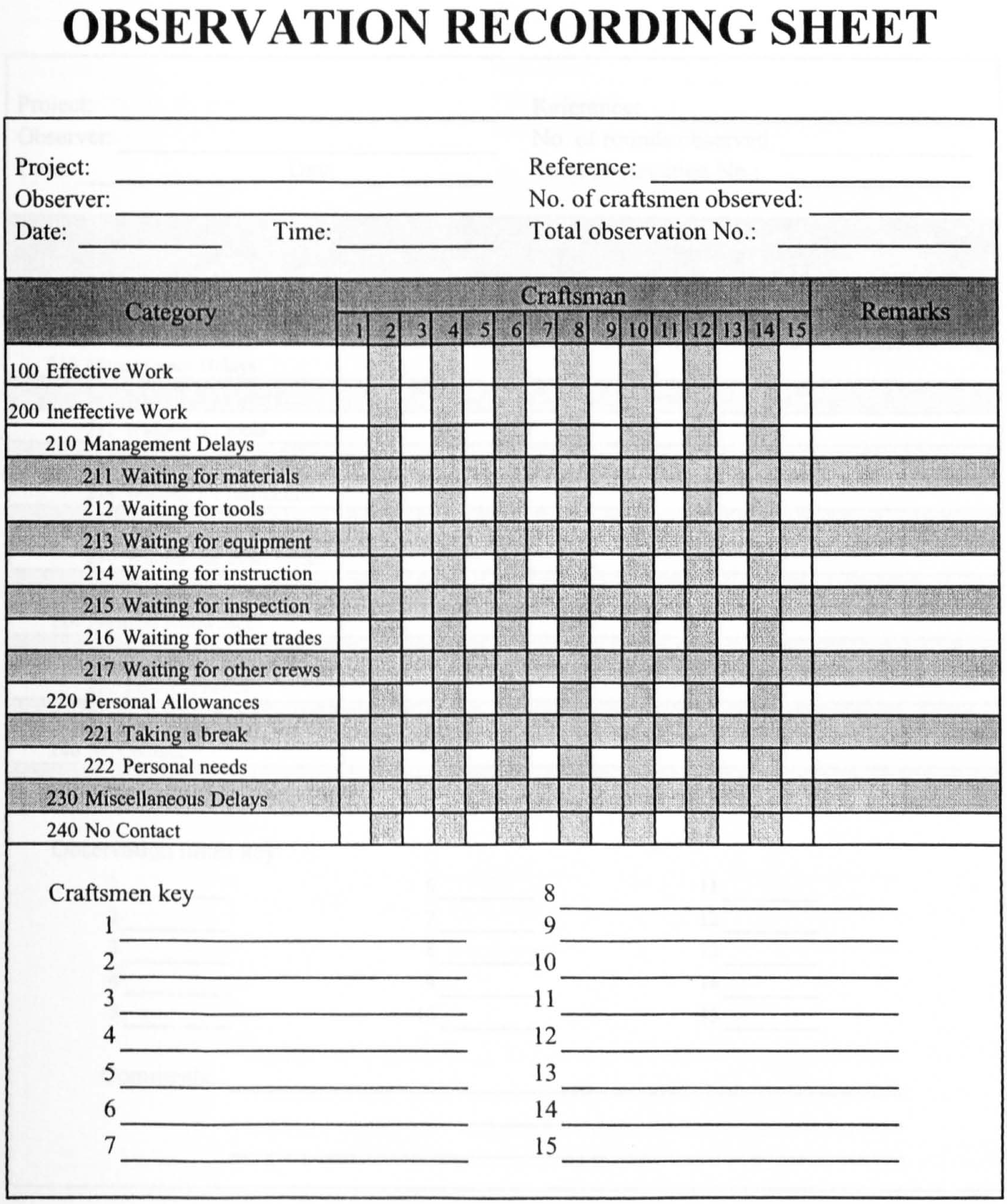
Since it is impossible in the construction industry to separate the fabrication shop from construction site, the author decided to implement the improved work-sampling technique in two cases each for fabrication shops and construction sites, making a total of four cases. The four cases are chosen based on the optimisation between time availability for the research and the representation of data, which conforms to Denscombe (2000), who suggested that a minimum of two case studies should be carried out. In addition, in order to achieve a sample which was as representative as possible, the two types of case study are different in scale. In other words, there will be one large scale fabrication shop and construction site and one small scale fabrication shop and construction site.

Although the availability of research sites is a problem, the author, fortunately, was able to find four cases that comply with the conditions discussed above. Sites 1 and 4 are classified as a large fabrication shop and a large construction site, respectively, while sites 2 and 3 are a small construction site and a small fabrication shop, respectively. These four cases were accessible during October 2001 and January 2002.

4.3.3.2.1. Design the necessary forms

An observation recording sheet, daily summary sheet, study summary sheet, study analysis sheet and observation time recording sheet have been developed for recording data from these 4 sites. The purpose of each form is identified below.

The Observation recording sheet is designed to record observations for each round and all relevant comments or notes about any aspect of observations made are recorded at the time for future assessment, so for every round of observations it is necessary to use a separate sheet. The particular objectives of the study, the degree of detail, the number of categories, and the number of men, machines, or conditions to be observed all govern the actual design of the observation recording sheet. Figure 4.2 exhibits an observation recording sheet for this program.



OBSERVATION RECORDING SHEET

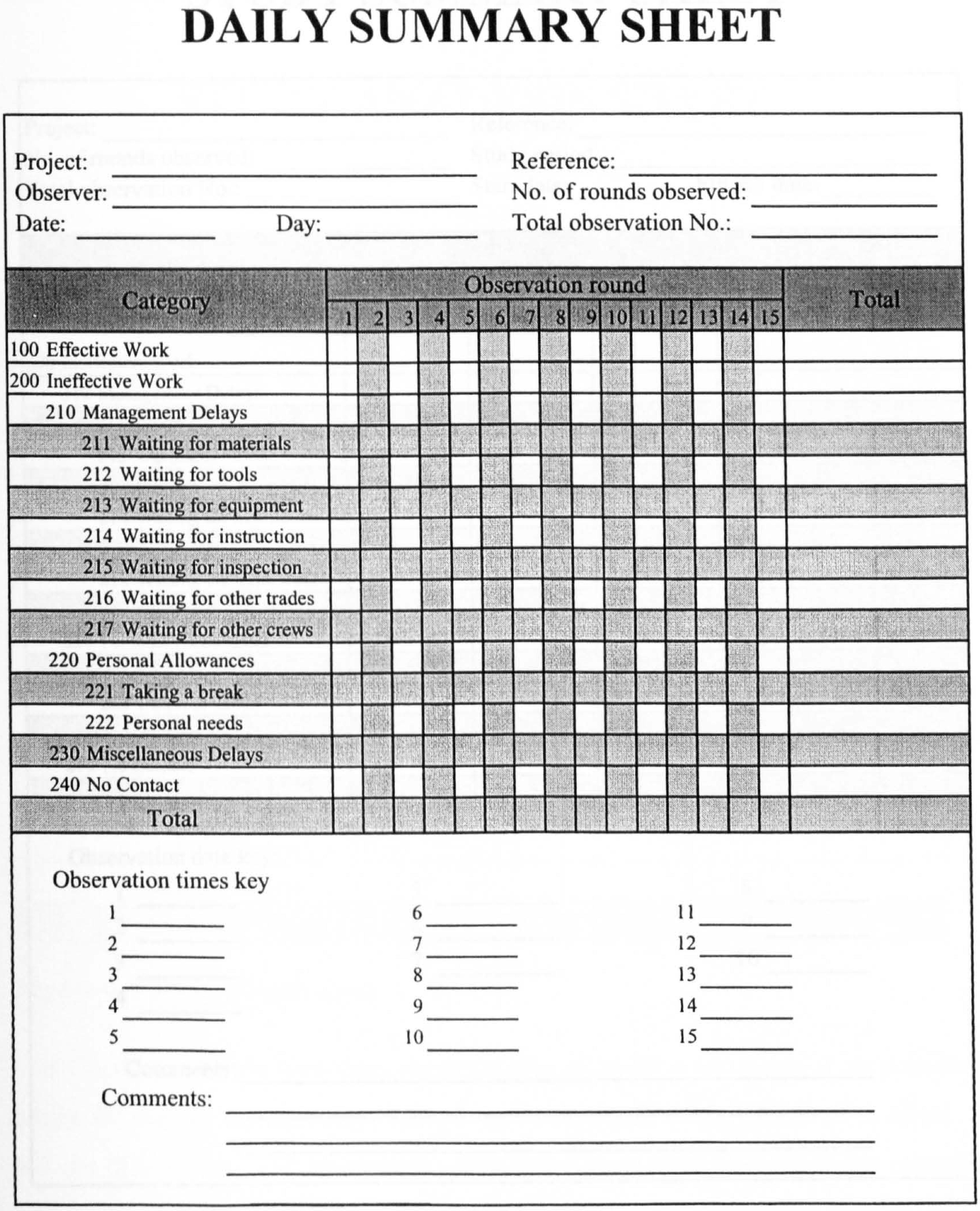
Project: ____________________ Reference: ____________________
Observer: ____________________ No. of craftsmen observed: __________
Date: __________ Time: __________ Total observation No.: __________

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work																
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades																
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 ____________________
2 ____________________
3 ____________________
4 ____________________
5 ____________________
6 ____________________
7 ____________________
8 ____________________
9 ____________________
10 ____________________
11 ____________________
12 ____________________
13 ____________________
14 ____________________
15 ____________________

Figure 4.2 Observation recording sheet

The Daily summary sheet is used to draw together the raw data from the observation recording sheets for a particular observation day and to prepare for the validity test of the study. This usually becomes necessary in a work-sampling study in order to avoid handling a large amount of paper. The sheet has a similar format to the observation recording sheets, but with minor changes to facilitate the collation of the information. A daily summary sheet developed for this study is shown in Figure 3.7.



DAILY SUMMARY SHEET

Project: ______________ Reference: ______________
Observer: ______________ No. of rounds observed: ______________
Date: ________ Day: ________ Total observation No.: ______________

Category	Observation round															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work																
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades																
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																
Total																

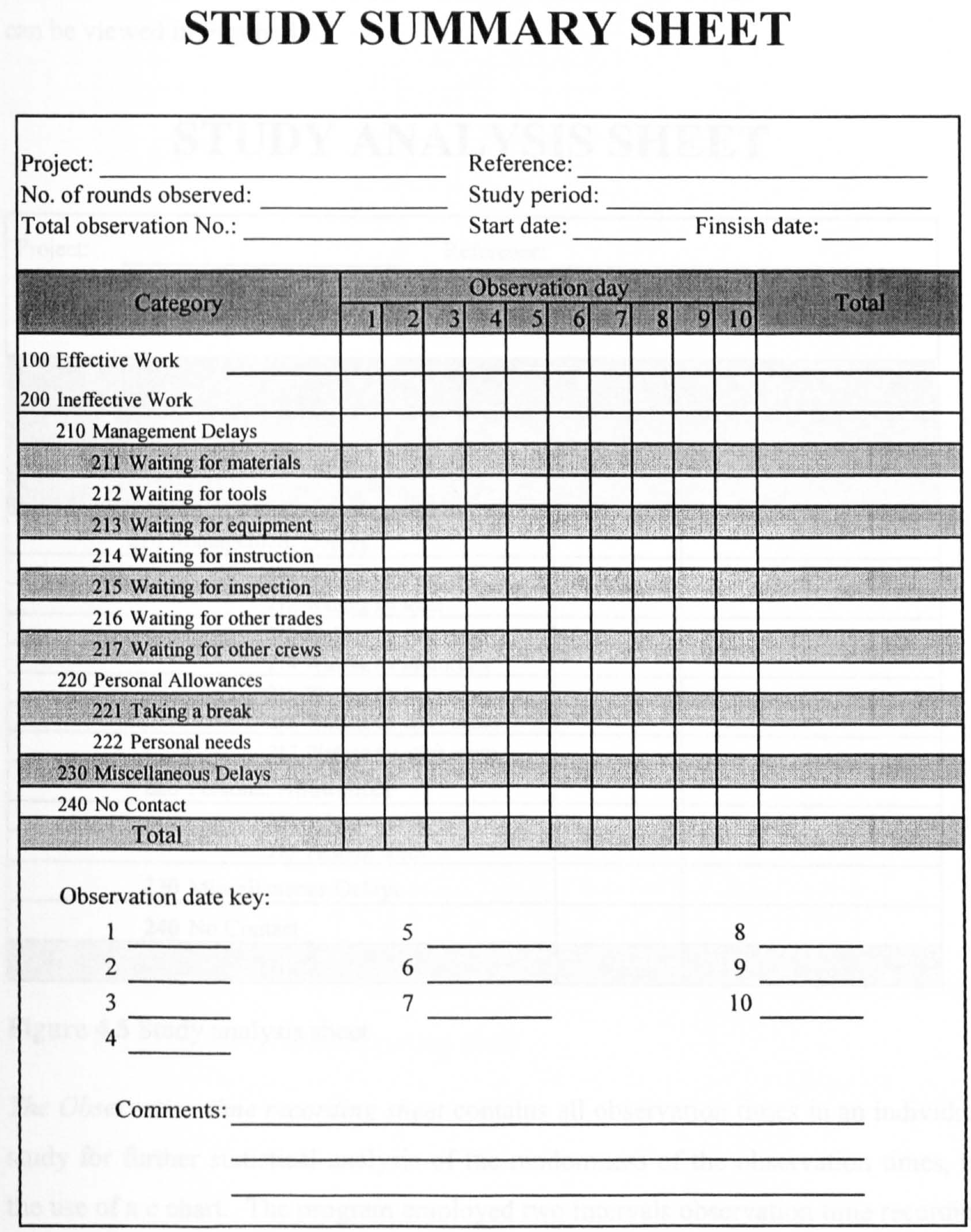
Observation times key

1 ________	6 ________	11 ________
2 ________	7 ________	12 ________
3 ________	8 ________	13 ________
4 ________	9 ________	14 ________
5 ________	10 ________	15 ________

Comments: ______________________________

Figure 4.3 Daily summary sheet

The Study summary sheet includes the data from daily summary sheets in preparation for the statistical analysis that will give the reliability of the study. Again, the sheet is of slightly different format to the two preceding sheets above, with minor changes to facilitate the collation of the information and to provide a more complete picture of the study. Figure 4.4 indicates a study summary sheet for this investigation.



STUDY SUMMARY SHEET

Project: ______________________ Reference: ______________________
No. of rounds observed: ____________ Study period: __________________
Total observation No.: ______________ Start date: ________ Finsish date: ________

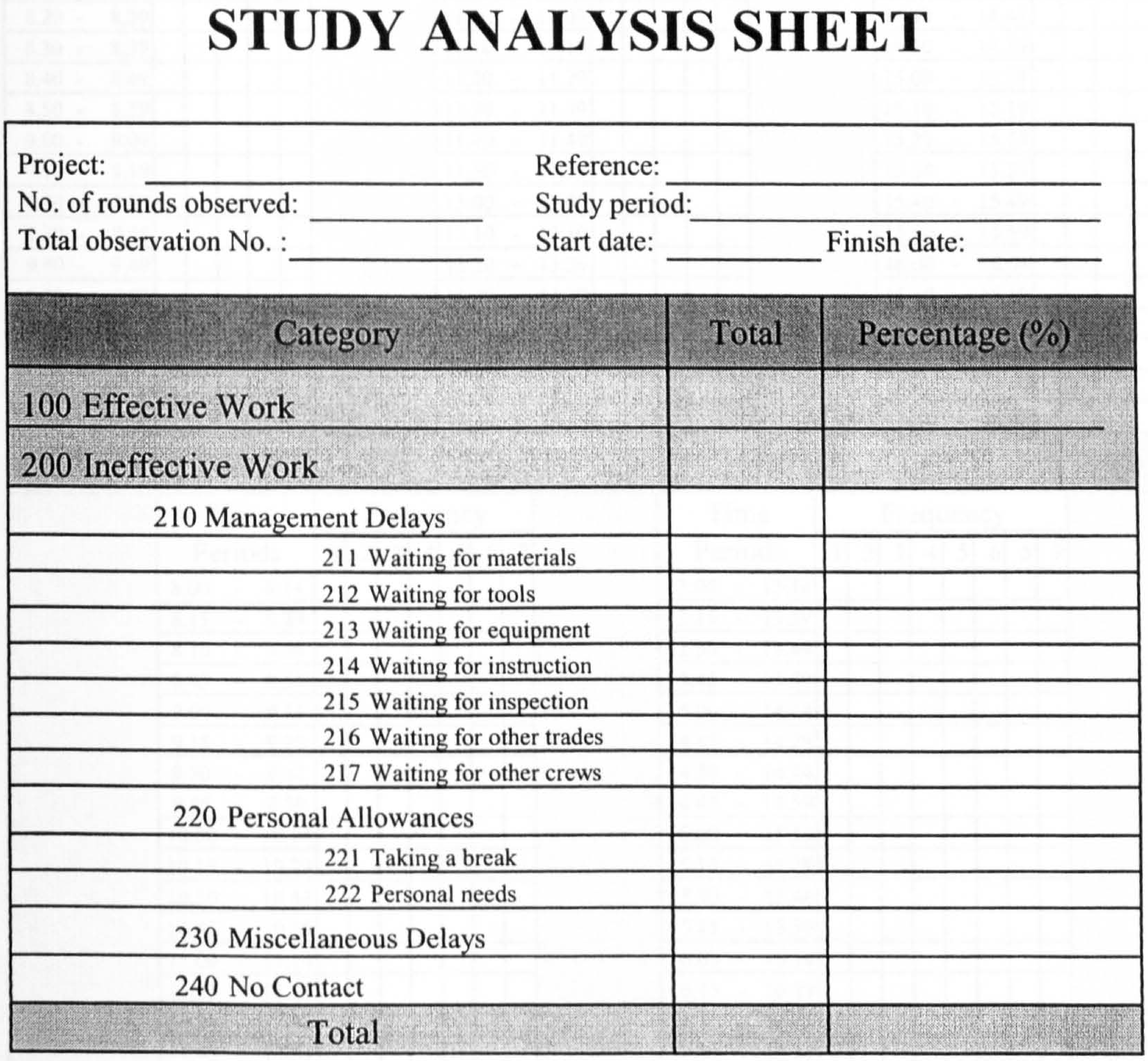
Category	Observation day										Total
	1	2	3	4	5	6	7	8	9	10	
100 Effective Work											
200 Ineffective Work											
210 Management Delays											
211 Waiting for materials											
212 Waiting for tools											
213 Waiting for equipment											
214 Waiting for instruction											
215 Waiting for inspection											
216 Waiting for other trades											
217 Waiting for other crews											
220 Personal Allowances											
221 Taking a break											
222 Personal needs											
230 Miscellaneous Delays											
240 No Contact											
Total											

Observation date key:
1 ________ 5 ________ 8 ________
2 ________ 6 ________ 9 ________
3 ________ 7 ________ 10 ________
4 ________

Comments: ______________________________
____

Figure 4.4 Study summary sheet

The Study analysis sheet is to be completed for the final stage of a work-sampling program. The sheet provides a breakdown by percentage of the time spent by the craftsmen observed on the various effective and ineffective working activities. The percentages arrived at can be related to the total clocked hours to give the amount of time spent on the particular activities to the accuracy defined and the degree of certainty calculated for the study. A study analysis sheet designed for this research can be viewed in Figure 4.5.



STUDY ANALYSIS SHEET

Project: ____________________ Reference: ____________________
No. of rounds observed: __________ Study period: ____________________
Total observation No. : __________ Start date: __________ Finish date: ________

Category	Total	Percentage (%)
100 Effective Work		
200 Ineffective Work		
210 Management Delays		
211 Waiting for materials		
212 Waiting for tools		
213 Waiting for equipment		
214 Waiting for instruction		
215 Waiting for inspection		
216 Waiting for other trades		
217 Waiting for other crews		
220 Personal Allowances		
221 Taking a break		
222 Personal needs		
230 Miscellaneous Delays		
240 No Contact		
Total		

Figure 4.5 Study analysis sheet

The Observation time recording sheet contains all observation times in an individual study for further statistical analysis of the randomness of the observation times, by the use of a *c* chart. The program employed two intervals observation time recording sheets, 48 intervals of 10 minutes each and 32 intervals of 15 minutes each (based on 480 working minutes per day). Figure 4.6 exhibits the sheet.

OBSERVATION TIME RECORDING SHEET

Project: ______________________ Reference: ______________________
No. of rounds observed: ______________ Study period: ______________________
Total observation No. : ______________ Start date: ________ Finish date: ________

48 INTERVALS OF 10 MINUTES EACH

Time Periods	Frequency					Time Periods	Frequency					Time Periods	Frequency				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
8.00 - 8.09						10.40 - 10.49						14.20 - 14.29					
8.10 - 8.19						10.50 - 10.59						14.30 - 14.39					
8.20 - 8.29						11.00 - 11.09						14.40 - 14.49					
8.30 - 8.39						11.10 - 11.19						14.50 - 14.59					
8.40 - 8.49						11.20 - 11.29						15.00 - 15.09					
8.50 - 8.59						11.30 - 11.39						15.10 - 15.19					
9.00 - 9.09						11.40 - 11.49						15.20 - 15.29					
9.10 - 9.19						11.50 - 11.59						15.30 - 15.39					
9.20 - 9.29						13.00 - 13.09						15.40 - 15.49					
9.30 - 9.39						13.10 - 13.19						15.50 - 15.59					
9.40 - 9.49						13.20 - 13.29						16.00 - 16.09					
9.50 - 9.59						13.30 - 13.39						16.10 - 16.19					
10.00 - 10.09						13.40 - 13.49						16.20 - 16.29					
10.10 - 10.19						13.50 - 13.59						16.30 - 16.39					
10.20 - 10.29						14.00 - 14.09						16.40 - 16.49					
10.30 - 10.39						14.10 - 14.19						16.50 - 16.59					

32 INTERVALS OF 15 MINUTES EACH

Time Periods	Frequency							Time Periods	Frequency							
	1	2	3	4	5	6	7		1	2	3	4	5	6	5	7
8.00 - 8.14								13.00 - 13.14								
8.15 - 8.29								13.15 - 13.29								
8.30 - 8.44								13.30 - 13.44								
8.45 - 8.59								13.45 - 13.59								
9.00 - 9.14								14.00 - 14.14								
9.15 - 9.29								14.15 - 14.29								
9.30 - 9.44								14.30 - 14.44								
9.45 - 9.59								14.45 - 14.59								
10.00 - 10.14								15.00 - 15.14								
10.15 - 10.29								15.15 - 15.29								
10.30 - 10.44								15.30 - 15.44								
10.45 - 10.59								15.45 - 15.59								
11.00 - 11.14								16.00 - 16.14								
11.15 - 11.29								16.15 - 16.29								
11.30 - 11.44								16.30 - 16.44								
11.45 - 11.59								16.45 - 16.59								

Figure 4.6 Observation time recording sheet

4.3.3.2.2. Develop and Validate Observation Times

Develop Observation Times

In work-sampling, random times are selected for the start of each tour of observations. These times should satisfy the requirement that every minute of the time that is defined as the sampling population has an equal chance of selection as a time of observation as every other minute. In addition, there should be no pattern to the selection of these times, so one time of observation may be considered as independent of any other time of observation.

Before observation times can be developed, nevertheless, it is essential to select an appropriate sampling procedure. Fortunately, Moder (1980) has clearly established five basic approaches for the adoption of observation intervals in several work-sampling situations. They are simple random sampling, systematic random sampling, restricted random sampling, stratified continuous random sampling and stratified non-continuous random sampling. The following nomenclature will be used in their definitions described below.

T = minutes in the work "day" being sampled (the term day may actually be a half-shift if sampling is interrupted for the lunch period).

N_D = number of work "days" in the study.

N_T = total number of rounds of observations in the study.

N = N_T/N_D = number of rounds of observations per "day."

T/N = average number of minutes between rounds of observations.

M = minutes required to complete a round of observations $M = T/N$ for continuous sampling and $M < T/N$ when sampling observations are part time.

1. Simple Random Sampling (SRS)

Simple random sampling is defined as the selection of N minutes from the population of T minutes without replacement, such that each combination of N of the T minutes has the same chance of being selected. This is equivalent to requiring that each minute has an equal chance of being selected for the sample. If two or more sample times are closer than M minutes, then it is assumed that additional observers will be recruited to assist in the data collection process.

2. Systematic Random Sampling (SyRS)

Systematic random sampling is based on a division of the work "day" into N equal time intervals; SyRS is defined as the drawing of a minute at random from the first sampling interval (1,2,......., T/N) for the start of the first round of observations in the "day," with subsequent rounds of observations starting systematically at intervals of T/N minutes. If the first round starts at time R (1 = R = T/N), then the remaining rounds during the "day" will start at (R+T/N), (R+2T/N),......, [R+(n-1)T/N]. Also, if the start of the final round of observations in the "day" does not allow sufficient time to complete the round, then an appropriate portion of the round must be conducted at the start of the same "day."

3. Restricted Random Sampling (RRS)

Restricted random sampling is defined as the use of SRS in the selection of the sample of size N from the population of T minutes with the restriction that the sample will be rejected and replaced if they are less than M minutes from sample times already drawn. Again, the same concept described in SyRS will be applied to the final sample in the "day," but the randomisation of the routes is not required.

4. Stratified Continuous Random Sampling (StCRS)

Stratified continuous random sampling is defined as the continuous collection of data, where M = T/N, with the proviso that each round of observations will be based on a randomly selected route, which can be accomplished in several ways depending on the circumstances dictated by the system being studied. A random route may be obtained by visualising the worker (or work station) locations as forming a loop, numbering them from 1 to K, and then selecting a random integer from (1,2,......,K) to determine the starting point of the round of observations. For example, if K = 8 and if 6 is drawn for the random starting point, then the route would be 6,7,8,1,2,3,4,5.

If it is deemed necessary, the direction of movement of the observer along the route can also be randomised so that a coin toss of heads might call for the above route, while tails would call for the reverse route 6,5,4,3,2,1,8,7. Finally, if additional variation is deemed necessary, several different route structures can be defined and randomly sampled. For example, the above routes may form a loop through the factory. Another route such as 1,2,3,6,5,4,7,8, might follow a figure eight pattern through the factory. This latter refinement is utilised when it is desirable to further randomise the direction of approach of the observer at each workstation. For this sampling procedure, the time to complete a round of observations (M) must include the average time required to return to the random starting point of each route.

5. Stratified Non-Continuous Random Sampling (StNCRS)

Stratified non-continuous random sampling is defined for the case where observation is non-continuous, i.e. M < T/N; it is based on the selection of a random starting time for the single round of observations taken in each time strata of T/N minutes, with the proviso that the concept as described in SyRS applies in each time stratum. If it is deemed necessary, the observation route can be randomised as described for StCRS.

Selection of a Sampling Procedure

In order to assist one to choose a suitable sampling procedure properly, Moder (1980) also created a decision tree diagram, as shown in Figure 4.7. Referring to Figure 4.7, the appropriate sampling procedure for this study is RRS, as worker bias is possible with systematic sampling, the data collection is not continuous and the use of randomised routes should be avoided as much as possible. Since the procedure has been identified, the observation times can now be created. The method is quite straightforward. As a simple example, consider a work shift of the construction industry in Thailand, where work usually starts at 8.00 hrs., continues until noon, where there is an hour off for lunch and recommences at 13.00 hrs. until 17.00 hrs. Furthermore, there are no specific rest periods or personal time periods, but rather the employee is allowed to attend to his own personal needs whenever he feels like it.

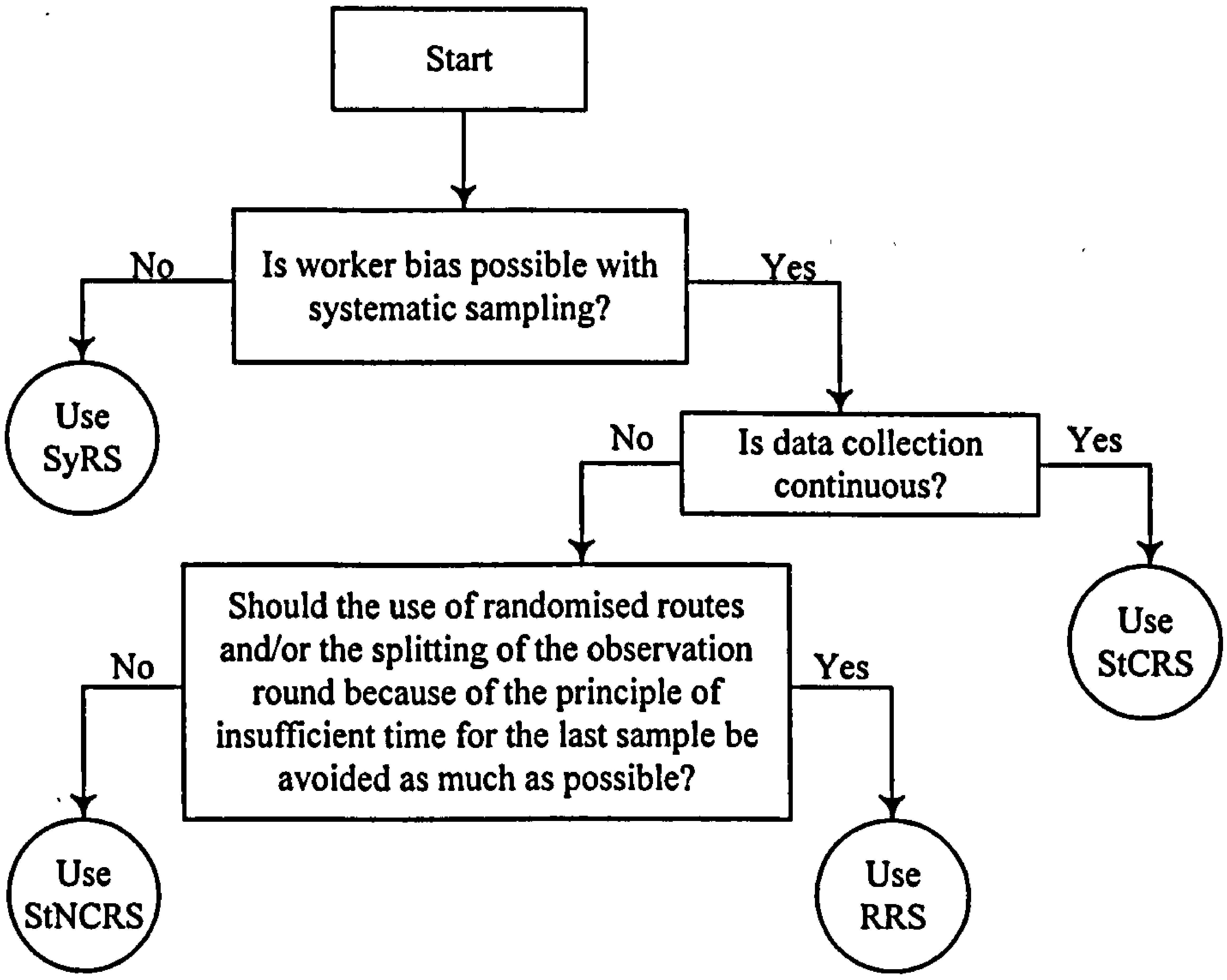


Figure 4.7 Decision tree diagram for the selection of a sampling procedure for a work-sampling study

Source: Moder, J. J. (1980a)

There is, consequently, a solid four-hour period in the morning and another in the afternoon. Starting with the first minute that an observation is possible, 8.00 hrs., it is assigned a consecutive minute number of 000. The next minute, 8.01 hrs., is assigned the number 001 and so forth until 11.59 hrs. This covers four hours or 240 minutes of work; since 000 represented 8.00 hrs, the last minute of observation in the morning would be at 11.59 hrs., whose consecutive number would be 239. The employees take one hour for lunch, during which time there is no sampling. The next time of observation would be 13.00 hrs., with a consecutive number of 240, and the process of assigning the numbers representing the minutes continues until 16.59

hrs., which would have the consecutive number 479. Therefore, random numbers are drawn from 000 to 479 inclusive.

There are two options for drawing random numbers; using standard tables of random numbers (Classical method) and using computer applications like Microsoft Excel (Advanced method). Firstly, with respect to the classical method, a random number table, such as Table 4.4, is completely random, so one can start from any point and proceed in any direction. There is only one rule to remember; a path should not be retraced nor should a number that has been selected previously be purposely selected again. If the number crops up more than once in the normal patterns it can be used, but it should not be made to be represented.

In this research, random numbers are assigned from 000 to 479, eight rounds of observations per day are specified, the sampling procedure is RRS, and the time required to complete an observation round is assumed to be 15 minutes. To illustrate the use of a random number table, start conveniently with the first three digits of the upper left-hand corner. Then, proceed down to the row below, taking the first three digits and so forth, and key these numbers to the times of the day. Accordingly, we have:

128
999___out
810___out
259
366
782___out
831___out

524___out
458
817___out
481___out
716___out
864___out
464

832___out
007
668___out
798___out
387
771___out
133

The useful numbers which remain, in numerical order, are:

007 = 8.07 hrs.
128 = 10.08 hrs.
133 = 10.13 hrs.
259 = 13.19 hrs.
366 = 14.06 hrs.
387 = 14.27 hrs.
458 = 16. 38 hrs.
464 = 16.44 hrs.

If simple random sampling (SRS) is selected as the sampling procedure, second observers will be required for the third and the eighth rounds of observation, since the intervals between those times and the previous ones are less than 15 minutes (the time, assumed, required to complete an observation round). However, this work-sampling study employs restricted random sampling (RRS), so 133, the third round, and 464, the last round, have to be removed. As the result, further random numbers must be drawn, by simply continuing down, to give:

190
180___out
000___out

560___out
743___out
520___out

255___out
102

From this list, we have the following useful numbers, in numerical number:

102 = 9.42 hrs.

190 = 11.10 hrs.

Again 0, 180, and 255 are out because they do not allow sufficient interval for an observation round at 7 (8.07 hrs.), 190 (11.10 hrs.), and 259 (13.19 hrs.), respectively. Finally, the observation times, as shown in Table 4.3, have been developed. To develop further observation times, the process is repeated, by simply continuing down, or starting by drawing numbers from anywhere in the table (only always bear in mind the rule discussed previously).

Table 4.3 An example of observation times for the program

Rounds of observation	1	2	3	4	5	6	7	8
Random numbers	007	102	128	190	259	366	387	458
Time (hrs.)	8.07	9.42	10.08	11.10	13.19	14.06	14.27	16.38

The other way to develop observation times, advanced method, is to employ a computer. Although there may be other software capable of random number generation, this study utilises Microsoft Excel. A random observation time could be generated by typing "=RAND()*(0.665972-0.333333)+0.333333" in any particular cell. This command automatically generates a random time between 8.00 hrs. to 16.49 hrs., less one hour for a lunch break from 12.00 hrs. to 12.59 hrs. Nevertheless, a random number generated in this way is required to be converted to a random time by using the format time function. Then the process and the procedure identified above is repeated until the number of observation rounds, for example, 8 rounds per day, have been accomplished.

Table 4.4 Table of four-digit random numbers

Source: Stoodley, K. D. C. (1974)

8538	5652	3825	8069	3638	8168	5874	3016	4916	4017
1680	1045	4207	9911	5120	1436	5478	2050	0140	9490
1274	1845	7586	5439	3651	4487	1124	6852	6376	7387
3789	9852	1384	0936	7248	3038	2330	9445	5546	5413
1372	3225	1340	3776	2064	0777	7695	5039	6354	6291
5148	8782	7006	1089	0744	2238	8057	2452	3469	2895
1263	7000	7839	8857	9399	3835	5821	6633	6282	8447
0389	6614	3807	1157	5260	4021	4981	9257	2320	8346
1409	9047	5305	7789	8097	0948	6271	7751	6712	0232
8964	8553	0229	6338	4159	6586	1574	5548	7673	9042
3313	7263	9491	6440	8692	8794	3350	4181	0177	7442
2225	0378	0714	1518	9732	4500	2248	9512	7958	2989
9647	7736	8648	2926	3545	4480	6638	3811	7919	7976
3795	1165	5704	5795	1863	5080	8657	5156	5719	3966
0533	5352	6389	2115	3288	2803	7439	0936	1779	6901
2915	6832	5731	2945	2672	6013	0031	0158	2378	8060
7623	8119	3966	2914	0255	1930	8304	3345	1881	0123
1238	1466	4158	1977	4613	2576	0033	2803	9396	6187
3350	2904	1031	8490	6096	7879	0786	8915	1796	7639
2296	4834	1507	7977	7418	2567	0075	7991	9106	1315
9275	4914	1027	8670	2944	7316	5207	2752	1037	2528
5422	0052	0210	7722	3427	0872	1519	1427	3150	0531
6711	2936	5465	8312	0641	6449	5129	1744	4065	2576
4077	7090	1939	8410	5075	4599	4099	1470	1060	1643
7210	0958	6718	4633	1330	2254	0073	1979	9303	4781
9783	1863	6896	6847	3813	1615	2945	4736	7009	9727
1215	6966	3207	2509	7752	1630	3383	0243	0213	5248
1093	8248	6654	7002	0273	6027	5619	5402	1889	1781
2266	6868	9686	1819	9240	9573	5411	3633	8428	1747
3240	6434	3634	9071	6608	7613	6845	2575	6771	4691
1798	8732	5286	5679	9257	4961	8908	8047	4269	8474
6874	0217	9489	8651	3659	0589	6865	1824	1299	4365
9151	6463	4540	2856	9313	1890	3378	0552	0198	3125
2429	7774	5442	0930	4648	1603	7129	9444	0993	8861
7988	9150	6019	8558	0872	8168	2981	8065	8648	3989
2336	5703	3163	1904	3129	7982	9262	2334	4107	3105
8611	3580	2236	0562	4365	0952	6361	6463	8262	4743
7148	8310	4966	0452	9533	5404	5524	7380	4473	5165
3692	3759	6633	4864	2335	5050	7969	1834	3280	2593
9207	5463	0403	1669	7313	1064	6549	0580	2152	0937
4564	7756	7562	7563	5114	0568	6217	1184	4346	5327
1145	1079	3905	2344	4009	2741	4767	9920	9968	5409
1568	2566	9566	5446	6355	9463	5669	2381	3892	9932
2204	3116	3036	0573	2156	5442	0522	8498	7151	7579
7428	3988	1076	6609	6488	1553	6746	0332	1369	1505
6137	7780	3106	0254	2094	5243	7566	6982	8275	2223
4404	7009	7525	5110	7767	1926	1900	2135	0200	6934
3265	1679	4779	9354	6167	0043	4031	9577	3742	7648
2130	2805	6675	9785	9814	7657	9783	4755	1957	2105
5941	0979	8287	5980	5116	6738	5668	2173	3023	8432
1286	8446	3494	5701	4927	3155	9975	6236	1394	4411
9991	3845	6342	8624	4090	6839	0637	3194	8225	1499
8105	7214	4355	7157	0722	9394	4124	0192	1235	5744
2598	0925	4598	3767	0304	4849	0358	2742	0427	0073
3661	9100	6794	5199	5292	1144	1880	7227	0979	8262
7820	5859	1665	6768	7482	5296	9139	3341	4511	7758
8315	8122	1963	6826	1969	7782	0584	3611	0958	0053
5240	3625	8117	3514	8676	5168	9402	4478	2839	8420
4580	2145	0695	8024	7396	3926	4780	3150	1705	7112
8179	2129	8555	0214	4608	1331	2600	1432	5934	0198
4818	7178	4122	5891	8913	6633	4918	5841	6782	6428
7169	7448	2351	5643	6620	0913	8295	0809	5347	0739
8641	0188	5995	6214	3065	1011	1402	5661	7511	3897
4643	6480	2838	3909	7264	7872	1889	8577	3310	4249
8322	7192	6548	6080	4392	7965	7814	1518	4455	6497
0073	6022	8657	1889	7082	9924	1744	2642	2576	9615
6682	5967	6422	2396	4137	8354	4675	7578	9025	9125
7981	2451	3231	7571	9207	3447	0592	8992	2378	1836
3874	0700	9079	1130	3922	2295	3238	1549	4683	1878
7710	1375	9922	5851	3571	6027	0586	2524	5256	6998
1330	0398	5823	8288	3200	6664	6126	0409	1962	8643
1901	0960	6463	4827	2235	5853	2457	2425	3754	3789
1892	0839	6213	2849	6522	5460	4789	0463	0214	5408
0007	5023	6005	9476	7923	4830	7448	4472	7204	6295
5602	7100	4894	8618	3221	7669	9651	8390	4152	1360
7430	3633	2260	7504	9087	2947	7292	4783	9257	3514
5203	8107	9008	2863	6839	7188	3294	9197	5957	1005
2552	1896	3401	5281	1957	5171	4249	9025	1256	0542
1026	9829	5385	3302	6708	4985	7919	2841	3221	1712
8095	5499	3351	9421	3388	9428	0833	5595	3724	3168
7625	7343	2179	5001	6571	2186	2380	1358	0437	9396
6101	1419	2260	6194	7400	1786	5506	0180	8112	0479
2420	8475	1902	5979	5678	0540	0728	5607	8107	2726
7424	6954	3552	2305	5957	8042	2909	9797	7872	7250
9985	9282	5236	1101	7554	2283	3885	9884	8673	4909
3484	8711	6899	4932	8079	5283	2266	9393	2427	0691
0531	7673	5483	8365	3760	6082	3804	0687	3408	4012
6624	1967	3602	8883	9511	0407	6128	7996	3329	5607
5811	8533	3016	4769	3527	9025	0416	4202	2013	8851
7306	3409	6234	2234	8613	0580	7037	0574	4010	1047
7166	9051	9646	5299	0589	7208	6075	9518	9951	1415
8143	1135	6317	1882	6907	0531	5325	3922	5023	2936
7030	5034	7435	6832	6297	6519	4011	0420	5663	2670
0597	1121	6194	2816	7837	7335	2636	4338	8798	6343
6944	5548	6127	6477	2984	3846	4968	4027	0483	6533
4899	9485	6316	2021	0844	8970	0320	8500	4670	9085
7460	3591	9133	0020	8382	5285	8288	9196	8052	0183
4772	3894	8216	7496	8460	0334	1810	4624	6199	8129
0710	8960	8925	5558	8762	8733	8302	9823	8612	0315
9498	8355	3426	4136	3048	8534	5759	6479	4809	9661

Validate Observation Times

After all observation times required have been developed, it is important to validate the observation times before their application. This is because, unless the observation times are valid, the data recorded will not be valid. A validity test of observation times can be done by the use of a *c* chart.

The *c* chart may be called the "chart for observations (or rounds of observation) per selected time interval." This chart is used in order to ensure randomness in the observation times. The chart is drawn on the assumption that about 99% of the data will lie between UCL and LCL. A typical chart is shown in Figure 4.8. The *c* chart can be defined as below.

$$\begin{aligned} UCL &= \bar{c} + 3\sqrt{\bar{c}} \\ CL &= \bar{c} \qquad \text{............(4)} \\ LCL &= \bar{c} - 3\sqrt{\bar{c}} \end{aligned}$$

where; $\bar{c}$ = an average number of observations round per interval

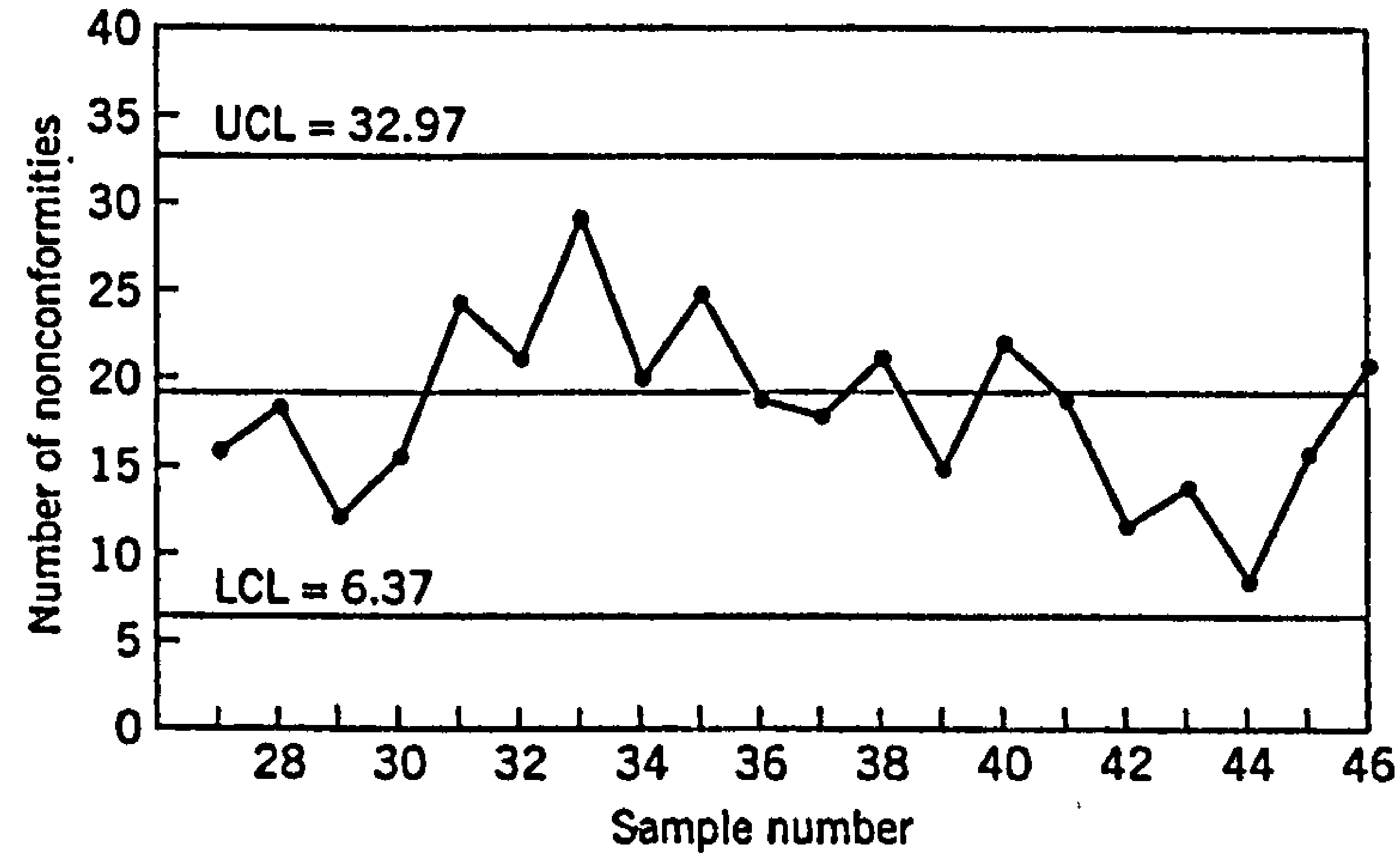


Figure 4.8 A typical *c* chart

Source: Montgomery, D. C. (1996, p. 279)

4.3.3.2.3. Record Data

If the planning and preparation work has been thorough, the actual taking of observations should not present any particular problems. At each observation point, the activities of each of the craftsmen seen are recorded in the appropriate box on the observation recording sheet. At the end of each working period, the observers pass all observation recording sheets to the study leader for processing. Observations, however, must never be taken for granted or allowed to be done in a sloppy manner. Since work-sampling is a statistical procedure, it is important that the data remain as unbiased as possible. The following rules should always be borne in the mind by the observers:

1. *Punctuality of the observation times.* It is necessary to follow the schedule of times for observations exactly in order to maintain randomness. Nevertheless, if the observations are not made on schedule, they still may be random. There are methods of testing this condition (previously described), in any case, the actual time should be noted. It is better to make a round of observations late or early than to omit the round.

2. *Avoidance of any biased habit patterns in making observations.* This rule applies not only to the route the observer follows, but also to any other habit, such as stopping at the same place each round for conversation or to check in, which might give undue advance notice of his observation. Or, if he passes a work station more than once, he may vary the part of the round at which he makes his observation.

3. *Precision in categorising observed activity.* The observer must be ruthlessly honest and must record the particular activity or delay of the machine or worker when he makes his observations. In other words, the observer must not attempt to anticipate any particular action, but rather record what he sees at the given instant of observation. For example, even if the worker is on the point of starting the machine when the observer arrives, unless the machine has actually started up the entry on the observation sheet must be placed in the appropriate delay column. Randomness of times of observation and the taking of large numbers of observations are the means of protecting the worth of the study. Consequently, if the observers follow the rules, the results will be satisfactory and will reflect the

true proportion in each category. In this research, if any craftsmen observed are idle, identification of the delay is ascertained by asking the particular craftsman the cause of the delay directly or, alternatively, the foreman for the particular trade. The record is then entered accordingly.

The implementation of the work-sampling on four construction cases in Thailand would explore which factors have the greatest potential to change the productivity, which is Research question no. 4, and to find out how effective work-sampling is in terms of a productivity improvement tool.

4.3.3.3 Justification of the Markov Process as a Prediction Tool

In order to find the answer for Research question no. 3, the Markov process will be employed. Since Markov analysis has been developed, the procedure has been successfully applied to a wide range of managerial decision making in marketing, such as market share analysis; production (such as machine maintenance); and finance, such as the ageing of accounts receivable (Dennis and Dennis, 1991). Example of vast areas of the implementation can be viewed from Herniter and Magee (1961); Linquist (1962); Buzacott and Callahan (1973); Bailey and Mahon (1975); Chao and Manne (1983); Sam and Wang (1984); and Love (1985).

Herniter and Magee (1961) preferred to know which catalogues to send to individual clients taking into account the costs and incomes derived, consequently, the authors carried out the Markov process to find out the infinite horizon expected, discounted net profit and long-run profit per unit time. The results when implemented increased the performance.

Linquist (1962) used this technique to find out how much hydroelectric power should be generated to supplement thermal power, and where the excess power may be sold, so that the expected production costs and net sales income, over a finite time horizon could be obtained. The states are the reservoir contents. The implementation confirmed the appropriateness of the model, which has been in use since 1959.

Buzacott and Callahan (1973) applied Markov analysis to clarify how a steelworks should make use of soaking pits, whose purpose is to raise ingots to the appropriate temperature for feeding into the primary rolling mill and to find out loss per unit time in the long run at the primary mills. Both hot and cold ingots are put into the soaking pits. When a soaking pit becomes empty, the decision to be made is which source, if any, to use to fill it. The states are descriptions of soaking pit configuration (numbers of empty pits, cold pits, and so on). Although the problem was simplified, the analysis indicated the nature of optimal policies and was used to guide subsequent simulations on the basis of which actual decisions were made.

Bailey and Mahon (1975) investigated at what age a vehicle of The British Army becomes too expensive to repair and should be replaced, with the objective of long-run cost per unit time. The states are the age and anticipated repair cost of the vehicle. The results suggested a proposed improved replacement policy for Army Vehicles, which offers a significant estimated saving of at least £0.5 million per year.

Chao and Manne (1983) had to made decisions concerning domestic energy production, energy imports and fill rates each year. The Markov process, therefore, was implemented to clarify the expected discounted net consumption after allowing for energy costs. The states are the stock levels of oil and states of the world market. Although not implemented, real data was used for an analysis of the period 1980-85.

Sam and Wang (1984) presented this procedure to assess the reliability performance of redundant standby systems in nuclear generating stations. These systems are inactive during the normal station operation, however they are required to operate for a specified period after the loss of the normal power supply during an emergency. The states are expected financial saving on optimisation between the number of redundant units and the number of repair teams. These authors specified that the Markov process provided a useful tool for comparing the effects of increasing the number of redundant units in the standby system or the number of repair teams to be organised during the mission.

Love (1985) applied the Markov process to a vehicle rental company to predict the discounted opportunity losses arising from not having vehicles available to meet demand. The company rents vehicles out at two depots to be returned to the other depot. Some vehicles are retained for service of a different kind. How many vehicles to retain for service between the two depots must be decided. The states are number of vehicles at one depot and the number of vehicles in service at each depot. The author reported that although multi-depot extensions are too complex to handle, the two-depot problem, involving an actual case of movement between Toronto and Vancouver, did provide results, which gave management a framework for decision-making.

Referring to these versatile successful implementations, there is no doubt about the effectiveness of the Markov process, as a prediction tool. Consequently, it is reasonable to apply this procedure to predict the results of a work-sampling study, so that question no. 3 can be answered.

4.4 Research Variables

Table 4.5 Factors affecting productivity gathered from previous studies

Factors	Authors						
	B&S	H&H	K(98)	K(97)	O&O	O	Z
Lack of material	X		X	X	X	X	X
Incomplete drawing		X					X
Lack of tools and equipment	X	X	X	X	X	X	X
Poor site conditions		X					X
Incompetent supervisors	X					X	X
Change orders		X					X
Rework	X		X	X		X	X
Tools/equipment breakdown		X	X	X	X		X
Poor communication							X
Poor site layout		X					
Inspection delay	X					X	X
Absenteeism	X	X	X	X		X	X
Instruction time	X		X	X		X	
Overcrowding	X		X	X			
Specification and standardisation							X
Interference	X		X	X			X
Weather		X					X
Workers turnover	X	X	X	X		X	X
Accident		X					X
Changing of foremen	X		X	X			

The twenty factors influencing the productivity of the construction industry in Thailand were gathered from a literature review of previous studies, which revealed that all of them have effect on construction productivity. These studies are Borcherding and Sebastian (B&S) (1980), Hanna and Heale (H&H) (1994), Kaming *et al.* (K/98) (1998), Kaming *et al.* (K/97) (1997), Olomolaiye and Ogunlana (O&O)

(1989), Olomolaiye *et al.* (O) (1987) and Zakeri *et al.* (Z) (1996). A list of the factors identified and the relevant author is shown in Table 4.5.

Figure 4.9 illustrates the relationship between the factors and changes in construction productivity, referring to the Research questions no. 1 and 2. The research will identify which five of them are the most significant factors affecting construction productivity and will specify what types of relationship they are, i.e. positively or negatively related.

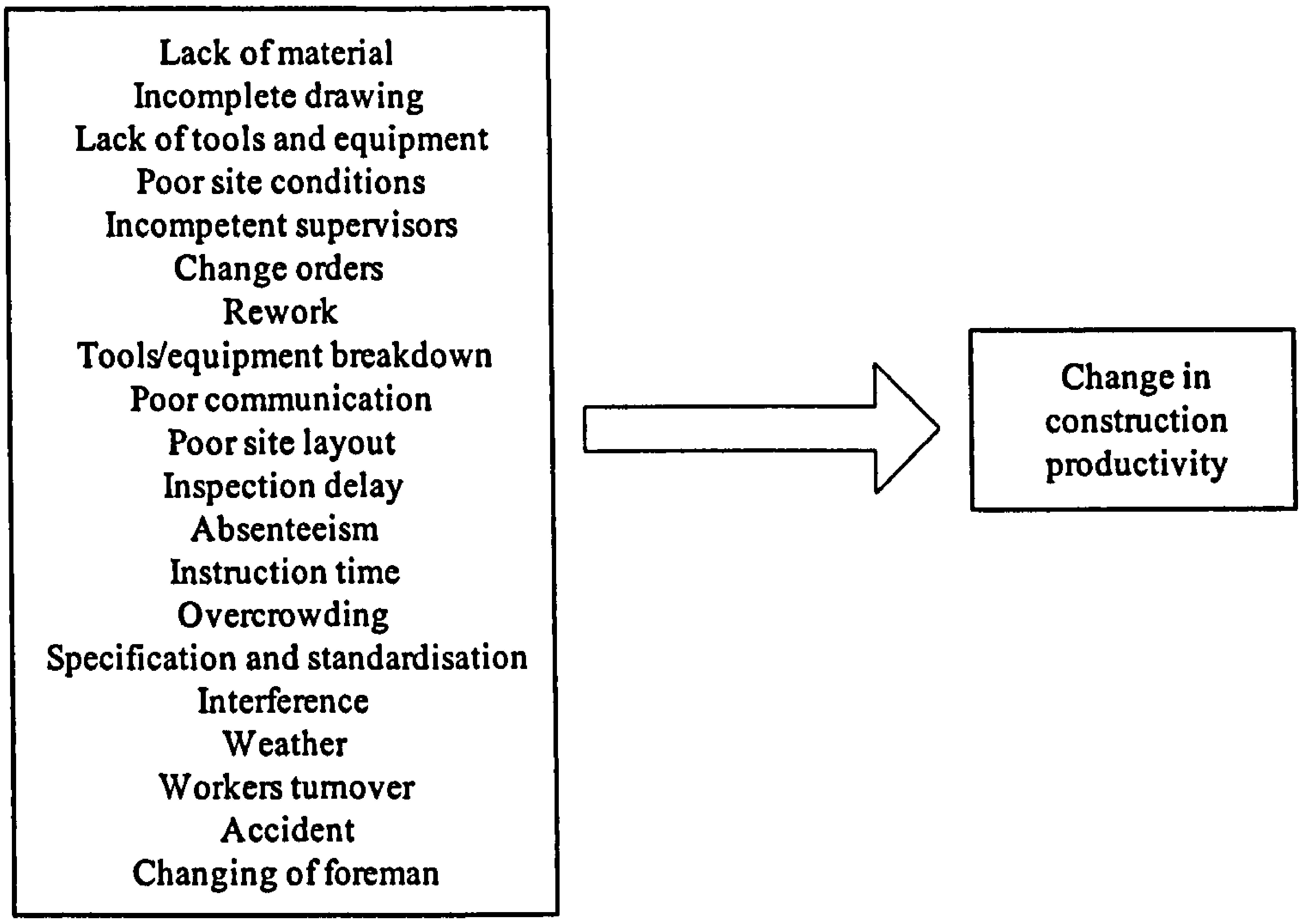


Figure 4.9 Research model demonstrating relationship between the 20 factors and the construction productivity improvement

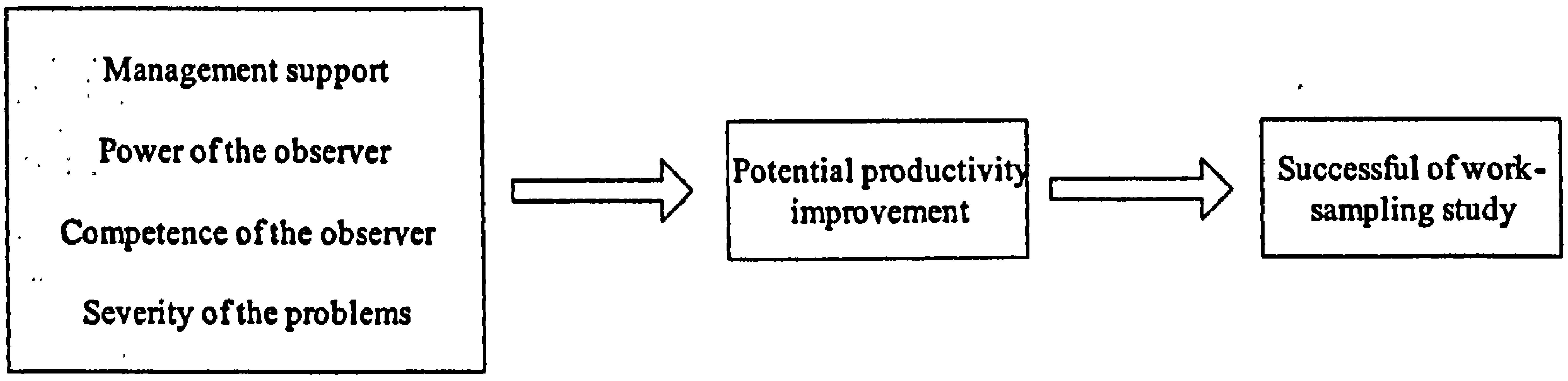


Figure 4.10 Research model demonstrating the relationship between the factors contributing to the success of a work-sampling study

Regarding Research question no. 4, Figure 4.10 shows those factors which have an effect on the success of a work-sampling application, having potential productivity improvement as an intervening variable. The factors were acquired from both the literature review and the experience of the author during the case study. Management support, the first factor, has been widely accepted by many authors as having a high level of influence on productivity improvement (Borcherding *et al.*, 1980; Anon, 1981; Howell, 1981; Strandell, 1982; Handa and Rivers, 1983; Horner *et al.*, 1987; and Thomas *et al.*, 1990). In addition, the other three factors included, are derived from the author's experience.

4.5 Validity Test

4.5.1 *p* Chart

Daily basis and observation round basis are two forms of validity test for this study, of which either can be calculated from the equation identified below:

$$\begin{aligned} UCL &= \bar{p} + 3\sigma_p = \bar{p} + 3\sqrt{\frac{\bar{p}(100-\bar{p})}{n}} \\ CL &= \bar{p} \qquad \qquad \qquad \text{..........(5)} \\ LCL &= \bar{p} - 3\sigma_p = \bar{p} - 3\sqrt{\frac{\bar{p}(100-\bar{p})}{n}} \end{aligned}$$

where; $\bar{p}$ = average percentage of delay

n = number of samples in an observation round

4.5.1.1 Daily Basis

Having done the tests, through the application of equation 5, the author has found that all the tests based on daily basis are within acceptable limits. Consequently, a typical daily basis *p* chart will be demonstrated, using data from the second study of site 3, as follows:

Table 4.6 Delay percentage of the second study for site 3 (by day)

Day	1	2	3	4	5	$\bar{p}$
% Delay	32.22	36.67	27.78	33.33	34.44	32.89

According to equation 5, where $\bar{p} = 32.89$ and $n = 90$,

$$\mathrm{UCL} = 32.89 + 3\sqrt{\frac{32.89 \times (100 - 32.89)}{90}} = 32.89 + (3 \times 14.85) = 47.74$$

$$\mathrm{CL} = 32.89$$

$$\mathrm{LCL} = 32.89 - 3\sqrt{\frac{32.89 \times (100 - 32.89)}{90}} = 32.89 - (3 \times 14.85) = 18.04$$

Therefore, UCL = 47.74, CL = 32.89 and LCL = 18.04. Then, % delay of a particular day can be plotted on the *p* chart, as shown in Figure 4.11.

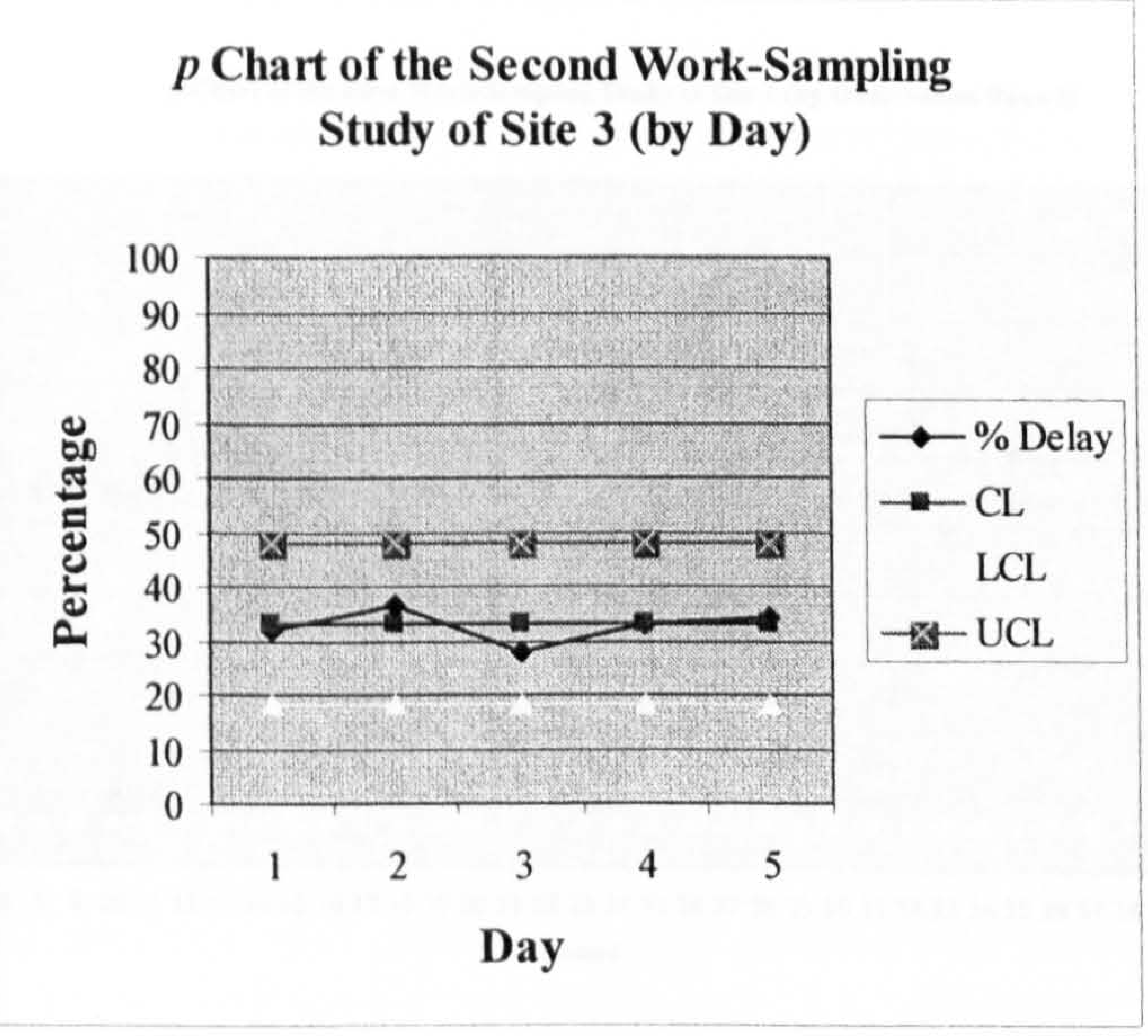


Figure 4.11 *p* chart for the second work-sampling study for site 3 (by day)

4.5.1.2 Observation Round Basis

There are four studies based on the observation round that contain abnormal events, which are the first study of sites 1, 2 and 3 and the second study of site 3. The explanations of these events are described below:

4.5.1.2.1 Site 1 (The First Study)

Table 4.7 Delay percentage for the first study for site 1 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	40	40	70	60	40	40	50	40	50	40	40	70	40	40	50
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	70	60	40	60	40	50	60	70	40	40	60	60	50	70	70
Rounds of observation	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
% Delay	70	70	50	40	60	60	50	50	70	50	40	60	60	70	70

According to equation 5, where $\bar{p} = 53.78$ and $n = 10$,

$$\mathrm{UCL} = 53.78 + 3\sqrt{\frac{53.78 \times (100 - 53.78)}{10}} = 53.78 + (3 \times 15.77) = 100.00$$

$$\mathrm{CL} = 53.78$$

$$\mathrm{LCL} = 53.78 - 3\sqrt{\frac{53.78 \times (100 - 53.78)}{10}} = 53.78 - (3 \times 15.77) = 6.48$$

Therefore, UCL = 100.00, CL = 53.78 and LCL = 6.48. Then, % delay of a particular round of observation can be plotted on the *p* chart, as shown in Figure 4.12.

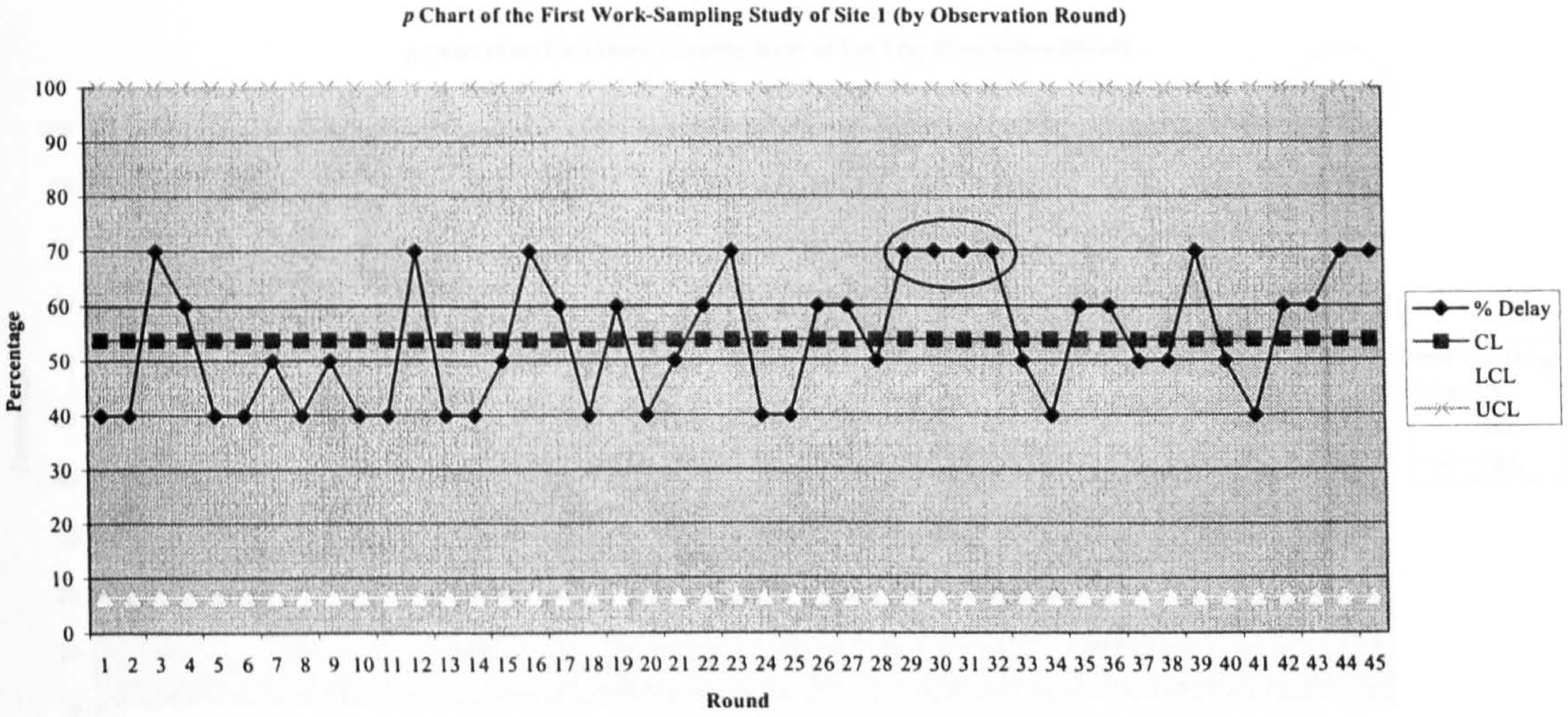


Figure 4.12 *p* chart for the first work-sampling study for site 1 (by observation round)

Referring to Figure 3.11, the unusual pattern occurring in observation round 29-32, falls into case *f*. The cause of the event is due to material unavailable for the fitter (mark/cut), so the delays are abnormally high. As the cause is cyclical, it cannot be eliminated.

4.5.1.2.2 Site 2 (The First Study)

Table 4.8 Delay percentage for the first study for site 2 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	50	50	60	40	20	40	60	40	40	40	50	70	40	70	30
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	60	40	40	40	60	20	40	30	40	50	50	40	30	50	50
Rounds of observation	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
% Delay	40	50	60	40	30	10	40	60	40	50	50	20	40	100	30

According to equation 5, where $\bar{p} = 44.44$ and n = 10,

$$\text{UCL} = 44.44 + 3\sqrt{\frac{44.44 \times (100 - 44.44)}{10}} = 44.44 + (3 \times 15.71) = 91.57$$

$$\text{CL} = 44.44$$

$$\text{LCL} = 44.44 - 3\sqrt{\frac{44.44 \times (100 - 44.44)}{10}} = 44.44 - (3 \times 15.71) = 0.00$$

Therefore, UCL = 91.57, CL = 44.44 and LCL = 0.00. Then, % delay of a particular round of observation can be plotted on the *p* chart, as shown in Figure 4.13.

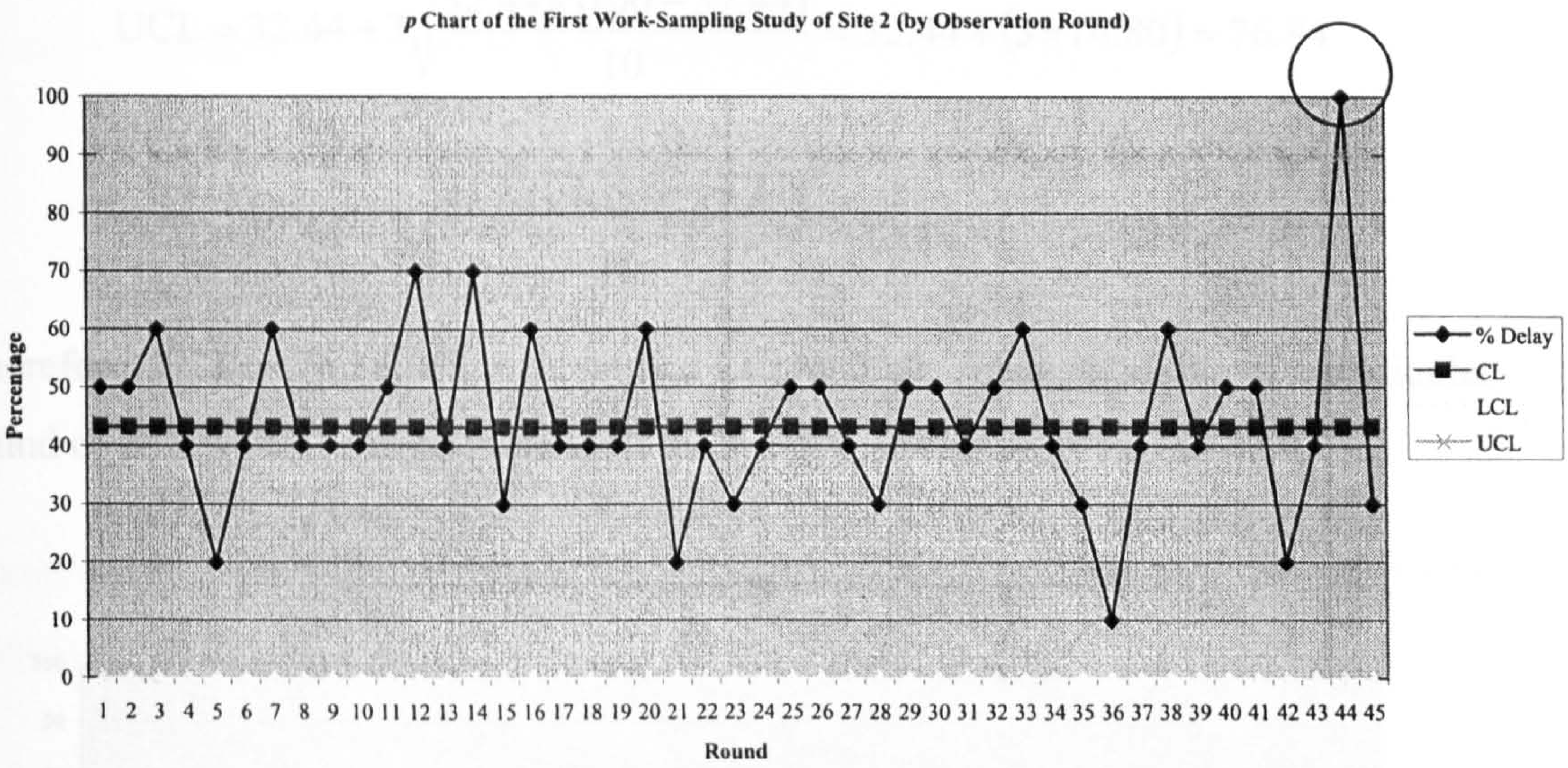


Figure 4.13 *p* chart for the first work-sampling study for site 2 (by observation round)

It is obvious that the % delay of observation round 44, 100%, is over the UCL, which is an abnormal pattern categorised as case a, according to Figure 3.11. This irregularly high delay occurred due to the effect of rain, so the associated data can be discarded. Therefore, the actual % delay, after eliminating the delay of this study, is 43.18%.

4.5.1.2.3 Site 3(The First Study)

Table 4.9 Delay percentage for the first study for site 3 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	10	40	20	40	40	20	60	30	20	0	40	30	80	10	40
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	50	10	40	20	40	20	60	30	40	60	20	30	30	0	50
Rounds of observation	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
% Delay	20	30	40	20	60	70	0	20	40	20	30	20	10	50	50

According to equation 5, where $\bar{p} = 32.44$ and n = 10,

$$\mathrm{UCL} = 32.44 + 3\sqrt{\frac{32.44 \times (100 - 32.44)}{10}} = 32.44 + (3 \times 14.80) = 76.84$$

$$\mathrm{CL} = 32.44$$

$$\mathrm{LCL} = 32.44 - 3\sqrt{\frac{32.44 \times (100 - 32.44)}{10}} = 32.44 - (3 \times 14.80) = 0.00$$

Therefore, UCL = 76.84, CL = 32.44 and LCL = 0.00. Then, % delay of a particular round of observation can be plotted on the *p* chart, as shown in Figure 4.14.

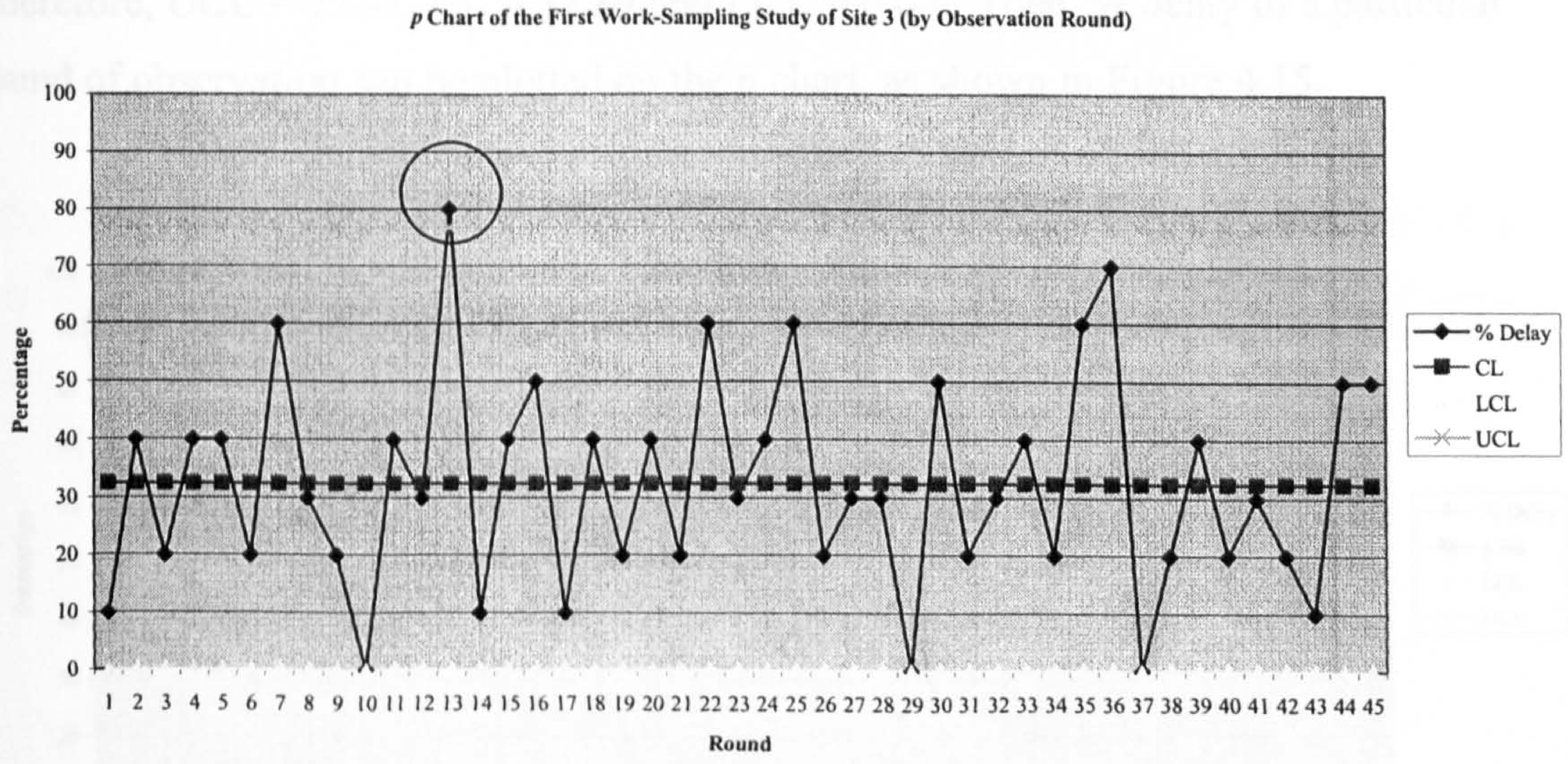


Figure 4.14 *p* chart for the first work-sampling study for site 3 (by observation round)

There is no doubt that the % delay of observation round 13, 80%, is over the UCL, which is an abnormal pattern categorised as case a, according to Figure 3.11. This unusually high idle time was due to late start/early finish, which is a cyclical delay, so it must be maintained.

4.5.1.2.4 Site 3 (The Second Study)

Table 4.10 Delay percentage for the second study for site 3 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	30	90	10	20	40	30	10	20	40	20	40	10	30	30	60
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	50	60	30	20	20	40	20	30	40	30	40	10	10	40	20
Rounds of observation	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
% Delay	30	30	20	50	50	50	30	40	50	20	30	30	40	50	20

According to equation 5, where $\bar{p} = 32.89$ and n = 10,

$$UCL = 32.89 + 3\sqrt{\frac{32.89 \times (100 - 32.89)}{10}} = 32.89 + (3 \times 14.86) = 77.41$$

$$CL = 32.89$$

$$LCL = 32.89 - 3\sqrt{\frac{32.89 \times (100 - 32.89)}{10}} = 32.89 - (3 \times 14.86) = 0.00$$

Therefore, UCL = 77.41, CL = 32.89 and LCL = 0.00. Then, % delay of a particular round of observation can be plotted on the *p* chart, as shown in Figure 4.15.

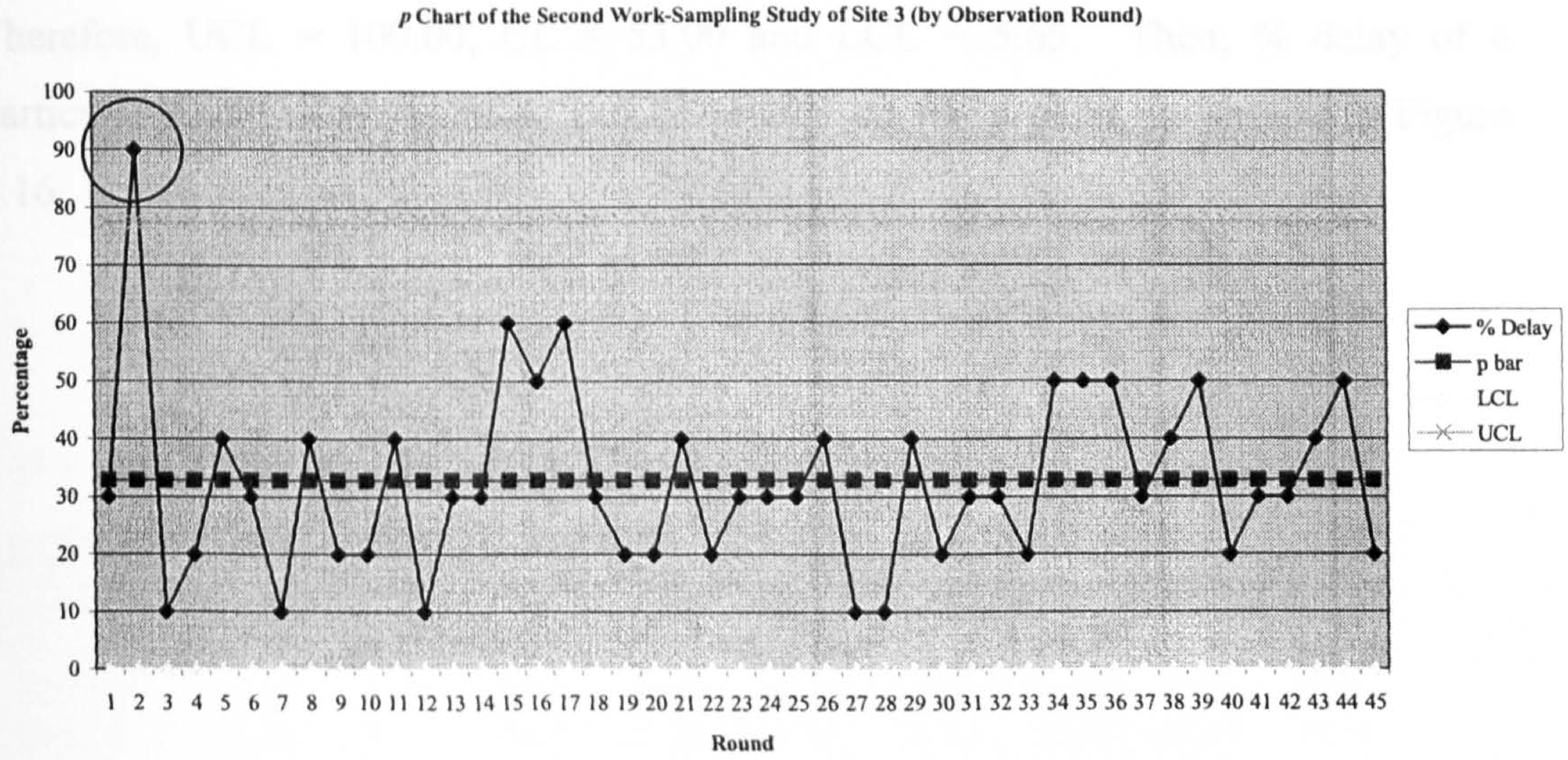


Figure 4.15 *p* chart for the second work-sampling study for site 3 (by observation round)

Similar to its first study, the abnormally high delay of observation round 2 of this study was due to late start/early finish, so the data must be kept.

4.5.1.2.5 Site 4 (The First Study)

Apart from those four abnormal charts, a typical observation round *p* chart, by using the data from the first study of site 4, is shown as below:

Table 4.11 Delay percentage for the first study for site 4 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	20	30	80	70	30	50	40	90	40	40	60	80	40	60	50
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	70	30	60	40	80	50	40	40	60	30	50	40	80	50	60
Rounds of observation	31	32	33	34	35	36	37	38	39	40					
% Delay	50	60	30	60	60	80	40	50	50	80					

According to equation 5, where $\bar{p} = 53.00$ and $n = 10$,

$$\mathrm{UCL} = 53 + 3\sqrt{\frac{53 \times (100 - 53)}{10}} = 53 + (3 \times 15.78) = 100.00$$

$$\mathrm{CL} = 53$$

$$\mathrm{LCL} = 53 - 3\sqrt{\frac{53 \times (100 - 53)}{10}} = 53 - (3 \times 15.78) = 5.65$$

Therefore, UCL = 100.00, CL = 53.00 and LCL = 5.65. Then, % delay of a particular round of observation can be plotted on the *p* chart, as shown in Figure 4.16.

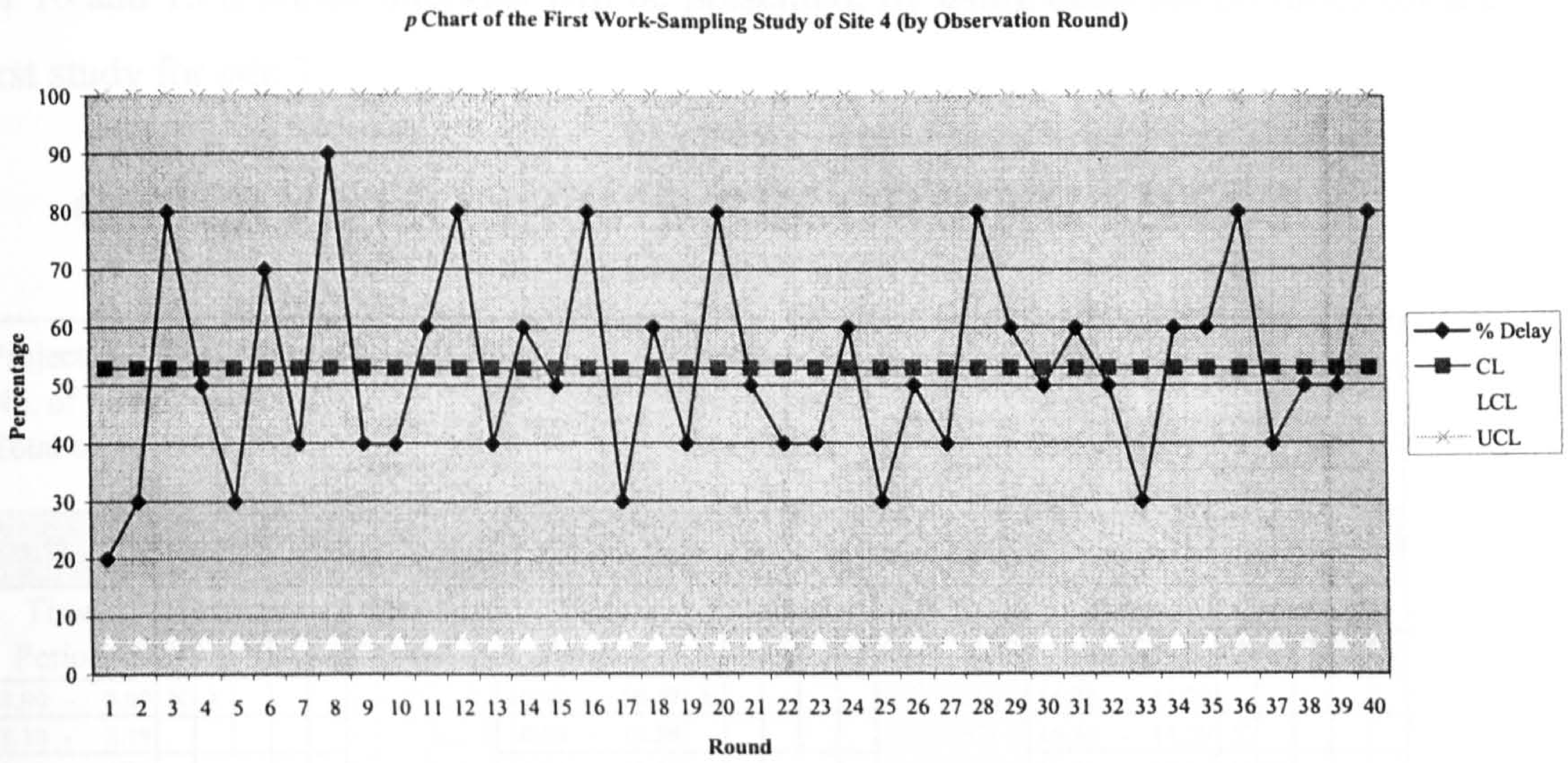


Figure 4.16 *p* chart for the first work-sampling study for site 4 (by observation round)

4.5.2 *c* Chart

In order to validate the randomness of observation times, this research applies 10 and 15 minutes interval to a *c* chart, both of which can be calculated as follow:

$$\begin{aligned} \mathrm{UCL} &= \bar{c} + 3\sqrt{\bar{c}} \\ \mathrm{CL} &= \bar{c} \qquad \qquad \ldots\ldots\ldots\ldots(4) \\ \mathrm{LCL} &= \bar{c} - 3\sqrt{\bar{c}} \end{aligned}$$

where: $\bar{c}$ = an average number of observation rounds per interval

Table 4.12 Observation times for the first study for site 3

Observation date	Round								
	1	2	3	4	5	6	7	8	9
26/11/01	9.16	9.33	10.46	13.10	13.29	14.00	14.47	15.55	16.34
27/11/01	8.01	8.45	9.03	9.59	10.25	13.38	14.16	15.29	16.39
28/11/01	9.05	9.47	10.29	11.21	11.44	13.20	14.49	15.14	16.10
29/11/01	9.34	10.23	10.47	11.17	11.48	14.30	15.17	16.02	16.31
30/11/01	8.06	8.49	9.40	10.16	11.41	13.06	13.57	14.18	15.40

After validating the randomness of all observation times, it has been found that none of them includes any abnormal patterns. Therefore, one example of a general *c* chart for 10 and 15 minutes intervals will be presented, by using observation times for the first study for site 3.

OBSERVATION TIME RECORDING SHEET

Project: Thai Nippon Steel (LMU) Reference: 13
No. of rounds observed: 45 Study period: 5 days
Total observation No. : 450 Start date: 26.11.2001 Finish date: 30.11.2001

48 INTERVALS OF 10 MINUTES EACH

Time Periods	Frequency					Time Periods	Frequency					Time Periods	Frequency				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
8.00 - 8.09	X	X				10.40 - 10.49	X					14.20 - 14.29					
8.10 - 8.19						10.50 - 10.59						14.30 - 14.39	X				
8.20 - 8.29						11.00 - 11.09						14.40 - 14.49	X	X			
8.30 - 8.39						11.10 - 11.19	X	X				14.50 - 14.59					
8.40 - 8.49	X	X				11.20 - 11.29	X	X				15.00 - 15.09	X				
8.50 - 8.59						11.30 - 11.39						15.10 - 15.19	X	X			
9.00 - 9.09	X	X				11.40 - 11.49	X	X	X			15.20 - 15.29	X				
9.10 - 9.19	X					11.50 - 11.59						15.30 - 15.39					
9.20 - 9.29						13.00 - 13.09	X					15.40 - 15.49					
9.30 - 9.39	X	X				13.10 - 13.19	X					15.50 - 15.59	X				
9.40 - 9.49	X	X				13.20 - 13.29	X	X				16.00 - 16.09	X				
9.50 - 9.59	X					13.30 - 13.39	X					16.10 - 16.19	X				
10.00 - 10.09						13.40 - 13.49						16.20 - 16.29					
10.10 - 10.19	X					13.50 - 13.59	X					16.30 - 16.39	X				
10.20 - 10.29	X	X	X			14.00 - 14.09	X					16.40 - 16.49					
10.30 - 10.39						14.10 - 14.19	X	X				16.50 - 16.59					

32 INTERVALS OF 15 MINUTES EACH

Time Periods	Frequency							Time Periods	Frequency							
	1	2	3	4	5	6	7		1	2	3	4	5	6	5	7
8.00 - 8.14	X	X						13.00 - 13.14	X	X						
8.15 - 8.29								13.15 - 13.29	X	X						
8.30 - 8.44								13.30 - 13.44	X							
8.45 - 8.59	X	X						13.45 - 13.59	X							
9.00 - 9.14	X	X						14.00 - 14.14	X							
9.15 - 9.29	X							14.15 - 14.29	X	X						
9.30 - 9.44	X	X	X					14.30 - 14.44	X							
9.45 - 9.59	X	X						14.45 - 14.59	X	X						
10.00 - 10.14								15.00 - 15.14	X	X						
10.15 - 10.29	X	X	X	X				15.15 - 15.29	X	X						
10.30 - 10.44	X							15.30 - 15.44								
10.45 - 10.59	X	X						15.45 - 15.59	X							
11.00 - 11.14								16.00 - 16.14	X	X						
11.15 - 11.29	X	X						16.15 - 16.29								
11.30 - 11.44	X							16.30 - 16.44	X	X	X					
11.45 - 11.59	X							16.45 - 16.59								

Figure 4.17 Observation time recording sheet for the first study for site 3

4.5.2.1 10 Minutes Interval

According to Table 4.12, the observation time recording sheet is filled out as shown in Figure 4.17. According to equation 4, where $\bar{c} = 45 \div 48 = 0.94$,

$$
\begin{aligned}
\text{UCL} &= 0.94 + 3\sqrt{0.94} = 0.94 + (3 \times 0.97) = 3.85 \\
\text{CL} &= 0.94 \\
\text{LCL} &= 0.94 - 3\sqrt{0.94} = 0.94 - (3 \times 0.97) = 0.00
\end{aligned}
$$

Therefore, UCL = 3.85, CL = 0.94 and LCL = 0.00, then the *c* chart is shown in Figure 4.18.

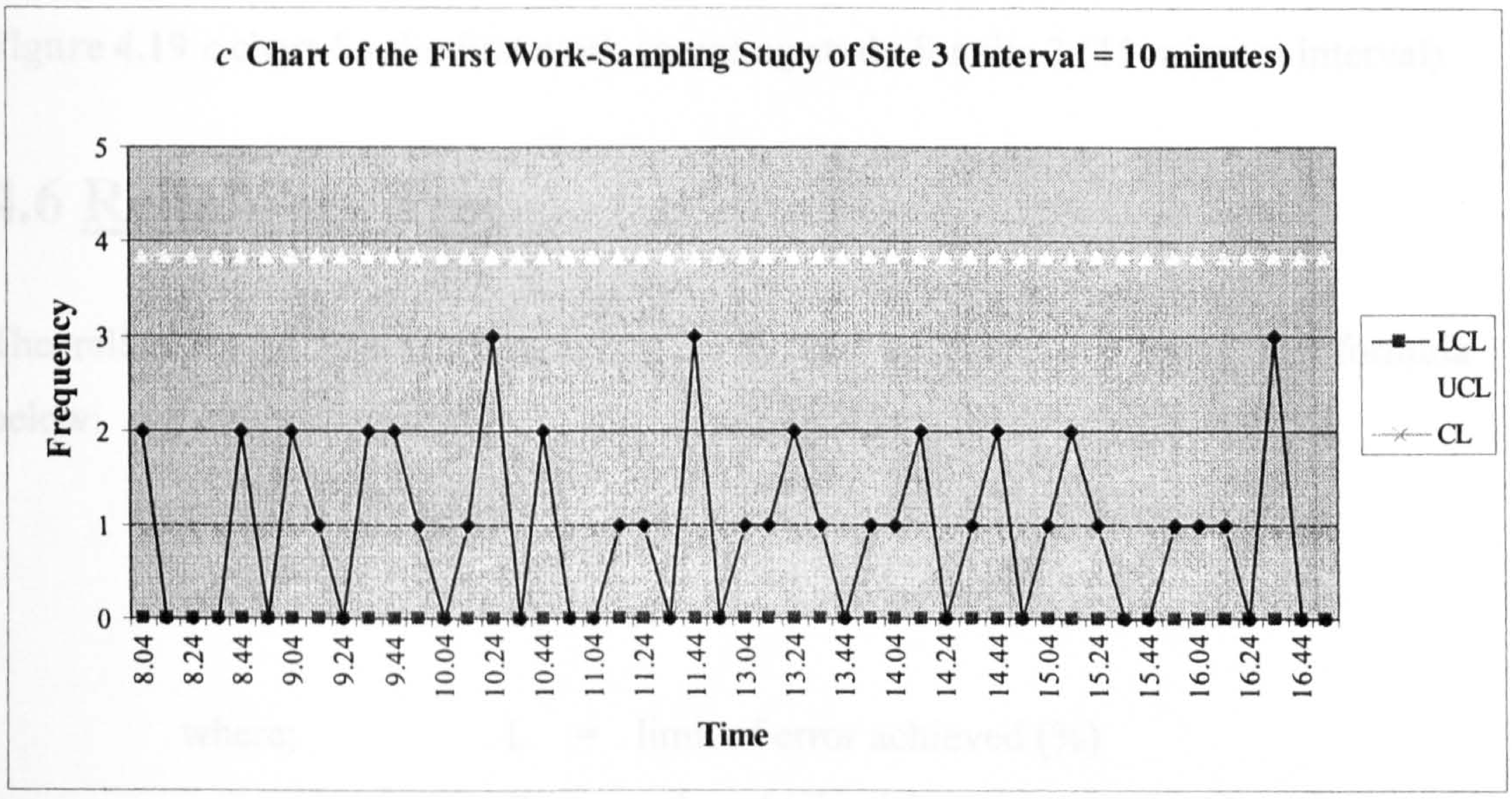


Figure 4.18 *c* chart for the first work-sampling study for site 3 (10 minutes interval)

4.5.2.2 15 Minutes Interval

According to Table 4.12 and equation 4, where $\bar{c} = 45 \div 32 = 1.41$,

$$
\begin{aligned}
\text{UCL} &= 1.41 + 3\sqrt{1.41} = 1.41 + (3 \times 1.19) = 4.98 \\
\text{CL} &= 1.41 \\
\text{LCL} &= 1.41 - 3\sqrt{1.41} = 1.41 - (3 \times 1.19) = 0.00
\end{aligned}
$$

Therefore, UCL = 4.98, CL = 1.41 and LCL = 0.00, then the *c* chart is shown in Figure 4.19.

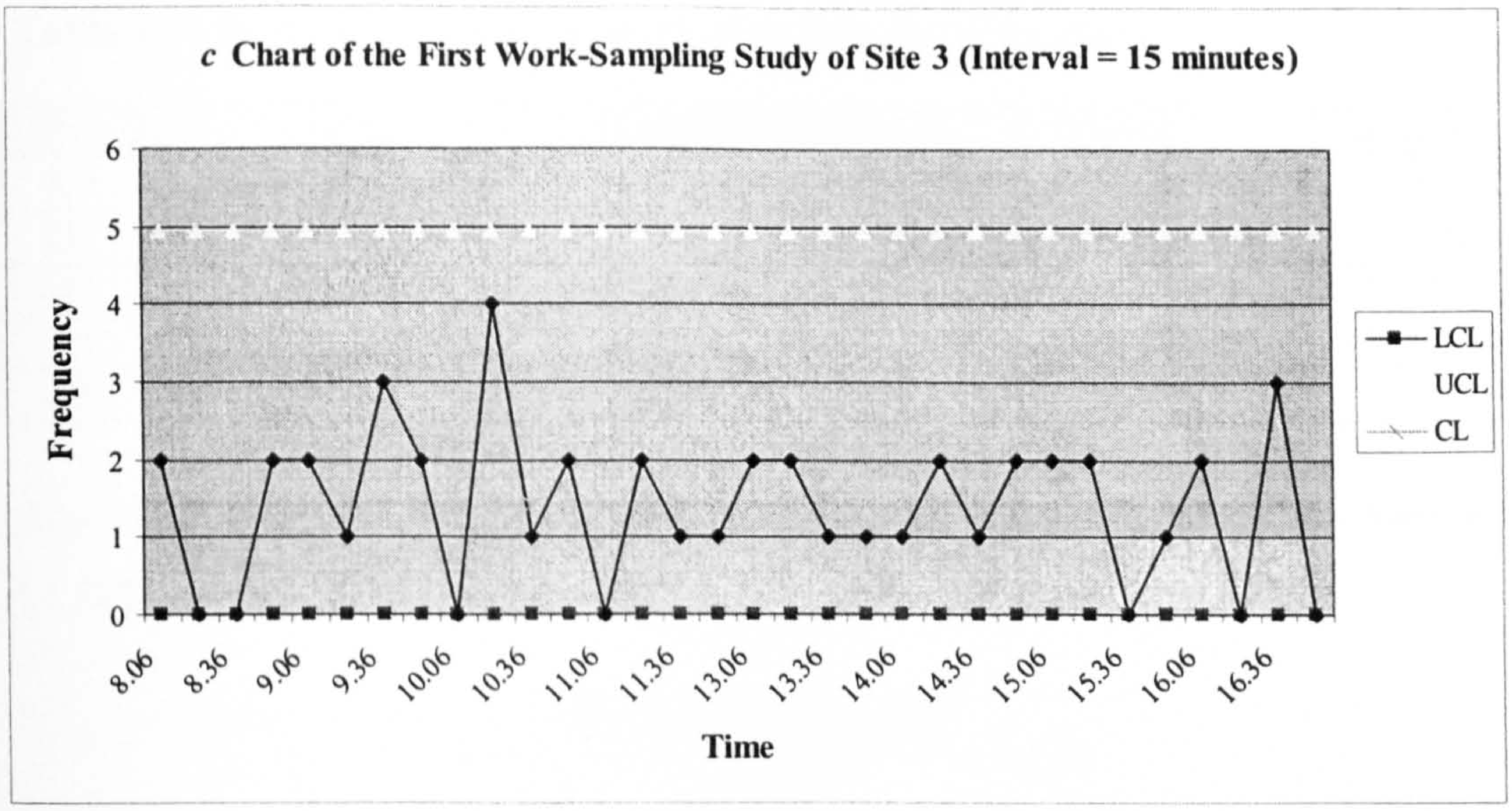


Figure 4.19 *c* chart for the first work-sampling study for site 3 (15 minutes interval)

4.6 Reliability Test

The reliability of this work-sampling study can be calculated using the formula below:

$$L = Z\sqrt{\frac{P(100-P)}{N}} \qquad \text{..........(2)}$$

where;

L = limit of error achieved (%)

Z = value obtained from statistical tables depending upon the level of confidence required for the estimate. In this case, taken as 2, which corresponds to 95% confidence.

P = percentage of activity observed of a particular category

N = number of observations achieved

Just like the validity test, the process of the reliability test is also repetitive, only the results for one of the eight studies will be presented, by using the data for the second study of site 1 (see Table 4.13).

Table 4.13 Results of the second work-sampling study for site 1

Code	Category	Average	Code	Category	Average
100	Effective Work	51.78%	216	Waiting for other trades	17.78%
211	Waiting for materials	0.22%	217	Waiting for other crews	10.89%
212	Waiting for tools	0.22%	220	Personal Allowances	7.12%
213	Waiting for equipment	3.11%	230	Late start/Early finish	6.44%
214	Waiting for instruction	2.00%			

According to equation 2, the reliability of effective work (code 100), where P = 51.78% and n = 450, is as follows:

$$L = 2\sqrt{\frac{51.78\times(100-51.78)}{450}} = \pm 4.76$$

This means, consequently, that we can conclude with 95% confidence, that the interval 47.02% to 56.54% will include the true % of effective work. Similarly, the reliability of waiting for materials could be obtained as below:

$$L = 2\sqrt{\frac{0.22\times(100-0.22)}{450}} = \pm 0.45$$

Likewise, we can conclude with 95% confidence that the true percentage of waiting for materials will fall within 0.00% to 0.67%. By repeating the process the reliability of every category as shown in Table 4.14.

Table 4.14 Reliability test of the second work-sampling study for site 1

Code	Category	Average	Limit of Error	Interval
100	Effective Work	51.78%	±4.76%	47.02%-56.54%
211	Waiting for materials	0.22%	±0.45%	0.00%-0.67%
212	Waiting for tools	0.22%	±0.45%	0.00%-0.67%
213	Waiting for equipment	3.11%	±1.66%	1.45%-4.77%
214	Waiting for instruction	2.00%	±1.33%	0.67%-3.33%
216	Waiting for other trades	17.78%	±3.66%	14.12%-21.44%
217	Waiting for other crews	10.89%	±2.97%	7.92%-13.86%
220	Personal Allowances	7.12%	±2.45%	4.67%-9.57%
230	Late start/Early finish	6.44%	±2.34%	4.10%-8.78%

4.7 Hypothesis Test

In order to conclude if there is a statistically significant productive time improvement between the first and the second work-sampling studies, a hypothesis test could be useful; the hypotheses for this study are:

H_0: $p_1 = p_2$

H_1: $p_1 > p_2$

Then, the test statistic for the above hypothesis is:

$$Z_0 = \frac{\bar{p}_1 - \bar{p}_2}{\sqrt{\bar{p}(100-\bar{p})\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \qquad \ldots\ldots\ldots\ldots\ldots(6)$$

where; p_1 = the average ineffective time for the first study (%)

p_2 = the average ineffective time for the second study (%)

$$\bar{p} = \frac{n_1\bar{p}_1 + n_2\bar{p}_2}{n_1 + n_2}$$

4.7.1 Site 1

$$\bar{p} = \frac{n_1\bar{p}_1 + n_2\bar{p}_2}{n_1 + n_2} = \frac{(450 \times 53.78) + (450 \times 48.22)}{450 + 450} = 51.00$$

$$Z_0 = \frac{\bar{p}_1 - \bar{p}_2}{\sqrt{\bar{p}(100-\bar{p})\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} = \frac{53.78 - 48.22}{\sqrt{51(100-51)\left(\frac{1}{450}+\frac{1}{450}\right)}} = 1.67$$

4.7.2 Site 2

$$\bar{p} = \frac{n_1\bar{p}_1 + n_2\bar{p}_2}{n_1 + n_2} = \frac{(450 \times 43.18) + (400 \times 40.25)}{450 + 400} = 41.80$$

$$Z_0 = \frac{\bar{p}_1 - \bar{p}_2}{\sqrt{\bar{p}(100-\bar{p})\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} = \frac{43.18 - 40.25}{\sqrt{41.80(100-41.80)\left(\frac{1}{450}+\frac{1}{400}\right)}} = 0.87$$

4.7.3 Site 3

$$\bar{p} = \frac{n_1\bar{p}_1 + n_2\bar{p}_2}{n_1 + n_2} = \frac{(450 \times 32.44) + (450 \times 32.89)}{450 + 450} = 32.67$$

$$Z_0 = \frac{\bar{p}_1 - \bar{p}_2}{\sqrt{\bar{p}(100 - \bar{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} = \frac{32.44 - 32.89}{\sqrt{32.67(100 - 32.67)\left(\frac{1}{450} + \frac{1}{450}\right)}} = -0.14$$

4.7.4 Site 4

$$\bar{p} = \frac{n_1\bar{p}_1 + n_2\bar{p}_2}{n_1 + n_2} = \frac{(400 \times 53.00) + (400 \times 50.75)}{400 + 400} = 51.88$$

$$Z_0 = \frac{\bar{p}_1 - \bar{p}_2}{\sqrt{\bar{p}(100 - \bar{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} = \frac{53.00 - 50.75}{\sqrt{51.88(100 - 51.88)\left(\frac{1}{400} + \frac{1}{400}\right)}} = 0.64$$

Since there is only site 1 that has $Z_0 > Z_{0.05} = 1.65$, we accept the null hypothesis (H_0) for the other three sites. There is strong evidence to support the claim that only the idle time of site 1 has decreased. In other words, the management of site 1 can say with 95% level of confidence that the effective time of the site has increased from 46% to 52%.

4.8 Summary

There are four primary questions that this research seeks to answer, by employing structured questionnaires engaging three groups of respondents, namely; project managers, foremen and craftsmen, implementing the improved work-sampling to four case studies in Thailand and applying the Markov process to the results of work-sampling. Data of this research will be validated by *c* and *p* charts. All variables concern with the study, reliability and hypothesis tests, are also identified in this chapter.

CHAPTER 5

FACTORS AFFECTING THE PRODUCTIVIY OF THE CONSTRUCTION INDUSTRY IN THAILAND

5.1 Introduction

There has been a lack of research on the construction industry in Thailand. The objectives of this chapter are to identify those factors affecting construction productivity in Thailand and their potential with respect to the opportunity for productivity improvement. To do so, 34 project managers (Makulsawatudom and Emsley 2001a and 2002), 57 foremen (Makulsawatudom and Emsley 2003) and 128 craftsmen (Makulsawatudom and Emsley 2001b) working in the construction industry in Thailand were asked to complete a structured questionnaire.

The factors affecting the productivity of the construction industry in Thailand were ranked according to the respondents' perception of their levels of influence and their potential for improvement (where applicable) based on the participants' overall experience in the industry. A relative importance index (RII) was employed in order to rank the factors for a particular group of respondents for further ranking.

Friedman two-way analysis of variance by ranks (F_r) was, then, applied to clarify whether there are any different perceptions of the factors by the three participating groups, with the results concluding that, at the 99% confidence level, there is no difference between views of the respondents. After that each factor was ranked according to its sum of the square of its individual rank, where the least comes first. These studies form the initial investigations into the Thailand construction industry, which aim to lead to overall productivity improvement.

5.2 The Construction Industry in Thailand

The characteristics of the construction industry are cost overruns and repeated delays, which are potentially more serious in developing countries (Mansfield *et al.*, 1994; Werna, 1993; Okpala and Aniekwu, 1988). Therefore, Altaf (1979) believed that attention to construction is more important in developing countries than in developed countries. In addition, in common with other developing countries such as Indonesia (Kaming *et al.*, 1997), Iran (Zakeri *et al.*, 1996), Malaysia (Yong, 1987), Nigeria (Mansfield *et al.*, 1994; Aniekwu and Okpala, 1988; Okpala and Aniekwu, 1988) and Saudi Arabia (Assaf *et al.*, 1995), the construction industry in Thailand also experiences productivity problems.

The construction industry in Thailand, like the construction industry in other countries, has been dominated by a small number of large companies (>1,000 employees) and a large number of small companies (<20 employees), representing 0.2% and 68.1%, respectively, of the 17,512 organisations in the industry. Furthermore, these large companies have 21.5% of the market share, while the small companies, major players in the industry, only have 9.9% of the market share. Considering all organisations, 8% are involved in site preparation, 75.1% and 9.3% have their core business in civil engineering and building installation respectively, while 7.1% and 0.5% are involved with building completion and plant hire, respectively (National Statistical Office, 1999).

In respect of the workforce, the construction industry employs 1.28 million of the 33.00 million available workers, of which 80-90% are males, and has a turnover of 311,672.1 Million Baht (£1 = 64.54 Baht in July 2001), which is about 4% of GDP. During the last 8 years, industry contribution to GDP has ranged between 3 and 8% (National Statistical Office, 1999). Any improvement in construction productivity would, consequently, assist the industry and the country to make significant financial savings. However, improvement cannot be achieved without identification of the causes of the problem.

5.3 Factors Affecting Productivity

The factors, which influence construction productivity, were gathered from a literature review of previous studies. These included Borcherding and Sebastian (B&S) (1980), Hanna and Heale (H&H) (1994), Kaming *et al.* (K/98) (1998), Kaming *et al.* (K/97) (1997), Olomolaiye and Ogunlana (O&O) (1989), Olomolaiye *et al.* (O) (1987) and Zakeri *et al.* (Z) (1996). A list of the factors identified and the relevant author is shown in Table 5.1. The most frequently occurring factors are ranked and will be used for comparison with the empirical work carried out in Thailand.

Table 5.1 Factors affecting productivity gathered from previous studies

Factors	Authors							Frequency	Rank
	B & S	H & H	K (98)	K(97)	O&O	O	Z		
Lack of material	X		X	X	X	X	X	6	2
Incomplete drawing		X					X	2	
Lack of tools and equipment	X	X	X	X	X	X	X	7	1
Poor site conditions		X					X	2	
Incompetent supervisors	X					X	X	3	
Change orders		X					X	2	
Rework	X		X	X		X	X	5	5
Tools/equipment breakdown		X	X	X	X		X	5	5
Poor communication							X	1	
Poor site layout		X						1	
Inspection delay	X					X	X	3	
Absenteeism	X	X	X	X		X	X	6	2
Instruction time	X		X	X		X		4	7
Overcrowding	X		X	X				3	
Specification and standardisation							X	1	
Interference	X		X	X			X	4	7
Weather		X					X	2	
Workers turnover	X	X	X	X		X	X	6	2
Accident		X					X	2	
Changing of foremen	X		X	X				3	

To ensure inclusiveness, the list of 20 factors was retained for the survey in Thailand.

5.4 Data Collection

These researches were conducted in Thailand during two periods. The first period was between November and December 2000 with project managers at the management level and craftsmen active at operative level, as the target groups. The second period was, approximately one year later, between October and December 2001, with foremen, working at low management level, as the target group. A structured questionnaire survey was selected to be the main study instrument, as it provided information needed for the study, quickly and relatively cheaply.

The questionnaire was designed in English, but was translated into Thai, and was approved by experienced persons in the industry, who have qualifications at either masters degree or PhD level. In general, the questionnaires launched to the three target groups mostly have the same contents, as the first part of the questionnaire asked for general information about the participants and their organisations. Nevertheless, in the last part, each foreman and craftsman were asked to rate the factors affecting construction productivity, and causes of these factors, on scale from 0 (no influence) to 5 (very great influence). Meanwhile, the last part of the project manager questionnaire required each participant to rate the factors affecting productivity on scale from 0 (no influence) to 5 (very great influence) and to rate each factor in respect of its potential for productivity improvement on a scale from 0 (no potential) to 4 (very high potential). In addition, respondents were welcome to add and rate factors that they believed to have an effect on construction productivity, apart from those included in the questionnaire.

A total of 40, 95 and 220 questionnaires were distributed to project managers, foremen and craftsmen, respectively. For project managers, most of the respondents were contacted through personal recommendation. Therefore, the number of questionnaires completed and returned was high, 34 out of 40 (85%). From 95 questionnaires distributed to foreman, 57 questionnaires, equal to a response rate of 60%, were completed and returned. The respondents consist of 3 major trades, which are 18 fitters, 12 steel erectors and 16 welders with 11 from other trades like surveyor, crane rigger and scaffolder. The craftsman questionnaires were not distributed directly to the craftsmen, but given to the project manager at each of five sites, who passed the questionnaires to his craftsmen at the time he thought it was appropriate. Finally, 128 questionnaires, equal to a response rate of 58.18%, classified into six groups of respondents (19 masons, 27 fitters, 26 carpenters, 20 steel fixers, 28 general labourers and 8 welders), were completed and returned. Table 5.2 exhibits the general characteristics of these projects. In order to rank the severity of the factors a relative important index (RII) was then employed.

Table 5.2 Participating projects' characteristics for craftsman questionnaire

Project characteristics	Project number				
	1	2	3	4	5
Title	Thai Polyethylene	Thai Micro Electronic Centre	Supply and Installation of Trunk Main	Polycarbonate Plant Project	Waste Water Treatment Project
Construction Type	Industrial	Building	Civil engineering	Industrial	Civil engineering
Procurement Method	Traditional	Construction Management	Traditional	Lump Sum	Turn Key
Value (Baht*)	3,000,000,000	240,000,000	167,000,000	120,000,000	100,000,000
Duration	14 months	12 months	24 months	8 months	18 months
(date)	Jun.00-Jul.01	Mar.98-Feb.99[1]	Nov.99-Oct.01	Sep.00-Mar.01	Jan.00-Jun.01
Location	Rayong	Chachoengsao	Bangkok	Rayong	Samutprakan

*£1 = 62.85 Baht in February 2001. [1] This project has been delayed

5.5 Results

5.5.1 Respondents' Characteristics

5.5.1.1 Gender

Referring to Table 5.3, the majority of the participants, over 90% of each group, are male. This is a typical composition of the workforce in this region.

Table 5.3 Respondents' gender

Gender	Respondent groups					
	Project manager		Foreman		Craftsman	
	Number	Percentage	Number	Percentage	Number	Percentage
Male	33	97.06	57	100.00	116	90.63
Female	1	2.94	0	0.00	12	9.32
Total	34	100.00	57	100.00	128	100.00

5.5.1.2 Age and working experience

Table 5.4 and Table 5.5 indicate age and working experience of the respondents respectively.

Table 5.4 Respondents' age

Respondent groups		Age group				Total
		25-34	35-44	44-55	> 55	
Project manager	Number	4	22	7	1	34
	Percentage	11.76	64.71	20.59	2.94	100.00
		Age group				
		15-20	21-30	31-40	41-50	> 50
Foreman	Number	0	5	15	36	1	57
	Percentage	0.00	8.77	26.32	63.16	1.75	100.00
Craftsman	Number	9	58	47	10	4	128
	Percentage	7.03	45.31	36.72	7.81	3.13	100.00

Table 5.5 Respondents' working experience

Respondent groups		Years of experience					Total
		< 5	5-10	11-20	> 20		
Project manager	Number	0	5	21	8		34
	Percentage	0	14.71	61.76	23.53		100.00
		Years of experience					
		< 2	2-5	6-10	11-20	> 20	
Foreman	Number	0	5	15	36	1	57
	Percentage	0.00	8.77	26.32	63.16	1.75	100.00
Craftsman	Number	14	43	47	17	7	128
	Percentage	10.94	33.59	36.72	13.28	5.47	100.00

According to the project managers interviewed, it takes 12 years for an inexperienced engineer to gain adequate experience to become a project manager. Therefore, it is reasonable that Table 5.5 shows that 85% of project managers have at least 11 years experience. In addition, it is not surprising that 88% of respondents are over 34 years old (see Table 5.4) as engineers in Thailand usually graduate between 22-24 years old.

It is widely accepted in Thailand that, generally, it takes about 15 years for an inexperienced craftsman to gain adequate experience to become a foreman. This is substantiated in Table 4, which shows that 65% of foremen have at least 11 years experience. Further, as craftsmen in Thailand usually start work between 18-20 years old, 82% of respondents are over 30 years old (see Table 5.4).

According to Table 5.4, over half of the craftsmen, 52.34%, are young workers aged between 15-30 years old. This could be because the nature of the industry is physically demanding. However, in the more traditional trades, such as welders and masons, many are over 30 years old, probably reflecting the length of training and period of experience required for the necessary skill acquisition. Approximately 90% of the craftsmen have at least two years construction working experience, and about 56% have over five years experience (see Table 5.5). Consequently, it is reasonable to assume that they were appropriately familiar with the problems of their trades.

During the last two decades, the majority of construction works have been public infrastructure projects. Consequently, civil works includes the maximum number of experienced respondents (for example, over 40% of participating project managers have at least 5 years experience in this field). However, the residential field has only started to grow in the last 8 years, so it contains the least number of experienced participants.

5.5.1.3 Level of education

According to Table 5, 67.65% of the project managers have first degrees, with the remainder qualified at masters level, while about 54% of participating foremen graduated from vocational college or higher and approximately 37% finished only junior high school or lower. Table 5.6 also confirms that, generally, the construction operative in Thailand has a low literacy level. The majority of the workers surveyed, 70.31%, held just a primary school certificate, the minimum qualification compelled by law.

Table 5.6 Respondents' level of education

Level of education	Respondent groups					
	Project manager		Foreman		Craftsman	
	Number	Percentage	Number	Percentage	Number	Percentage
Primary School	0	0.00	15	26.32	90	70.31
Junior High School	0	0.00	6	10.53	26	20.31
High School*	0	0.00	5	8.77	12	9.38
Vocational College*	0	0.00	13	22.80	0	0.00
Undergraduate Diploma	0	0.00	18	31.58	0	0.00
First degree	23	67.65	0	0.00	0	0.00
Master degree	11	32.35	0	0.00	0	0.00
PhD Level	0	0.00	0	0.00	0	0.00
Total	34	100.00	57	100.00	128	100.00

* Comparable status

5.5.1.4 Type of organisation

Table 5.7 shows the type of respondents' organisations. The majority, between 62.50%-82.35%, are main contractors, while 14.72%-37.50% and 0%-1.75% are sub-contractors and sub-contractor labour only, respectively.

Table 5.7 Type of respondents' organisations

Type of organisation	Respondent groups					
	Project manager		Foreman		Craftsman	
	Number	Percentage	Number	Percentage	Number	Percentage
Main contractor	28	82.35	42	73.68	80	62.50
Sub-contractor	5	14.72	14	24.57	48	37.50
Sub-contractor labour only	1	2.94	1	1.75	0	0.00
Total	34	100.00	57	100.00	128	100.00

5.5.1.5 Length of stay with current employer

Over half of the project managers (58.82%) and foremen (82.45%) have worked for their organisation for at least 6 years, and almost one third (32.35%) and 59.64%, respectively, for over 10 years (see Table 5.8), reflecting that they have a fairly high commitment to their organisation. Unfortunately, this does not seem to be applicable to the craftsman, as 61.88% of the participants have worked for their organisation for less than 5 years (see Table 5.8).

Table 5.8 Respondents' length of stay with current employer

Length of stay	Respondent groups					
	Project manager		Foreman		Craftsman	
	Number	Percentage	Number	Percentage	Number	Percentage
< 2	4	11.77	0	0.00	48	37.50
2-5	10	29.41	10	17.54	44	34.38
6-10	9	26.47	13	22.82	30	23.44
11-20	9	26.47	33	57.89	5	3.91
> 20	2	5.88	1	1.75	1	0.78
Total	34	100.00	57	100.00	128	100.00

Table 5.9 Respondents' general opinion of organisation

Respondent groups	Opinion of		Rank					Total
			V. good	Good	Fair	Poor	V. poor	
Project manager	Employer	Number	8	23	3	0	0	34
		Percentage	23.53	67.65	8.82	0.00	0.00	100
	Subordinates	Number	1	31	2	0	0	34
		Percentage	2.94	91.18	5.88	0.00	0.00	100
	Working environment	Number	1	27	6	0	0	34
		Percentage	2.94	79.41	17.65	0.00	0.00	100
	Level of payment	Number	1	25	6	2	0	34
		Percentage	2.94	73.53	17.65	5.88	0.00	100
Foreman	Employer	Number	6	46	5	0	0	57
		Percentage	10.53	80.70	8.77	0.00	0.00	100.00
	Subordinates	Number	6	48	3	0	0	57
		Percentage	10.53	84.21	5.26	0.00	0.00	100.00
	Working environment	Number	1	24	31	1	0	57
		Percentage	1.75	42.10	54.39	1.75	0.00	100.00
	Level of payment	Number	0	5	38	14	0	57
		Percentage	0.00	8.77	66.66	24.56	0.00	100.00
Craftsman	Employer	Number	1	60	63	4	0	128
		Percentage	0.78	46.88	49.22	3.13	0.00	100.00
	Working environment	Number	1	29	85	10	3	128
		Percentage	0.78	22.66	66.41	7.81	2.34	100.00
	Level of payment	Number	0	0	94	22	12	128
		Percentage	0.00	0.00	73.44	17.19	9.38	100.00

5.5.1.6 General opinion of organisation

Respondents were asked to provide their opinion of their employers, subordinates, working environment and level of payment, by ranking their opinion on a 5-point Likert scale from 5 (very good) to 1 (very poor) (see Table 5.9). It can be concluded that all of the participants, except 3.13% of the responding craftsmen, are satisfied with their employers and subordinates and only 1.75% and 10.15% of the participating foremen and craftsmen, respectively, are dissatisfied with their working environment (i.e. rank them poor or very poor). However, none of the craftsmen respondents and only a minority of the foremen respondents, 8.77%, think that their salary is high (i.e. rank it good or very good). On the opposite side, only 5.88% of participating project manager are dissatisfied with their salary (i.e. rank it poor or very poor).

5.5.2 Respondents' Attitude toward Productivity and Productivity Improvement

Table 5.10 Factors affecting construction productivity in Thailand

Factors	Respondent groups						Overall rank
	Project managers		Foremen		Craftsmen		
	RII	Rank	RII	Rank	RII	Rank	
Lack of material	0.642	1	0.605	1	0.504	1	1
Incomplete drawing	0.593	2	0.564	2	0.464	3	2
Lack of tools and equipment	0.539	6	0.550	3	0.497	2	3
Poor site conditions	0.515	8	0.485	7	0.461	5	4
Incompetent supervisors	0.554	4	0.477	8	0.438	7	5
Change orders	0.510	9	0.512	6	0.424	9	6
Rework	0.490	11	0.538	4	0.434	8	7
Tools/equipment breakdown	0.461	13	0.532	5	0.444	6	8
Poor communication	0.525	7	0.439	13	0.418	10	9
Poor site layout	0.505	10	0.459	10	0.408	13	10
Inspection delay	0.559	3	0.462	9	0.371	17	11
Absenteeism	0.475	12	0.459	10	0.398	14	12
Instruction time	0.544	5	0.439	13	0.348	19	13
Overcrowding	0.441	15	0.389	17	0.462	4	14
Specification and standardisation	0.422	17	0.427	15	0.409	12	15
Interference	0.456	14	0.406	16	0.388	15	16
Weather	0.392	18	0.351	19	0.417	11	17
Workers turnover	0.431	16	0.368	18	0.387	16	18
Accidents	0.373	20	0.444	12	0.361	18	19
Changing of foremen	0.382	19	0.313	20	0.311	20	20

In the main body of the questionnaire, the respondents were asked to scale the importance of the factors presented to them on the Likert scale. The factors were then ranked using a relative importance index (RII), as shown in Table 5.10. A RII of greater than 0.5 indicates that the respondents rated the factors to have more than a moderate influence on productivity. RII can be calculated as below:

$$\mathrm{RII} = \frac{\text{Total score}}{\text{No. of respondents} \times \text{No. of rank score}}$$

In order to certify that there is consensus between these groups of respondents, Friedman analysis of variance by ranks (F_r) is employed, as shown below:

$$F_r = \left[\frac{12}{Nk(k+1)}\sum_{j=1}^{k} R_j^2\right] - 3N(k+1)$$

where;

$F_r =$ coefficient of the friedman analysis of variance by ranks

$N =$ number of subjects

$k =$ number of variables

$R_j =$ sum of ranks for the *j*th variable

In this research, $N = 3$, $k = 20$, so $F_r = 43.38$ which, referring to table of critical values of the chi-square distribution when $df = k - 1 = 19$, is significant between 0.01 and 0.001 (Siegel and Castellan, Jr., 1988). Therefore, we can conclude with 99% confidence that there is a consensus on the factors between the three groups of respondents. Then, all the factors were ranked according to the sum of the squares of their particular ranks.

A further question sought to find out if there is any correlation between each pair of respondents (i.e. the project managers and the foremen, the project managers and the craftsmen, and the foremen and the craftsmen). This can be done by the calculation of the rank correlation (r_s), as follows:

$$r_s = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

where;

$r_s =$ coefficient of rank correlation

$n =$ number of paired observations

$d =$ difference between the ranks for each pair of observations

The rank correlation indicates with over 99.5% confidence that there is correlation between the perceptions of both the project managers and the foremen and the foremen and craftsmen on the factors, but no obvious significant correlation between the project managers and the craftsmen.

Table 5.11 Critical factors influencing the construction productivity

Rank	Factors	Influence ranked score						Potential ranked score					Total CFI score	RII
		0	1	2	3	4	5	0	1	2	3	4		
1	Lack of material	0	3	5	2	8	16	0	1	14	14	5	358	0.405
2	Incomplete drawings	0	2	3	10	12	7	0	1	13	14	6	330	0.373
3	Incompetent supervisors	0	3	7	7	10	7	0	2	11	14	7	329	0.372
4	Lack of tools and equipment	0	4	4	10	12	4	0	1	12	16	5	309	0.350
5	Absenteeism	0	3	11	10	8	2	0	2	10	19	3	307	0.347
6	Poor communication	0	2	9	12	4	7	0	3	11	13	7	301	0.340
7	Instruction time	0	1	8	11	9	5	0	1	11	16	6	299	0.338
8	Poor site layout	0	5	7	8	10	4	0	1	13	14	6	298	0.337
9	Inspection delay	0	0	6	14	10	4	0	1	13	19	1	294	0.333
10	Rework	0	6	5	12	7	4	0	1	12	15	6	291	0.329
11	Occasional working overtime	1	2	11	11	7	2	0	4	7	18	5	266	0.301
12	Change orders	0	2	7	13	11	1	0	5	13	13	3	265	0.300
13	Tools/equipment breakdown	0	5	8	13	6	2	0	1	13	15	5	261	0.295
14	Specification and standardisation	1	6	9	8	7	3	0	2	11	16	5	261	0.295
15	Interference from other trades or other crews	0	3	12	12	5	2	0	1	18	11	4	245	0.277
16	Workers turnover and changing crewmembers	0	2	16	11	4	1	0	6	9	13	6	233	0.264
17	Scheduled working overtime	2	6	9	12	4	1	1	2	11	15	5	226	0.256
18	Safety (accidents)	0	10	12	6	1	5	0	3	10	16	5	220	0.249
19	Poor site conditions	0	5	4	13	7	5	2	6	19	6	1	207	0.234
20	Changing of foremen	2	6	12	10	2	2	0	4	11	14	5	204	0.231
21	Overcrowding	0	8	9	7	7	3	0	9	16	6	3	190	0.215
22	Shift work	7	5	7	11	3	1	5	5	7	14	3	182	0.206
23	Weather	1	5	15	9	2	2	7	11	12	4	0	114	0.129

The explanation for this finding lies in the social positions of the groups of respondents. A foreman, who is the middleman between a project manager and craftsmen, should understand the problems of both sides better than the project managers and craftsmen understand each other. For example, the project managers and the foremen agreed that inspection delay was a fairly significant hindrance to productivity because the problem was ranked 3rd and 9th, respectively, however the craftsmen ranked it 19th, which clearly shows a different collective opinion. The proximity of different groups to the factor influencing productivity was also shaping attitudes. For example, the foremen and the craftsmen believe tools/equipment breakdown is a severe problem, as they ranked it 5th and 6th, respectively, but the project managers do not seem to think so, since they ranked tools/equipment breakdown 13th.

Apart from ranking the factors, the participating project managers were also asked to rate their potential for improvement (from 0 to 4). The raw rankings were multiplied together to produce a critical factor index (CFI), which were then summated and divided by 26 (the number of possible values for the CFI) to give a relative importance index (RII). Table 5.11 gives the factors ranked according to their RII. Please note that the rank score of potential for improvement is odd number (0-4), while the rank score of influential is even number (0-5). *The purpose for even number is to stimulate the respondents to think carefully whether the factors have less or more than moderate influence on the productivity, but not for the odd number that allow the participants to rank moderate potential.*

5.5.3 Discussion

After the identification of the critical factors from the long list of factors influencing productivity, it has been decided that, in this paper, the factors influencing productivity will be the unit of analysis. This choice has been made since it enables the full range of opinions from project managers to tradesman to be assessed so to form an explanation of why the top five factors are influential in acting as blocks to construction productivity. However, it is noticeable that the 'raw' factors are close to the critical factor for four of these in the top five. Within the top five, the research drilled down inside each factor to seek explanation for 'why' they appear as important as they do (see Table 5.10).

5.5.3.1 Lack of material

Lack of material was highlighted as the most critical factor affecting productivity by all participants. This is not surprising, as materials are essential for the construction process and, if materials are short for a particular activity, this could affect other project activities.

The project managers revealed that this is mainly due to *contractors' liquidity problems*, where many contractors have insufficient finance to procure the necessary materials. In addition, when suppliers have previously experienced lack of payment, they may hold delivery until payment has been made. An *incompetent project manager* who gives inadequate priority to material procurement and has insufficient knowledge of materials, including appropriate substitutes was also mentioned, in addition to *imported material* and *poor co-ordination between site and office.*

In order to get a wider angle on this issue, the foremen and operatives were asked to rank general causes of material unavailability, based on their working experience. Similar to the ranking of the factors, the RII was calculated first, and then the rank correlation (r_S), rather than F_r, was calculated. The rank correlation concluded with 95% confidence that there is a correlation between the perceptions of the foremen and craftsmen on the causes of material unavailability. Likewise, every cause was ranked according to the sum of the squares of its particular ranks and the results are displayed in Table 5.12.

Table 5.12 Causes of material unavailability

Factors	Groups of respondent						Overall rank
	Foremen			Craftsmen			
	Total score	RII	Rank	Total score	RII	Rank	
Shortage of funds	188	0.550	1	357	0.465	1	1
Waste due to negligence/sabotage	187	0.547	2	340	0.443	2	2
Improper materials storage	185	0.541	3	316	0.411	5	3
On site transportation difficulties	178	0.520	5	320	0.417	4	4
Inadequate planning	174	0.509	7	333	0.434	3	5
Improper materials delivery to site	178	0.520	4	307	0.400	8	6
Improper material usage to specification	153	0.447	8	310	0.404	7	7
Fluctuation in availability	174	0.509	6	305	0.397	9	8
Improper material handling on site	150	0.439	9	315	0.410	6	8
Excessive paper work for request	129	0.377	10	295	0.384	10	10

Shortage of funds was highlighted as the most significant cause of material shortage, confirming the opinion of the project managers discussed above. There is no doubt that this factor causes productivity problems, since it leads to, for example, materials acquisition difficulties and the improper use of tools and equipment.

Waste due to negligence/sabotage was cited second. An example of waste due to negligence is when, instead of searching for an appropriate size of off-cut steel sheet, a craftsman uses a brand new steel sheet. Operative sabotage is when operatives purposely damage or waste materials.

Ranked third, as a major cause of material unavailability, was *improper materials storage.* An example of this is the deterioration of formwork due to it being left outside. *On site transportation difficulties*, for example, an access road which is too narrow for a trailer to turn and unorganised loading areas for materials, was ranked fourth.

5.5.3.2 Incomplete drawing

Incomplete drawing was ranked as the second most critical factor affecting construction productivity by the responding project managers and foremen, and third by the craftsmen, confirming that incomplete drawings are another significant construction productivity problem in Thailand. Since incomplete drawings prevent a project from being progressed smoothly due to, for example, delays for revision or clarification, there is no doubt why this factor has a high effect on productivity. This factor occurs due to clients' limited time and budget for the designer to do the design in order to expedite the bidding process, and/or error from the designer. Nevertheless, in order to find the causes of this factor, the surveyed foremen were asked to rank general causes of incomplete drawing, based on their overall construction working experience; the results are exhibited in Table 5.13.

Table 5.13 Causes of incomplete drawing

Rank	Factors	Ranked score						Total number	Total score	RII
		0	1	2	3	4	5			
1	Designer provided insufficient detail	0	3	8	22	15	9	57	190	0.556
1	Inadequate examination of approved drawing	2	4	11	9	18	13	57	190	0.556
3	Impractical design (by designer)	0	6	10	17	14	10	57	183	0.535
4	Inexperienced draftsmen	0	6	10	16	17	8	57	182	0.532
4	Incomplete site survey	0	5	14	14	13	11	57	182	0.532
6	Inadequate time provided to draftsmen to complete	0	5	13	17	16	6	57	176	0.515
7	Inadequate proposal	1	6	11	17	14	8	57	175	0.512

Designer provided insufficient detail and *inadequate examination of approved drawing* were both cited as the most significant causes of incomplete drawing.

Designer provided insufficient detail wastes time while clarification is sought, and, if work has started, it may have to be suspended. Additionally, a tight schedule and a lack of circumspection of the examiner are major causes of the inadequate examination of approved drawings.

An example of *impractical design*, which was highlighted third, included tolerances which are too precise. Ranked fourth, as a major cause of incomplete drawing, were *inexperienced draftsmen* and an *incomplete site survey*. A lack of work understanding means that an inexperienced draftsman may produce drawings which are inadequate while an incomplete site survey means that a draftsman has to rely only on his professional judgement, which may be incorrect and lead to incomplete drawing.

5.5.3.3 Lack of tools and equipment

Tools and equipment are important, as without them work cannot be done progressively or to the required quality. Lack of proper tools and equipment arise from management ignorance of maintenance programmes, leading to inefficient use, the use of old and obsolete equipment and a shortage of spare parts. Alternatively a project manager may overestimate the capacity of a machine, resulting in insufficient numbers of the machine being employed. Nevertheless, in order to confirm the causes of this factor, the responding foremen were asked to rank general causes of lack of tools and equipment; the results are exhibited in Table 5.14.

Table 5.14 Causes of lack of tools and equipment

Rank	Factors	Ranked score						Total number	Total score	RII
		0	1	2	3	4	5			
1	Improper maintenance	0	3	9	15	19	11	57	197	0.576
2	Shortage of funds to procure	7	4	7	6	14	19	57	187	0.547
3	Inadequate planning	1	4	10	14	22	6	57	184	0.538
4	Various sites are being constructed at the same time	2	5	7	18	16	9	57	182	0.532
5	Improper tools/equipment application	1	4	14	20	8	10	57	174	0.509
6	Broken tools/equipment have not been reported	0	8	16	13	7	13	57	172	0.503
7	Unorganised storage	2	5	17	12	10	11	57	170	0.497
8	Delay in inter-site loan	0	9	14	18	10	6	57	161	0.471

Improper maintenance was specified as the most crucial cause of lack of tools and equipment. Although break-down maintenance may be preferred, rather than preventive maintenance, when a number of tools or equipment breaks-down at the same time, this will lead to a shortage problem. *Fund shortage to procure* was ranked second, and there is no doubt that insufficient funds, just like the case of lack of material, lead to procurement and maintenance difficulties.

Highlighted third, as the most influential cause of lack of tools and equipment, is *inadequate planning.* For example, the capacity of a machine may be over-estimated, resulting in insufficient numbers of the machine being employed. *Various sites being constructed at the same time* was ranked fourth. For example, if a number of generators are demanded for projects which are taking place at the same time, this may lead to an insufficient number of generators. Hiring or loaning generators, in this case, may alleviate the problem. *Improper tools/equipment application* was ranked fifth. This includes, for example, using a vertical gauge to remove slag, instead of a slag hammer, which reduces its accuracy, or using a adjustable spanner, instead of a hammer, which loosens its adjuster.

5.5.3.4 Poor site conditions

Poor site conditions was ranked fourth. Effects of poor site conditions vary from site to site and may lead to working difficulties and unsafe working conditions, and, consequently, accidents may occur, which cause delay. *Poor site preparation* is the only cause of this factor revealed by the project managers. Although site conditions are mostly outside a project manager's control, the respondents suggested that site preparation, such as ground levelling and installation of lighting and fire fighting systems, should be compulsory, and would significantly decrease the effect of poor site conditions on productivity.

5.5.3.5 Incompetent supervisors

This factor was ranked fifth in respect of its effect on construction productivity. Incompetent supervisors work slowly and may be responsible for defective work and inappropriate application of tools and equipment. One cause of this factor is *poor* *human resource management,* where inappropriate people are promoted to a supervisory role. The project managers believed that there was considerable potential for productivity improvement by implementing employee in-house training and ensuring supervisors were correctly selected.

5.5.4 Productivity Problems Compared with other Countries and the Literature

5.5.4.1 Comparison with other countries

Several authors have carried out investigations into productivity problems in various countries, all of which have used different factors. In order to compare the results obtained previously with the results of this study, six factors have been selected, which were also highlighted by other authors, and the ranking of these factors is shown in Table 5.15. From this, it is reasonable to conclude that lack of material is the most crucial productivity problem internationally, as the factor was ranked first in every country surveyed. However, causes of this factor may be different between developed and developing countries, since this research identified that the major cause of lack of material is shortage of funds, which seems inapplicable to developed countries like UK and USA.

Table 5.15 Comparison of productivity problems with other countries

Factors affecting productivity	Thailand	Indonesia[1]	Iran[2]	Nigeria[1]	UK[1]	USA[1]
	Rank	Rank	Rank	Rank	Rank	Rank
Lack of material	1st	1st	1st	1st	1st	1st
Lack of tools and equipment	2nd	5th	2nd	3rd	5th	2nd
Rework	3rd	2nd	4th	2nd	3rd	3rd
Supervision delays (Instruction time)	4th	6th	N/A	4th	4th	4th
Absenteeism	5th	4th	3rd	5th	6th	6th
Interference	6th	3rd	5th	6th	2nd	5th

[1] Kaming et al. (1997) [2] Zakeri et al. (1996)

It is also fair to say that developed countries have more problems with interference than developing countries. Meanwhile, both rework and supervision delays are experienced at about the same level, but developed countries suffer less from absenteeism.

In more detail, when focusing only on developing countries, the results of these studies, shown in Table 5.15, were ranked on an ordinal scale, except for Indonesia, which was ranked on an interval scale, and so, unfortunately, a rigorous analysis cannot be applied (Kaming *et al.,* 1997). This may be a reason why productivity problems in Indonesia appear different from other developing countries. However, when comparing the problems with the other three remaining developing countries, it is quite clear that Thailand, Iran and Nigeria experience lack of tools and equipment in addition to lack of material.

5.5.4.2 Comparison with the Literature

The comparison of the leading factors identified in the literature with the factors emerging from the survey gives an interesting result. The crude count of the factors from the literature compared with the dominant factors is on the left and the survey ranks are on the right.

Table 5.16 Comparison of the factors in the literature and the survey

Literature rank count	Factors	Survey rank
1	Lack of tools and equipment	3
2	Lack of material	1
2	Absenteeism	12
2	Workers turnover	18
5	Rework	7
5	Tools/equipment breakdown	8

It is notable, referring to Table 5.16, that, after the top two, there is little similarity in the rank order. The issues of absenteeism and workers turnover, which ranked highly in the literature surveys through the 1980's and 1990, have a social dimension and the greater emphasis upon managing out people problems could have an impact upon the change in rank order. The issue of rework will have been attended to by the more thorough Quality Control (early 1980's), Quality Assurance (mid to late 1980's) and Total Quality Management (mid 1990's), such measures would have focused upon ensuring that quality issues were at the forefront of management attention, with a subsequent reduction of rework.

Finally, the tools/equipment breakdown seems to be less relevant in the Thai survey. Since this featured as a problem through the 1980's to 1990's, equipment reliability has improved – perhaps as a function of the attention to quality management, alluded to earlier - by the equipment manufacturer. Of the greatest note, however, is the durability of the top two in both lists, which are matters of logistics – supply lines of the right 'thing' to the right 'place' at the right 'time'. This is the managerial challenge to the construction industry and lessons from the retail sector, especially the food supermarkets sector, could be usefully applied to the construction industry.

5.6 Summary

This chapter has revealed the top five most significant factors influencing construction in Thailand, namely; lack of material, incomplete drawing, lack of tools and equipment, incompetent supervisors and poor site conditions. Comparison of the productivity problems with other countries and the literature and a discussion are also provided. In addition, the causes of these factors and how to improve productivity is also discussed.

CHAPTER 6

THE APPLICATIONS OF WORK-SAMPLING AND FDS

6.1 Introduction

Since all theoretical aspects concerned with this research have been clarified, this chapter will demonstrate the results of work-sampling studies and foreman delay surveys (FDS). The study applies to 4 cases, which consist of two construction sites and two fabrication shops. Furthermore, for one case from both categories (Sites 1 and 4) only work-sampling was carried out, while the remaining two (Sites 2 and 3) undertook both work-sampling and FDS. The two main reasons that FDS is implemented on only one case from both categories are, firstly, to compare the results of these two techniques to see how FDS results comply with the particular results of a work-sampling program and, secondly, to see how effective a work-sampling study is, if it is the only technique carried out.

Each study, which lasts about 4 weeks, divides into three main sections. The first section, during the first week, is for the first application of work-sampling, where the purpose is to appreciate the situation and productivity problems during that particular period. Then, the second section, which occurs during an interval of approximately two weeks, enables management to respond to the results of the first work-sampling. Finally, a second one-week work-sampling is implemented to detect if there is any productivity improvement, arising from management actions implemented during the previous section. Please note that for the sites that implement both work-sampling and FDS, FDS is carried out during the same period as work-sampling.

The author plays both the study leader and observer roles, so all presentations, observations and data analysis are the author's tasks. However, the author can only report the productivity problems for a particular site, but decisions and suggestions to respond to these problems are the management's role. Furthermore, at the end of each study, the management will be informally asked for feedback, with regards to the work-sampling program and FDS (where applicable) and the participating foremen will also be asked individually and informally for feedback, in respect of FDS, where the survey is implemented.

6.2 Site 1: Italian-Thai Development Public Company Limited (Fabrication Shop Wiharndaeng)

This Steel Fabrication Shop was established in 1979 at Bang Pa-In, Ayudthaya under the management of the Siam Machinery and Equipment Co., Ltd. (Ital Thai Group). On October 1st, 1990 the Steel Fabrication Shop was transferred to be under the management of the Italian-Thai Development Corp., Ltd. (The factory is located at Siam Machinery & Equipment's Area). On March 24th, 1994, the company was renamed as a public company as Italian-Thai Development Limited. On March 1st, 1996 the factory was established in the Italian-Thai Industrial Complex at Wihandaeng, Saraburi Province.

The Industrial Complex consists of two fabrication shops, Phase I and II, with covered roofs, with areas of 5,400 and 5,940 m^2, respectively. Apart from the two shops, the Complex includes a big assembly yard (10,044 m^2), blasting shop (504 m^2), storage area for raw material and finished product (8,375 and 18,000 m^2, respectively) and office (1,134 m^2). The total capital invested for this complex is approximately 650,000,000 Baht[1].

At this time, this industrial complex employs 13 engineers, 20 supervisors, 13 foremen, 181 craftsmen and 43 office & project co-ordinators (accounting, administrator, cost, safety, general). There are, in addition, 4 major trades of craftsmen, 106 fitters (mark-cut, assembly, drilling), 32 welders, 12 finishers and 31 handlers (rigger & crane). The main products of this shop are macro structures, for example, steel towers, car bridges, train bridges, formwork and industrial building. During both rounds of the study, two jobs were being fabricated, a train bridge and electricity pylon columns.

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[1] 1 GBP = 65.41 Baht (on 1 November 2001)

6.2.1 Detail of the Study

Work-sampling is the only technique applied to this site. The author was allowed to carry out the study between 15 October and 12 November 2001. During each work-sampling study 450 samples were observed and the study was undertaken for 5 consecutive days, during which 90 samples were taken from 9 rounds of observation every day. The first work-sampling was from 15 to 19 October, while the second study was carried out between 8 and 12 November, which allowed an interval of approximately 3 weeks for the management to improve its productivity, with regards to the results of the first study.

According to the ratio of the numbers of craftsman of each trade to the total number of craftsmen, the 10 samples include 5 fitters (1 is mark/cut), 2 each for welders and riggers and 1 finisher. In addition, an observation round would require 20 minutes to complete. After the study had been completed, two sets of five consecutive days of study, 90 rounds of observations in total and two sets of 450 samples have been achieved. Table 6.1 specifies observation times for these studies.

Table 6.1 Observation times of work-sampling study for site 1

Study no.	Observation date	Round								
		1	2	3	4	5	6	7	8	9
1	15/10/01	9.22	9.59	10.32	10.57	13.08	13.42	14.28	14.59	15.53
	16/10/01	9.53	10.12	11.19	13.57	14.43	15.33	15.58	16.24	16.55
	17/10/01	8.00	8.44	9.41	10.59	11.29	13.17	14.58	15.29	16.19
	18/10/01	8.44	9.46	10.34	11.18	11.56	13.44	14.16	14.51	16.52
	19/10/01	8.17	8.48	9.42	10.42	13.08	13.45	14.16	14.43	15.01
2	8/11/01	8.56	9.17	10.22	11.16	13.15	13.58	14.22	15.25	15.52
	9/11/01	8.34	9.39	10.48	11.46	13.13	13.41	14.35	15.52	16.27
	10/11/01	8.27	8.50	10.02	11.23	11.51	14.44	15.07	16.01	16.25
	11/11/01	8.18	9.29	10.37	11.19	11.45	13.19	13.48	14.40	15.14
	12/11/01	8.13	8.54	9.22	9.44	10.07	10.40	13.00	15.15	16.30

6.2.2 Results of the Study and Analysis

6.2.2.1 Results of the Study

6.2.2.1.1 The First Work-Sampling Study

The first work-sampling application revealed that the average effective time of the craftsmen on site 1 was only 46%, equal to 3 hours and 42 minutes (based on 8 working hours a day), and, the remaining 54% ineffective time can be classified as follows (see Figure 6.1 and Figure 6.2): waiting for materials 3%, waiting for equipment 2%, waiting for instruction and other trades 11% each, and waiting for other crews 14%. Moreover, personal allowances and late start/early finish accounted for 7% and 6%, respectively.

6.2.2.1.2 The Second Work-Sampling Study

This investigation showed that the average effective time was 52% and the ineffective time was 48%, which is accounted for by 7% personal allowances, 6% late start/early finish, 3% waiting for equipment, 2% waiting for instruction, 18% waiting for other trades and 11% waiting for other crews (see Figures 6.3 and 6.4).

STUDY ANALYSIS SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 11
No. of rounds observed: 45 Study period: 5 days
Total observation No. : 450 Start date: 10.15.01 Finish date: 10.19.01

Category	Total	Percentage (%)
100 Effective Work	208	46.22
200 Ineffective Work	242	53.78
210 Management delays	184	40.89
211 Waiting for materials	12	2.67
212 Waiting for tools	0	0.00
213 Waiting for equipment	11	2.44
214 Waiting for instruction	50	11.11
215 Waiting for inspection	0	0.00
216 Waiting for other trades	49	10.89
217 Waiting for other crews	62	13.78
220 Personal Allowances	32	7.11
221 Taking a break	23	5.11
222 Personal needs	9	2.00
230 Miscellaneous Delays	26	5.78
240 No Contact	0	0.00
Total	450	100.00

Figure 6.1 Data analysis sheet of the first work-sampling study for site 1

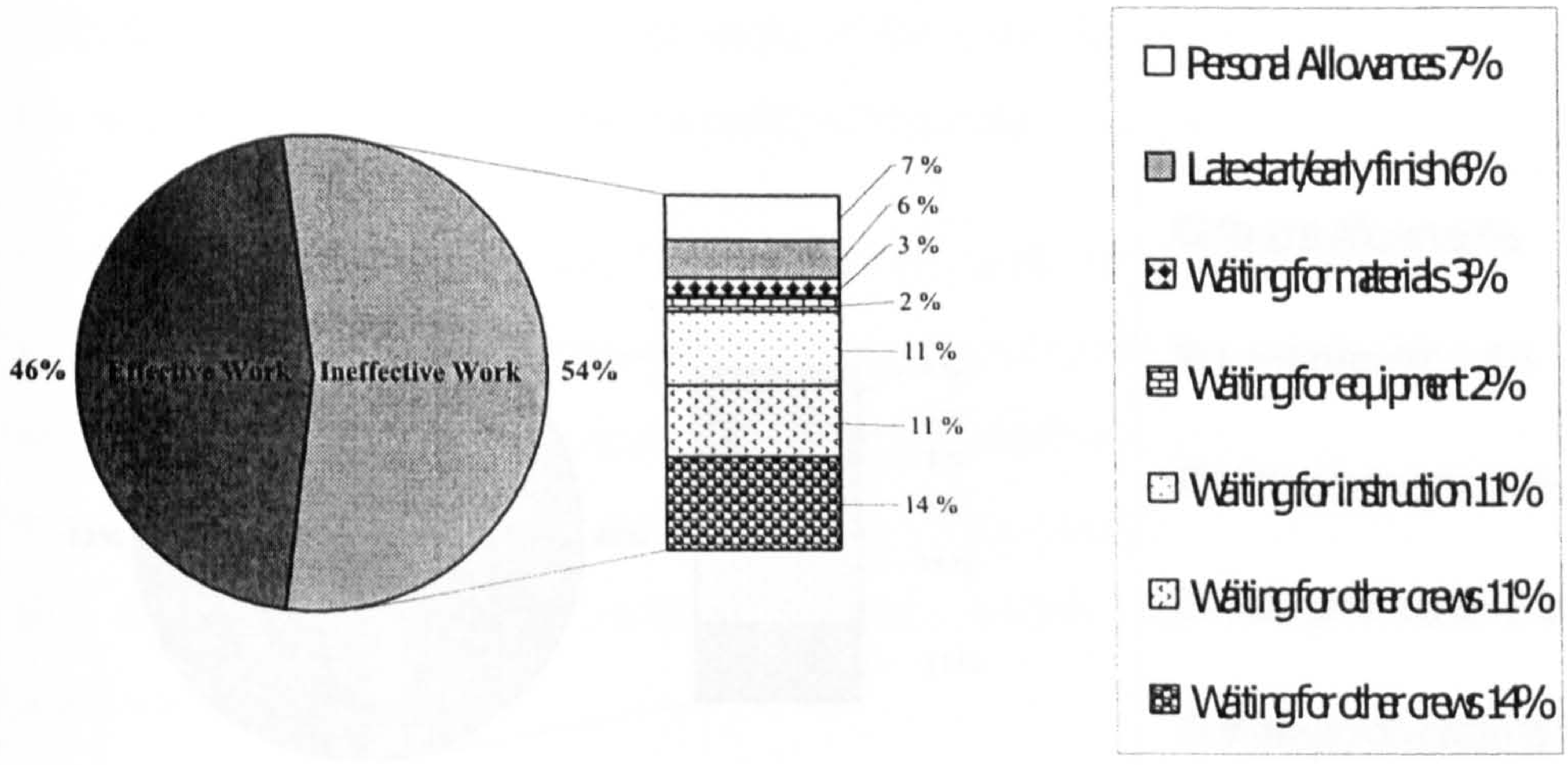

Figure 6.2 Graphical presentation of the first work-sampling study for site 1

STUDY ANALYSIS SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 21
No. of rounds observed: 45 Study period: 5 days
Total observation No. : 450 Start date: 7.11.01 Finish date: 11.11.01

Category	Total	Percentage (%)
100 Effective Work	233	51.78
200 Ineffective Work	217	48.22
210 Management Delays	156	34.67
211 Waiting for materials	1	0.22
212 Waiting for tools	1	0.22
213 Waiting for equipment	14	3.11
214 Waiting for instruction	9	2.00
215 Waiting for inspection	2	0.44
216 Waiting for other trades	80	17.78
217 Waiting for other crews	49	10.89
220 Personal Allowances	32	7.11
221 Taking a break	25	5.56
222 Personal needs	7	1.56
230 Miscellaneous Delays	29	6.44
240 No Contact	0	0.00
Total	450	100.00

Figure 6.3 Data analysis sheet of the second work-sampling study for site 1

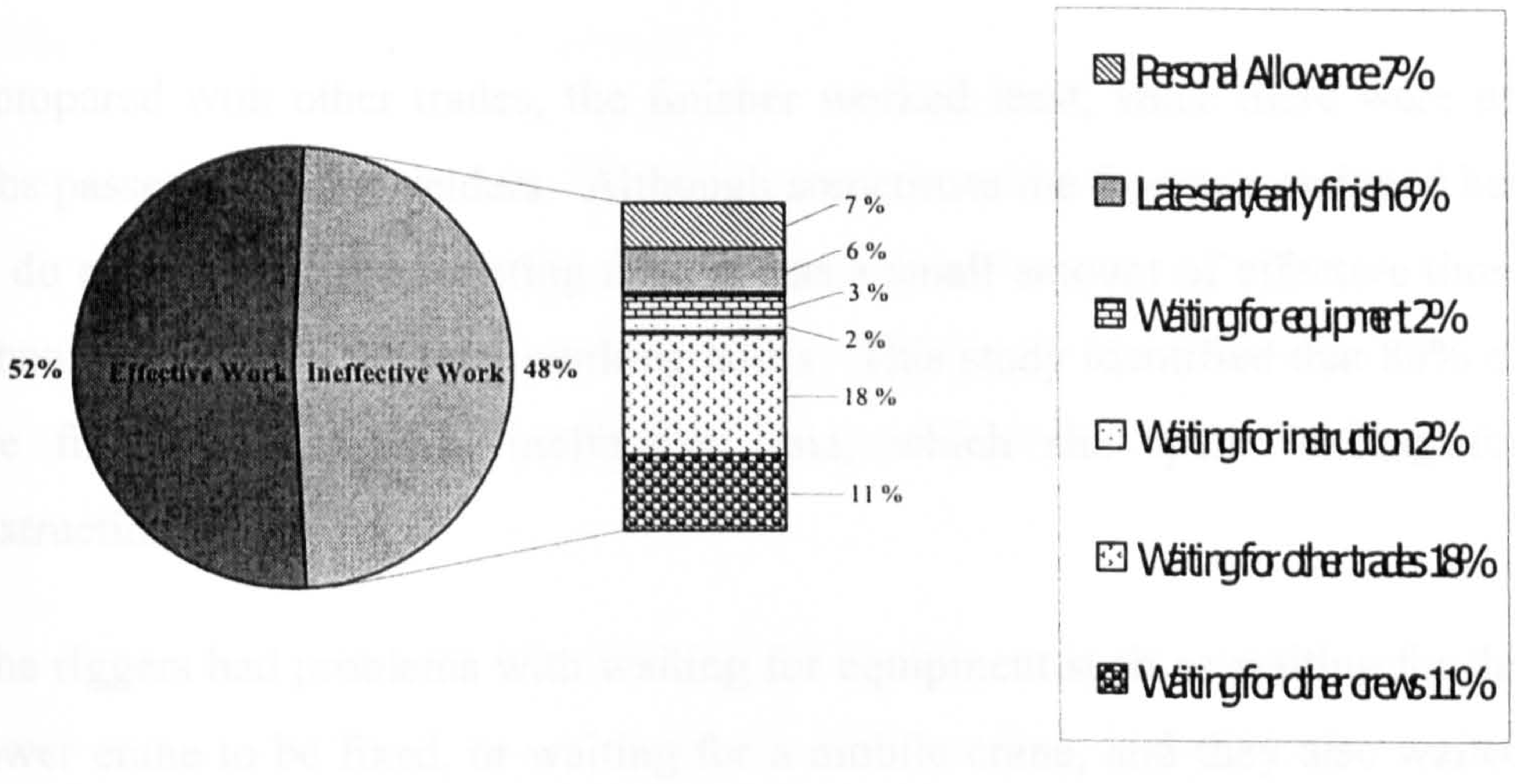

Figure 6.4 Graphical presentation of the second work-sampling study for site 1

6.2.2.2 Data Analysis

The situations described below are what the author perceived during observations:

- Generally, fitters (mark/cut) run their jobs smoothly, the only problem they faced was waiting for materials (L beam) from the store, which particularly happens in this trade. In other words, when waiting for materials the 3% lost was only from mark/cut operations. The author found that the problem caused delay of about 1.5 days from 5 days of the study (about 30% of working time). For the last two days of the investigation, the fitters moved to assemble TEMPO (a structure) as their materials had run out.

- The obvious problem for a fitter is waiting for other crews, due to, probably, an imbalanced numbers of crewmembers. Most of the time while taking samples, the operatives were standing idle watching other crewmembers work. As a result, most of the 14% of waiting for other crews were contributed by the fitter.

- The welders only worked normally on the first two days of the study. From the afternoon of the second day until the last day, the welders moved to work with the fitters, during which for most of the time they were idle. Therefore, the welders contributed to the majority of time lost waiting for other trades.

- Compared with other trades, the finisher worked least, since there were no jobs passed from the welders. Although sometimes the foreman assigned her to do extra work, like counting nuts, it was a small amount of effective time, when compared to the total working hours. This study identified that 80% of the finisher's time was ineffective time, which she spent waiting for instruction.

- The riggers had problems with waiting for equipment such as waiting for the tower crane to be fixed, or waiting for a mobile crane, and they also waited for instruction. Nevertheless, this trade worked with least interruption.

- Every trade was guilty of late start/early finish. This delay caused 6% of the total working hours lost per day (30 minutes per craftsman per day), which is a significant loss. The author sometimes found that operatives stopped working and prepared to have lunch 30 minutes earlier than scheduled. This is one of the most interesting problems of this site.

Table 6.2 Comparison of the first and second work-sampling study for site 1

Category	The fist study	The second study	Different
Effective work	46%	52%	Gain 6.0% (29 mpcpd*)
Waiting for materials	3%	0.2%	Gain 2.8% (13 mpcpd)
Waiting for tools	0%	0.2%	Loss 0.2% (1 mpcpd)
Waiting for equipment	2%	3.1%	Loss 1.1% (5 mpcpd)
Waiting for instruction	11%	2%	Gain 9.0% (43 mpcpd)
Waiting for inspection	0%	0.4%	Loss 0.4% (2 mpcpd)
Waiting for other trades	11%	18%	Loss 7.0% (33 mpcpd)
Waiting for other crews	14%	11%	Gain 3.0% (14 mpcpd)
Personal allowances	7%	7%	-
Late start/early finish	6%	6%	-
		Total	**Gain 6.0% (29 mpcpd)**

* mpcpd = minutes per craftsman per day

The second study took place around 3 weeks after the management had been informed of the results of the first study. This time work-sampling specified that the effective time was 52% (see Figure 6.4), which was an increase of approximately 11% when compared with the first study. The author can conclude, with 95%

confidence, that there had been improvement of effective time from 46% to 52% (see 4.7.1 for explanation of how this conclusion has been made). Table 6.2 compares results of the first and second investigation.

Overall, the work situations for the first and the second work-sampling study were fairly constant, for example, welders and finishers did not have much work to do. The increment in effective time, consequently, during the second investigation was the result of actions taken in responding to the first study's result, which can be described as follows:

- It is clear that waiting for materials, which was the only delay experienced by the fitters (mark/cut), was dramatically decreased (2.8% of total working hours) and, as a result, it contributed to the increase in effective time.
- Referring to the first study, the main productivity problem of the fitters was crew imbalance, which led to waiting for other crews. However, this problem was overcome by rearranging the numbers of the crew from 4 to 3, so a part of the increase in effective time arose from this improvement (see Table 6.2).
- Waiting for instruction and waiting for other trades were the main problems of welders and finishers, according to the first study. Similarly, there was still a less than desirable amount of work available for them in this study. Since, however, there were now clearly identified jobs for each trade, waiting for instruction was sharply reduced (from 11% to 2%) and transferred to waiting for other trades category, which made the percentage in this category obviously increase (from 11% to 18%).
- Riggers could keep the same good working pace, as they did in the first study. Waiting for instruction, which was a part of their problem, was completely solved. Consequently, they were the final contributors that allowed an increase in productive time.
- Unfortunately, management ignored the late start/early finish of the operatives. Probably, it was not the right time for them to alleviate this delay.

6.2.3 Feedback from the Project Manger

The project manager thought that the work-sampling could imply a crew imbalance problem for that particular period of the study. For example, if the study indicated that the welder experiences a lot of idle time, while the fitter is very busy, this implies an imbalance in crew numbers between the two trades. Therefore, transferring craftsmen from other trades, like mark/cut, to other fitters' jobs to assist them increase their output could retrieve the problem. Generally, the shop has its own craftsman ratio of 1:1:2:4 (mark/cut:grinder:welder:fitter).

Work-sampling, unfortunately, does not identify the causes of delays, for example, waiting for material is the delay either from the vendor or on site, which requires further investigation. Furthermore, when considering waiting for inspection, the project manager has to find out if lack of planning by the foreman is the cause of the delay. The project manager, moreover, believes that work-sampling should be implemented at the early stage of construction, as it can highlight idle time, and be carried out continuously in order to check crew balance. In addition, the project manager implied that work-sampling is suitable not only for fabrication shops, but also on site, as it suggests where to manage labour productively, and he would like to implement this technique once a month.

6.3 Site 2: PCM Processing (Thailand) New Factory

PCM Processing (Thailand) Ltd. is the owner of this project, located at Amata Nakorn Industrial Zone, Chonburi (an eastern province in Thailand), which is called "PCM Processing (Thailand) New Factory". This project, the second factory, was designed and constructed by Thai Shimizu Company Limited on an area of 1,500 m^2 (15m x 100m). The factory, when finished, will coat rolled steel, then cut sheets to order. The customer, after that, will use these sheets to produce such items as microwaves, air conditioners and computers.

PCM Processing (Thailand) New Factory Project lasted for 6 months, from 1 October 2001 to 31 March 2002, and had a value 20,000,000 bahts[1]. At the period of accessing the site, 31 October 2001, the project was 10% completed, with the car park and scrap box area completely finished, with the project being 8% ahead of schedule. Furthermore, the pavements and gutters were being constructed, with the major works being site preparation and formwork, using most of the craftsmen, meanwhile the remainder were preparing the footings for foundation work.

There were 1 project manager, 3 engineers, 2 foremen and 39 craftsmen working on this site. Craftsmen, additionally, could be classified into four main trades, 19 carpenters, 5 masons, 2 steel fixers and 13 general labourers. However, during the second study, the numbers of craftsmen increased to 80 (40 carpenters, 9 masons, 6 steel fixers and 25 general labourers). The second sampling commenced on 14 November 2001,when the project was 30% completed, with the project now being 17% ahead of schedule. In addition, in more detail, gutters and piling were 100% finished, pavements 40%, foundations 50% and columns 60% finished.

6.3.1 Detail of the Study

Site 2 implemented both work-sampling study and foreman delay surveys (FDS) and the study started on 31 October and finished on 17 November 2001. The first work-sampling study, where 450 samples were recorded from 45 observation rounds, in addition to FDS, was carried out between 31 October and 4 November. As there were 19 carpenters, 5 masons, 2 steel fixers and 13 general labourers, which add up to 39 craftsmen in total, 10 samples were randomly picked from 5 carpenters, 1 mason, 1 steel fixer and 3 general labourers (5:1:1:3). The time required, furthermore, to complete a round of observation was 10 minutes.

The second study was initiated between 14 to 17 November, 10 days after the first study, as requested by the project manager. Although the number of craftsmen had increased to 80 (40 carpenters, 9 masons, 6 steel fixers and 25 general labourers), the number of samples per trade remained the same. This is because the percentage of numbers of craftsmen in a particular trade to the total number of craftsmen is

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[1] 1 GBP = 62.73 Baht (on 30 November 2001)

approximately the same, when compared with the first sampling (5:1:1:3). Nevertheless, the second investigation of work-sampling observed only 400 samples over 4 consecutive days and 10 rounds of observations per day. All 85 rounds of observation times for this study are shown in Table 6.3.

Table 6.3 Observation times of the work-sampling study for site 2

Study no.	Observation date	Round 1	2	3	4	5	6	7	8	9
1	31/10/01	9.16	9.33	10.46	13.10	13.29	14.00	14.47	15.55	16.34
	1/11/01	8.01	8.45	9.03	9.59	10.25	13.38	14.16	15.29	16.39
	2/11/01	9.05	9.47	10.29	11.21	11.44	13.20	14.49	15.14	16.10
	3/11/01	9.34	10.23	10.47	11.17	11.48	14.30	15.17	16.02	16.31
	4/11/01	8.06	8.49	9.40	10.16	11.41	13.06	13.57	14.18	15.40

Study no.	Observation date	Round 1	2	3	4	5	6	7	8	9	10
2	14/11/01	9.52	10.11	10.31	11.55	13.44	14.07	15.02	15.26	15.48	16.56
	15/11/01	8.00	8.50	9.55	10.45	11.30	13.50	14.26	15.20	15.37	16.10
	16/11/01	8.10	8.55	10.46	11.36	11.55	14.04	14.56	15.49	16.02	16.29
	17/11/01	8.19	8.33	8.59	9.13	10.23	10.49	11.29	13.04	14.03	14.27

6.3.2 Results of the Study and Analysis

6.3.2.1 Results of the Study

6.3.2.1.1 The First Work-Sampling Study and Foreman Delay Surveys

- **Work-sampling study**

The first work-sampling study at site 2 revealed that the average effective time of this site was 57%, equal to 4 hours and 34 minutes, while the 43% of ineffective time includes: personal allowance 10%, 2% each for late start/early finish, waiting for equipment, waiting for other trades and waiting for other crews 27% (see Figure 6.5 and Figure 6.6).

STUDY ANALYSIS SHEET

Project: PCM Processing (Thailand) New Factory Reference: 12
No. of rounds observed: 45 Study period: 5 days
Total observation No. : 440 Start date: 10.31.01 Finish date: 4.11.01

Category	Total	Percentage (%)
100 Effective Work	250	56.82
200 Ineffective Work	190	43.18
210 Management Delays	135	30.68
211 Waiting for materials	0	0.00
212 Waiting for tools	0	0.00
213 Waiting for equipment	9	2.05
214 Waiting for instruction	0	0.00
215 Waiting for inspection	0	0.00
216 Waiting for other trades	7	1.59
217 Waiting for other crews	119	27.05
220 Personal Allowances	46	10.45
221 Taking a break	44	10.00
222 Personal needs	2	0.45
230 Miscellaneous Delays	7	1.59
240 No Contact	2	0.45
Total	440	100.00

Figure 6.5 Data analysis sheet of the first work-sampling study for site 2

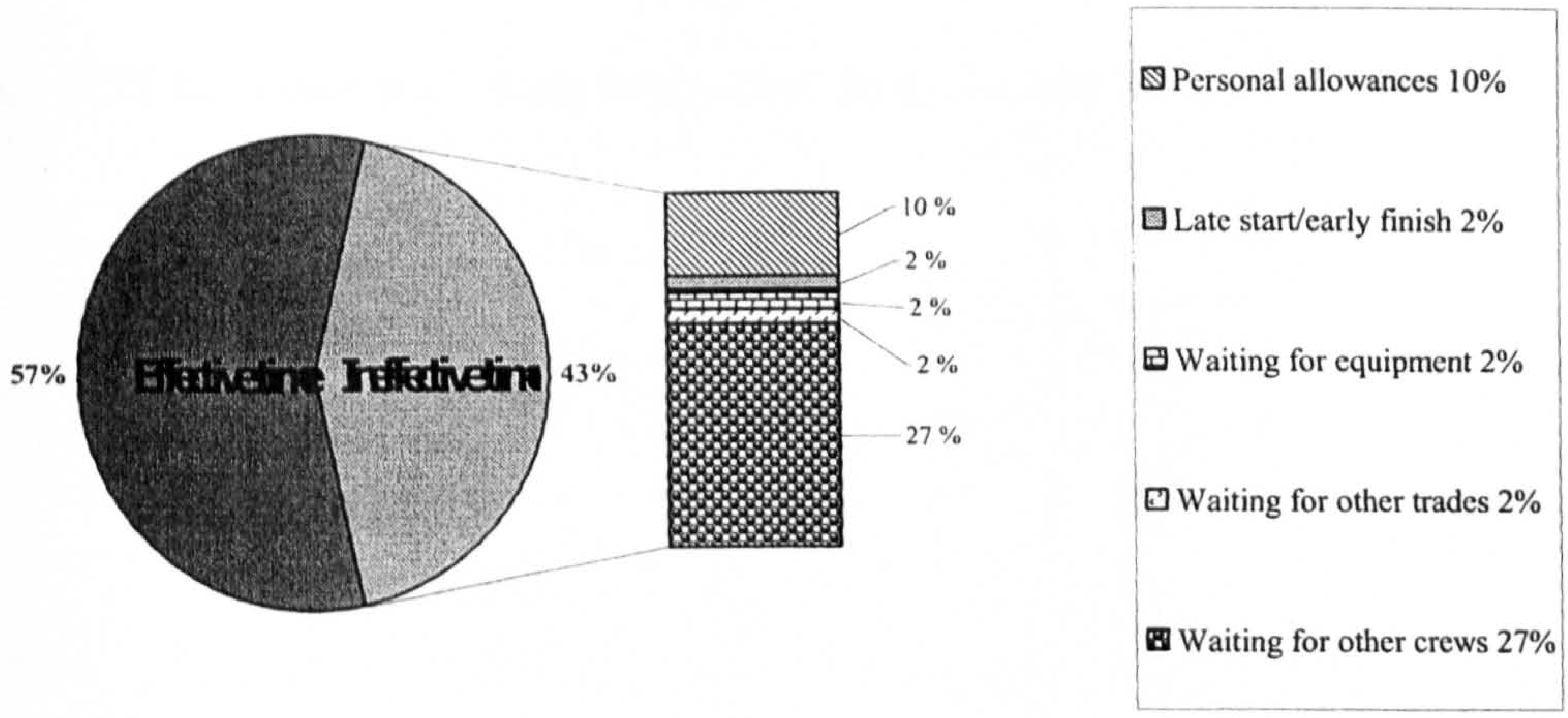
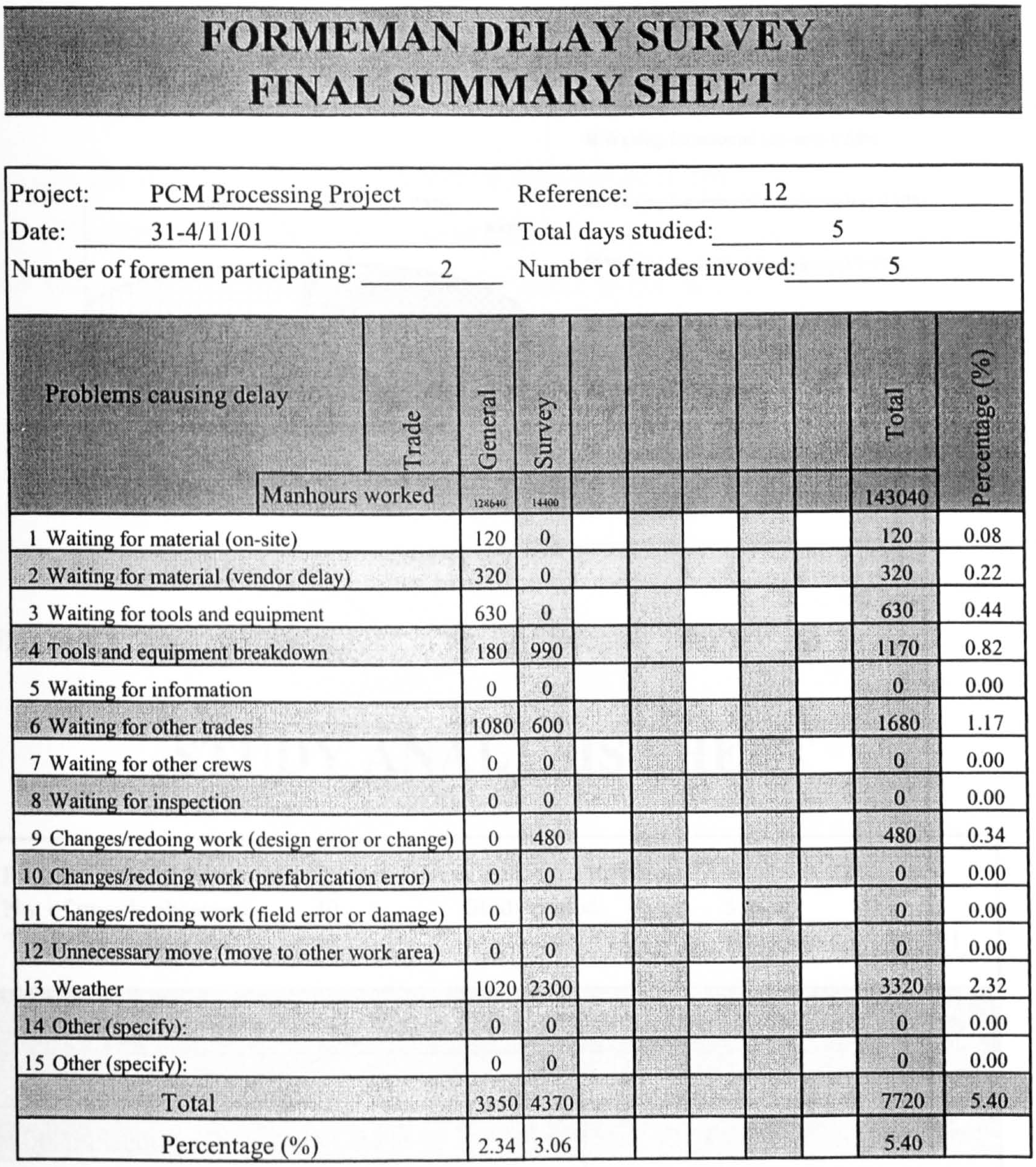


Figure 6.6 Graphical presentation of the first work-sampling study for site 2

❖ Foreman delay surveys

As there were only two foremen working on this site, the survey results were presented refer directly to the foremen (Mr. Teerapong and Mr. Boonthum), rather than to the trades. For the five consecutive days of study, which consisted of 2,384 man-hours (143,040 man-minutes), FDS reported that there was only a 5.40% delay, equal to 127 man-hours (7,620 man-minutes), and are described below (see Figure 6.7 and Figure 6.8):

- Waiting for material (on-site): cement (Mr. Teerapong) 0.88%;
- Waiting for material (vendor delay): ready mixed concrete (Mr. Teerapong) 0.22%;
- Waiting for tools and equipment: sling (20 tons) and bending machine ((Mr. Teerapong) 0.44%;
- Tools and equipment breakdown: pile cutting machine (Mr. Teerapong) and pile driver sling (Mr. Boonthum) 0.82%;
- Waiting for other trades: waiting for survey marking (Mr. Teerapong and Mr. Boonthum) 1.17%;
- Changes/redoing work (design error or change): piling section (Mr. Teerapong) 0.34%; and
- Weather: rain 2.32%.



FORMEMAN DELAY SURVEY
FINAL SUMMARY SHEET

Project: PCM Processing Project
Reference: 12
Date: 31-4/11/01
Total days studied: 5
Number of foremen participating: 2
Number of trades invoved: 5

Problems causing delay / Trade	General	Survey						Total	Percentage (%)
Manhours worked	128640	14400						143040	
1 Waiting for material (on-site)	120	0						120	0.08
2 Waiting for material (vendor delay)	320	0						320	0.22
3 Waiting for tools and equipment	630	0						630	0.44
4 Tools and equipment breakdown	180	990						1170	0.82
5 Waiting for information	0	0						0	0.00
6 Waiting for other trades	1080	600						1680	1.17
7 Waiting for other crews	0	0						0	0.00
8 Waiting for inspection	0	0						0	0.00
9 Changes/redoing work (design error or change)	0	480						480	0.34
10 Changes/redoing work (prefabrication error)	0	0						0	0.00
11 Changes/redoing work (field error or damage)	0	0						0	0.00
12 Unnecessary move (move to other work area)	0	0						0	0.00
13 Weather	1020	2300						3320	2.32
14 Other (specify):	0	0						0	0.00
15 Other (specify):	0	0						0	0.00
Total	3350	4370						7720	5.40
Percentage (%)	2.34	3.06						5.40	

Figure 6.7 FDS final summary sheet of the first study for site 2

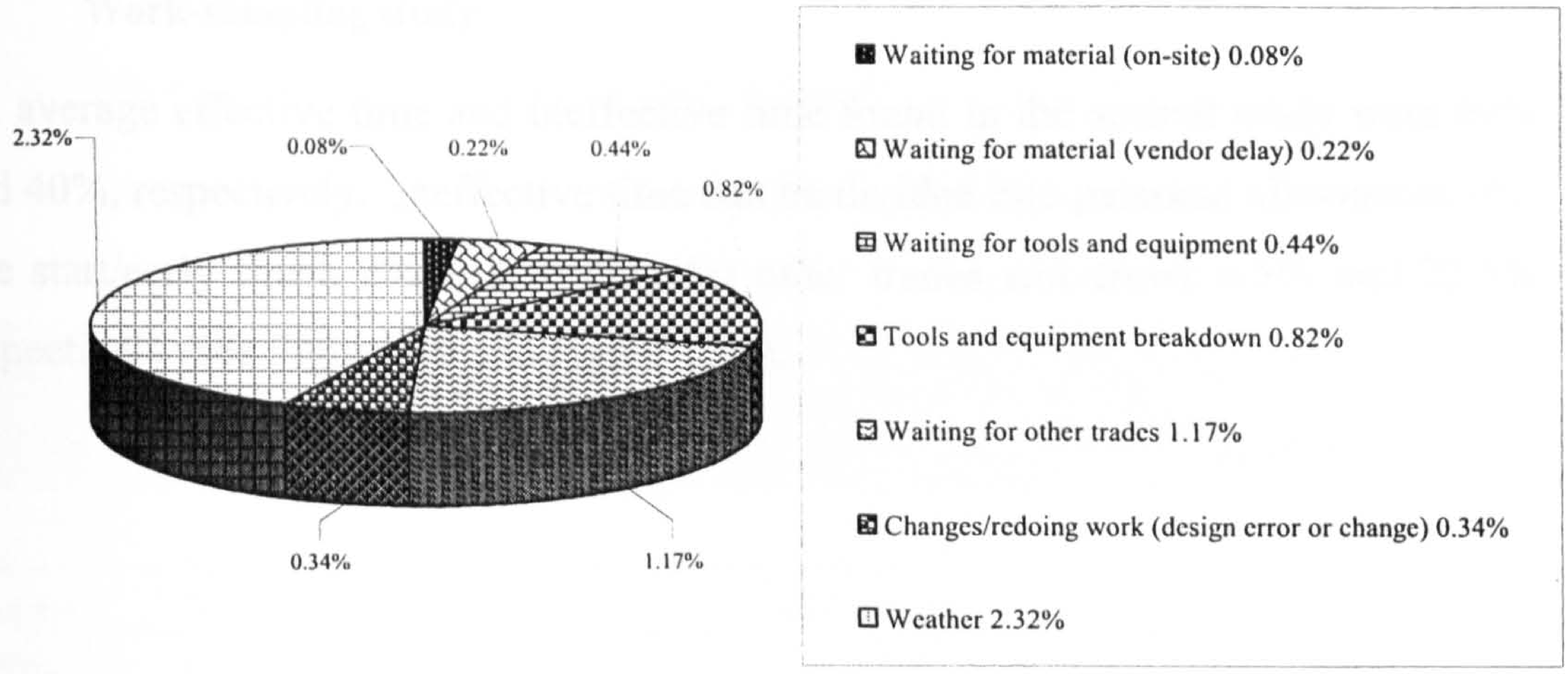
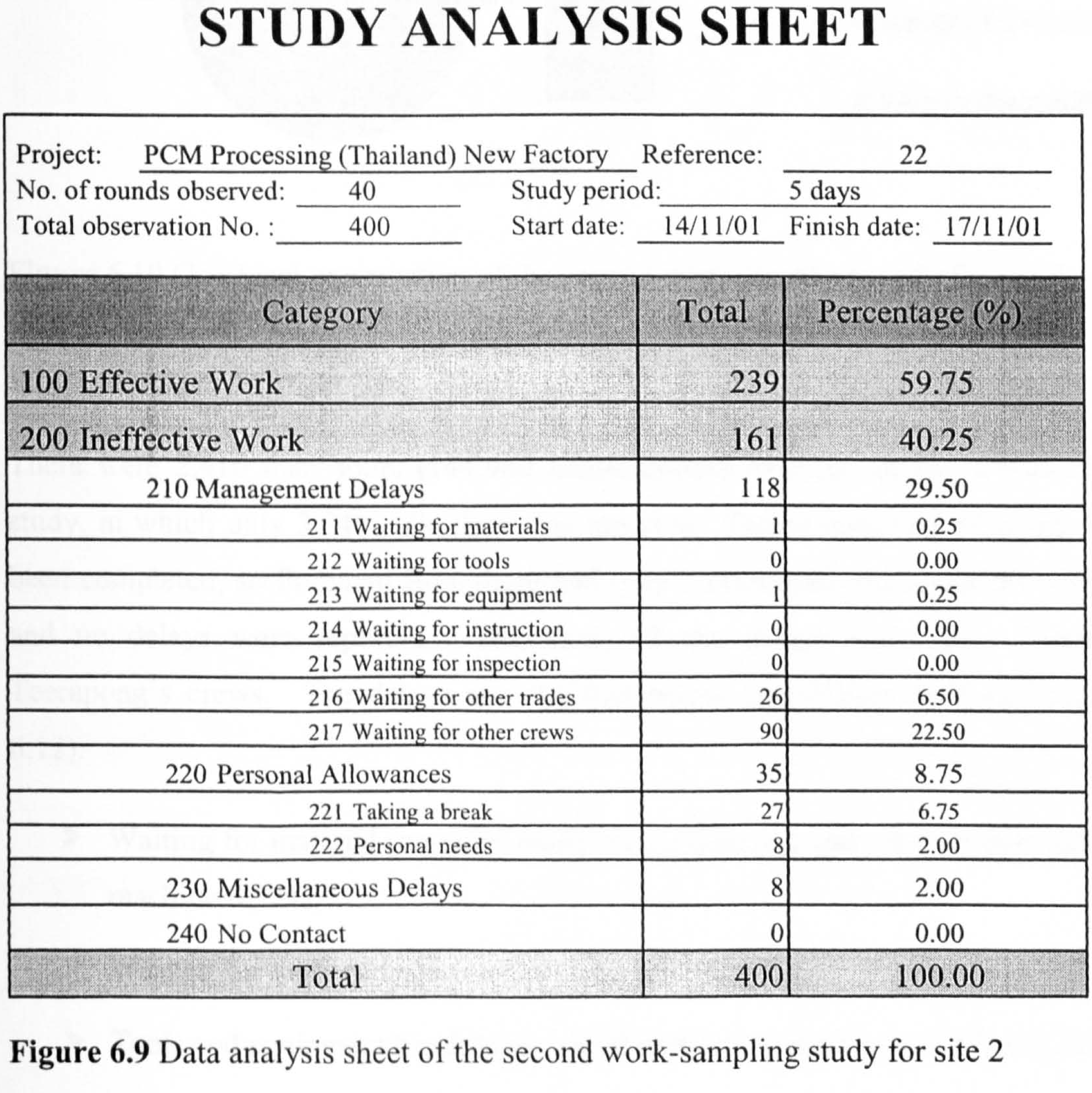


Figure 6.8 Graphical presentation of the first foreman delay surveys for site 2



STUDY ANALYSIS SHEET

Project: PCM Processing (Thailand) New Factory Reference: 22
No. of rounds observed: 40 Study period: 5 days
Total observation No. : 400 Start date: 14/11/01 Finish date: 17/11/01

Category	Total	Percentage (%)
100 Effective Work	239	59.75
200 Ineffective Work	161	40.25
210 Management Delays	118	29.50
211 Waiting for materials	1	0.25
212 Waiting for tools	0	0.00
213 Waiting for equipment	1	0.25
214 Waiting for instruction	0	0.00
215 Waiting for inspection	0	0.00
216 Waiting for other trades	26	6.50
217 Waiting for other crews	90	22.50
220 Personal Allowances	35	8.75
221 Taking a break	27	6.75
222 Personal needs	8	2.00
230 Miscellaneous Delays	8	2.00
240 No Contact	0	0.00
Total	400	100.00

Figure 6.9 Data analysis sheet of the second work-sampling study for site 2

6.3.2.1.2 The Second Work-Sampling Study and Foreman Delay Surveys

- **Work-sampling study**

An average effective time and ineffective time found in the second study were 60% and 40%, respectively. Ineffective time can be divided into personal allowances 9%, late start/early finish 2% and waiting for other trades and crews 6.5% and 22.5% respectively (see Figure 6.9 and Figure 6.10).

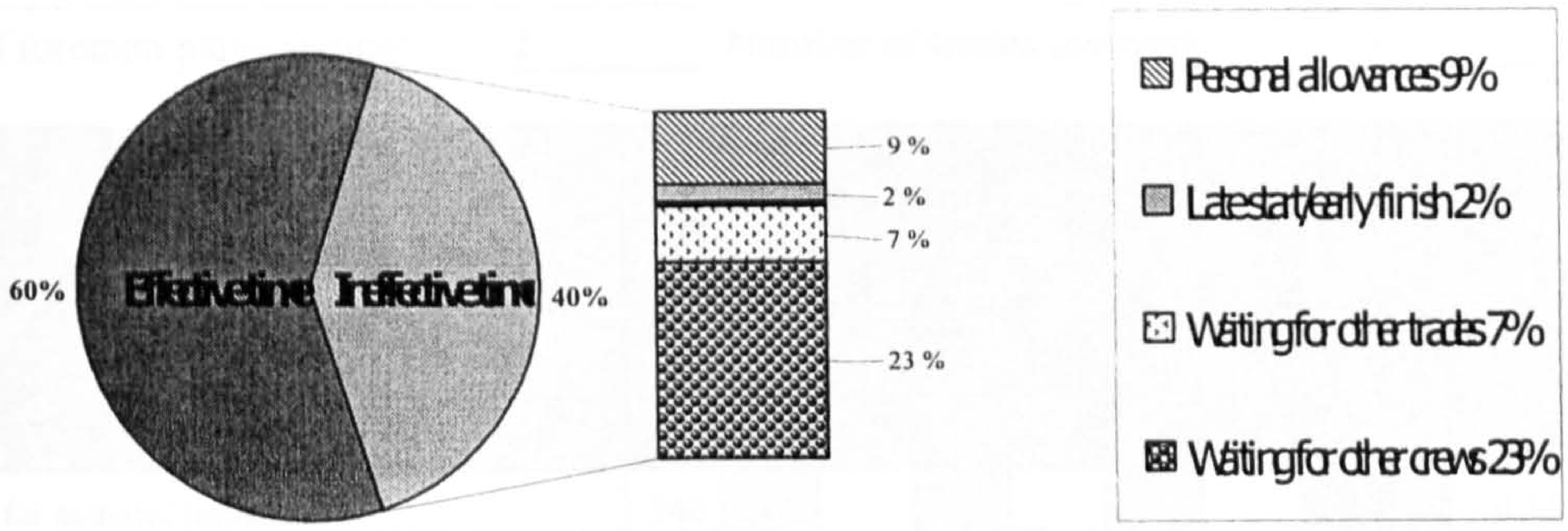


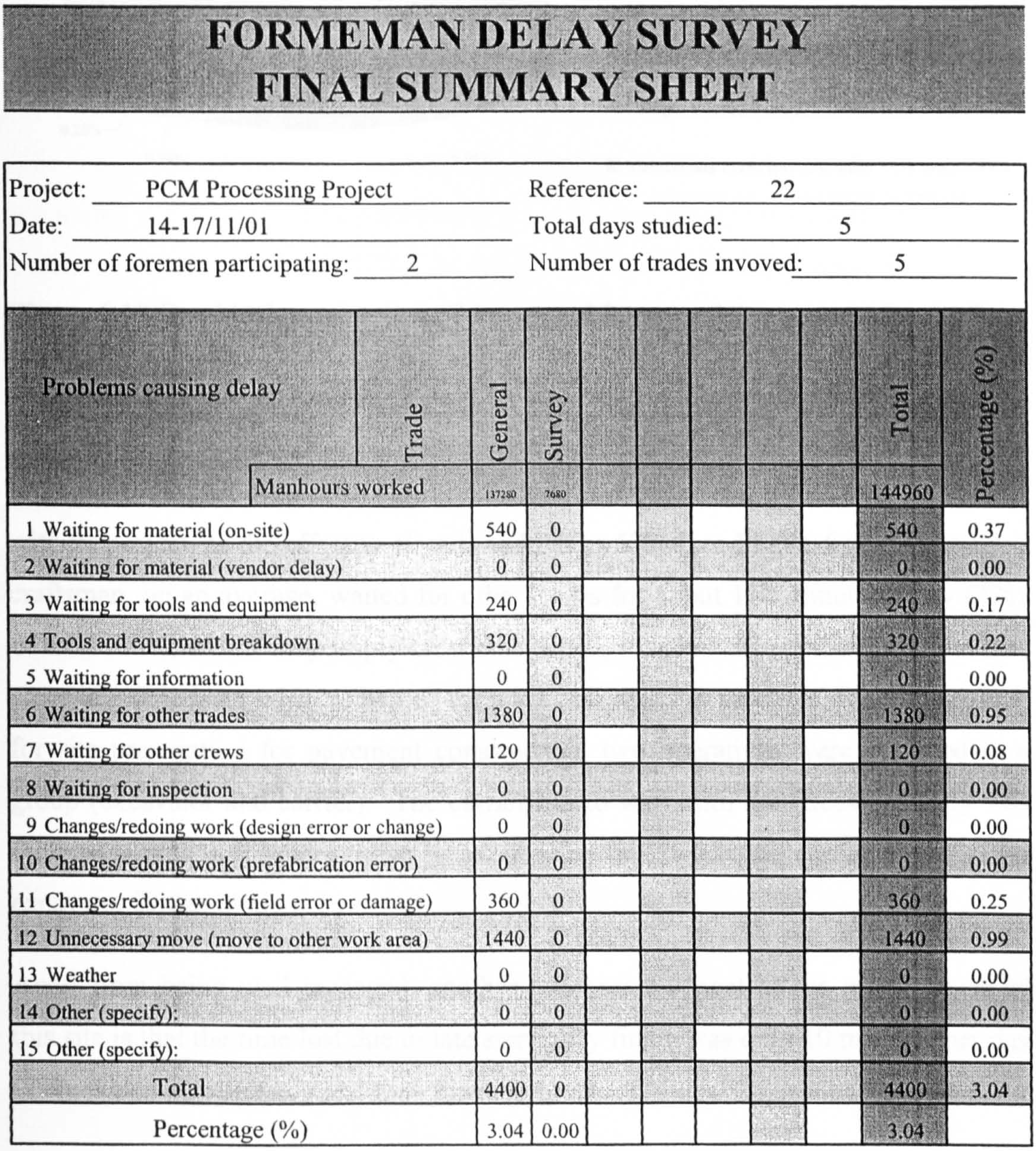
Figure 6.10 Graphical presentation of the second work-sampling study for site 2

- **Foreman delay surveys**

There were 2,416 man-hours (144,960 man-minutes) included in the second FDS study, in which only 3.04% idle time was reported. Please note that all piling had been completed, so Foreman Boonthum had only 3 craftsmen left under his control and no delays were reported. Therefore, all the delays were from Foreman Teerapong's crews. The delays are clarified below (see Figure 6.11 and Figure 6.12):

- Waiting for material (on-site): ready mixed concrete and wire for pile cutting machine 0.37%;
- Waiting for tools and equipment: pump 0.17%;
- Tools and equipment breakdown: metal cutting machine and backhoe 0.22%;

- Waiting for other trades: wait for survey marking 0.95%;
- Waiting for other crews 0.08%;
- Change/redoing work (field error or damage): expand footing at C2 0.25%;
- Unnecessary move (move to other work area) 0.99%.



FORMEMAN DELAY SURVEY
FINAL SUMMARY SHEET

Project: PCM Processing Project
Reference: 22
Date: 14-17/11/01
Total days studied: 5
Number of foremen participating: 2
Number of trades invoved: 5

Problems causing delay / Trade	General	Survey						Total	Percentage (%)
Manhours worked	137280	7680						144960	
1 Waiting for material (on-site)	540	0						540	0.37
2 Waiting for material (vendor delay)	0	0						0	0.00
3 Waiting for tools and equipment	240	0						240	0.17
4 Tools and equipment breakdown	320	0						320	0.22
5 Waiting for information	0	0						0	0.00
6 Waiting for other trades	1380	0						1380	0.95
7 Waiting for other crews	120	0						120	0.08
8 Waiting for inspection	0	0						0	0.00
9 Changes/redoing work (design error or change)	0	0						0	0.00
10 Changes/redoing work (prefabrication error)	0	0						0	0.00
11 Changes/redoing work (field error or damage)	360	0						360	0.25
12 Unnecessary move (move to other work area)	1440	0						1440	0.99
13 Weather	0	0						0	0.00
14 Other (specify):	0	0						0	0.00
15 Other (specify):	0	0						0	0.00
Total	4400	0						4400	3.04
Percentage (%)	3.04	0.00						3.04	

Figure 6.11 FDS final summary sheet of the second study for site 2

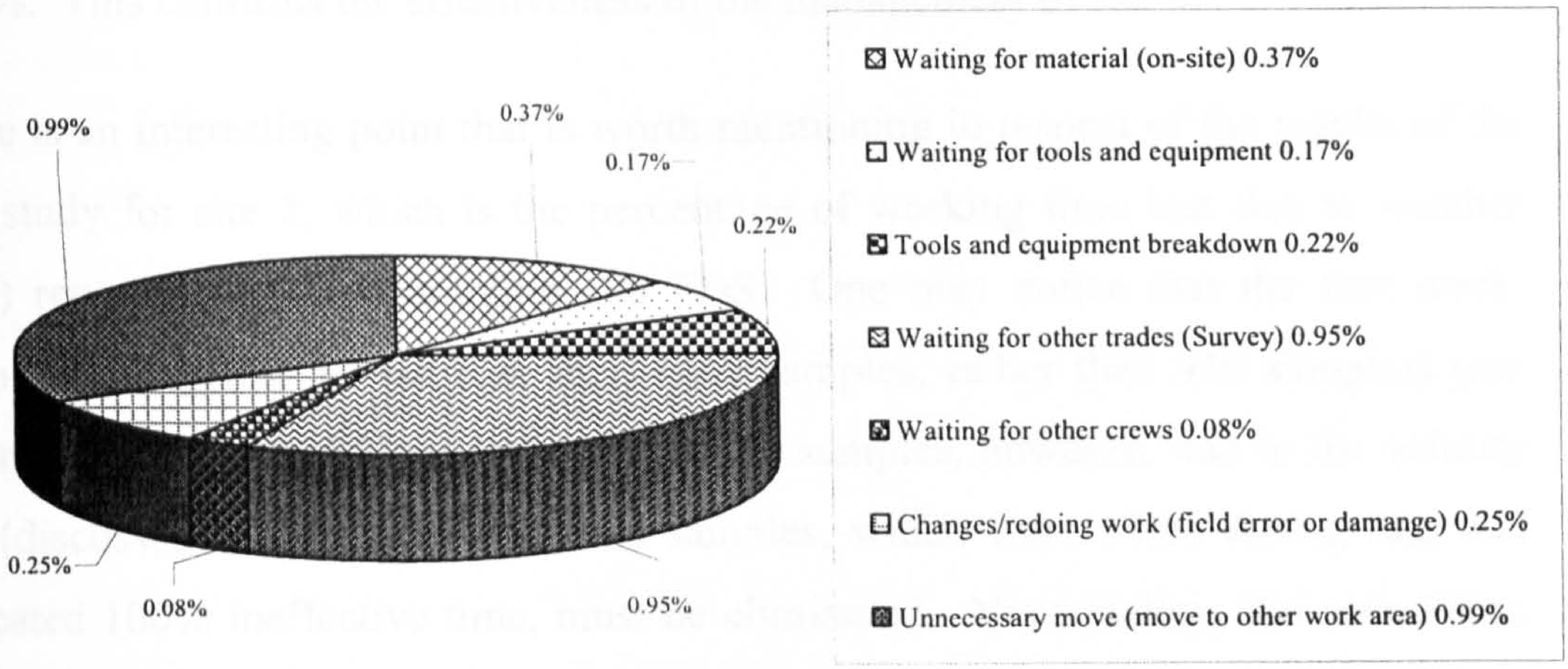


Figure 6.12 Graphical presentation of the second foreman delay surveys for site 2

6.3.2.2 Data Analysis

In general, the author is confident to conclude that the management was doing well with its project, as the effective time is as high as 57% (see Figure 6.6). Although a craftsman, on an average, waited for other crews for about 130 minutes a day (27% of total time), which may imply crew imbalance, it seems acceptable to the author, since idle time is an inherent part of the work process. For example, for earthmoving for site preparation for pavement construction, two operatives were assigned in a group (excavator and carrier). The carrier has to wait until the excavator fully fills the basket with soil before it can be taken away and, while the carrier is away, the excavator is also idle.

Apart from being well managed, another impressive aspect of the management of this site is that the time lost due to late start/early finish was only 10 minutes per day (2%), which significantly less than the other sites.

With regards to the results of the FDS, delays as low as 5.40% were highlighted, which comply with the work-sampling study that specified the jobs here were going very smoothly. Especially, if delay caused by weather (rain), which is an uncontrollable delay, was eliminated, the controllable delay would decrease to 3.08%. This confirms the effectiveness of the management of site 2.

There is an interesting point that is worth mentioning in respect of the results of the first study for site 2, which is the percentage of working time lost due to weather (rain) reported by work-sampling and FDS. One may notice that the first work-sampling study was 10 samples short (440 samples, rather than 450 samples) (see Figure 6.5). In fact, this study observed 450 samples, however, due to the validity test (discussed in 4.5.1.2.2), these 10 samples, which were taken during rain and indicated 100% ineffective time, must be eliminated. Nevertheless, if a calculation was made, 2.22% ineffective time would be accounted for by weather (rain), while it is clear that FDS specified 2.32% (see Figure 6.7). Having a FDS result close to that arising from work-sampling implies having an FDS accuracy as high as that arising from work-sampling.

There is also some results that work-sampling and FDS reported differently. For example, waiting for other crews, which were accounted for 22% and 0.08% from work-sampling and FDS, respectively (see Figures 6.9 and 6.12). This is understandable, since it is a principle of FDS that any particular delays will be noted when it lasts at least 15 minutes, so most of waiting for other crews, which last less than 15 minutes, were not detected by FDS, but do via work-sampling.

On the other hands, waiting for material, which were not reported by work-sampling because the incident occurred during observation times interval, but 0.37% by FDS. The similarity and contrary of the results reveals from these examples support that work-sampling and FDS contribute to each other. Here a note of caution needs to be introduced, as the data from the FDS and work-sampling are not directly comparable given the different ways in which the data was collected. However the data has remarkable correlation.

After the results of the first study had been presented to the committee for 10 days, the project manager asked the author to carry out the second study, as he believed what he had done in order to respond to the first study had been stabilised. Table 6.4 indicates a comparison of the results of the first and second investigations.

Table 6.4 Comparison of the first and second study of site 2

Category	The first study	The second study	Different
Effective work	57%	60%	Gain 3.0% (14 mpcpd*)
Management delays (waiting for materials, tools and equipment, other trades, other crews)	30%	29.5%	Gain 1.5% (7 mpcpd)
Personal allowances	10%	8.5%	Gain 1.5% (7 mpcpd)
Late start/early finish	2%	2%	-
		Total	**Gain 3.0% (14 mpcpd)**
Foreman Delay Surveys	3.08%	3.04%	**Decrease 0.04%**

* mpcpd = minutes per craftsman per day

The 3% increase in effective work for the second work-sampling study, when compared with the first study, arises from two parts. The first is a 4.84% (30% down to 29.5%) decrease in management delay, when compared with the first study. Second, there is a 1.5% productive time increase due to less personal allowances (personal allowances decreased 15%, when compared with the first study). The main reason for the decrease came from the first three days of the second study, which were a little bit cloudy, not as sunny as the first study, so exhaustion due to working under strong sun was dramatically decreased.

Although there is no statistically significant improvement for site 2 (see 4.7.2.), this series of studies has confirmed that this site has a high productive time (57%-60%) and this high rate can be maintained even when the number of craftsmen has approximately doubled from the first study (40 at first and 85 at the second). There is no doubt, the more operatives, the more difficult it is to manage a project. Nevertheless, this seems to have had no effect on the management of site 2. The results of the FDS is another thing that confirms the professional management of this site, since the results of both studies only reveal avoidable delays in the order of 3%.

6.3.3 Feedback from the Project Manager and the Foremen

6.3.3.1 The Foremen's Opinion

The foremen think FDS is a useful tool, since it highlights particular problems for them. As the result, they can perceive the problems more clearly and correctly respond to them, which make the foremen's work easier. FDS also motivates the foremen to initiate better planning, in reacting to the results of the first implementation. The foremen, in addition, believe that it would be beneficial if the management implemented FDS regularly, as it makes the foremen feel that their boss is interested in helping them solve their problems.

6.3.3.2 The Project Manager's Opinion

The project manager was satisfied with the accuracy of work-sampling results and specified that work-sampling could identify problems for him. For example, when waiting for equipment, due to cutting machine breakdown, the project manager responded by investigating the source of the problem, which may have been because of the rain. Then, a rain protector was installed to prevent the problem. In addition, work-sampling could assist him in planning, job sequencing and substituting jobs during delay. However, he said that the inability to differentiate between rework and craftsman work rate and effectiveness are the weak points of work-sampling. The project manager further explained that work-sampling is a good tool for managing labour productivity, in respect of minimising delays, and FDS is a great tool for managing foremen, with regard to encouraging them to carry out advanced planning. Therefore, he prefers to implement both tools every two weeks.

When asked to choose only one tool, nevertheless, the project manager implied he would select FDS, as it provides a better perception of problems than work-sampling and could guide the project manager to solve the problems at their source. Furthermore, as FDS reports the problems experienced by foremen, but which are out of their control, these may be the origin of rework. However FDS could prevent that, by reporting those causes to the project manager. Apart from the above, the project manager also believes that FDS offers him a fair and accurate account of the delays, which are occurring.

6.4 Site 3: Thai Nippon Steel Engineering & Construction Co.Ltd.

Thai Nippon Steel Engineering & Construction Co., Ltd. (TNS) was established in 1987 in a joint venture between Nippon Steel Corporation and the Italthai group. The yard is located at Tai-Ban, Samutprakarn province, approximately 60 km south of Bangkok at the mouth of the Chao Phraya River. For the past 14 years, TNS has been fabricating offshore structures for the development of Thailand's gas fields, which generate over 30% of the country's electricity.

The total area of the yard is 130,000 m^2 of which approximately 30,000 m^2 is allocated for outdoor material storage of steel plates, and tubes. Furthermore, the yard includes a 3,700 m^2 covered fabrication shop, sand blasting and painting activities occupy 2,408 m^2 and there is a 90,000 m^2 assembly area, which encompasses an area to fabricate Tripod jacket and decks and an area to fabricate 4 pile jackets and decks. The current number of employees is 405, of which 43 are management and administration, 84 are engineering and technical and 278 are tradesmen and labour.

Leg Mating Unit (LMU), the project studied, had a total value of approximately 21,000,000 Baht[1]. The project started in 27 October 2001 and was expected to be completed by 31 December 2001, a period of about 2 months. LMU, as the name implies, is an assembly guide for the processing of the deck and its 8 legs in order to distribute the deck weight, around 5,000 tons, equally to all 8 legs. Therefore, 8 units were being constructed, with an individual complete unit weighing close to 40 tons and being 1.9 m in diameter.

At the period of accessing the site, 26 November 2001, the LMU project was 63% completed, which was about 4% behind schedule. Additionally, the project employed 1 project manager, 2 engineers, 1 supervisor, 4 foremen and 30 craftsmen. The craftsmen, moreover, can be classified into 2 main groups, 12 fitters and 18

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[1] 1 GBP = 62.67 Bath (on 12 December 2001)

welders. Consequently, for the sample, 4 craftsmen are from the fitters and 6 from the welders, which come to a total of 10 samples.

The second sampling began, as requested by the project manager, on 11 December 2001, when the project was 76% completed. Unfortunately, the project progress was worse, when compared with the period of the first sampling, since it was now delayed 8% against the original plan (expected 84%). The completion date had been postponed to 15 January 2002. Nevertheless, the number of craftsmen for each trade was still stable and, as the result, the previous sample could be continued for the second sampling.

6.4.1 Detail of the Study

On site 3, just like site 2, two techniques, work-sampling study and foreman delay surveys (FDS) were carried out. The author accessed the site from 26 November to 15 December 2001, with the first and the second study taking place between 26 to 30 November and 11 to 15 December, respectively. Referring to the numbers of welders and fitters specified above, 10 samples were randomly chosen from 4 welders and 6 fitters and were sampled for both studies, since the ratio was stable. Furthermore, 15 minutes was required to finish a round of observations. Each work-sampling study collected 450 samples, using 90 rounds of observation in total, with the times of observations identified in Table 6.5.

Table 6.5 Observation times of the work-sampling study for site 3

Study no.	Observation date	Round								
		1	2	3	4	5	6	7	8	9
1	26/11/01	9.16	9.33	10.46	13.10	13.29	14.00	14.47	15.55	16.34
	27/11/01	8.01	8.45	9.03	9.59	10.25	13.38	14.16	15.29	16.39
	28/11/01	9.05	9.47	10.29	11.21	11.44	13.20	14.49	15.14	16.10
	29/11/01	9.34	10.23	10.47	11.17	11.48	14.30	15.17	16.02	16.31
	30/11/01	8.06	8.49	9.40	10.16	11.41	13.06	13.57	14.18	15.40
2	11/12/01	9.00	9.54	10.19	13.02	14.06	14.48	15.49	16.28	16.54
	12/12/01	8.48	9.38	10.53	13.00	13.55	14.59	15.48	16.05	16.49
	13/12/01	8.24	9.32	10.29	13.14	13.53	14.56	15.27	15.47	16.58
	14/12/01	8.18	8.42	10.34	11.27	13.17	13.36	14.17	15.02	15.56
	15/12/01	8.39	9.32	9.49	10.51	11.08	11.43	13.10	14.38	15.27

6.4.2 Results of the Study and Analysis

6.4.2.1 Results of the Study

The results of the first and the second work-sampling study and foreman delay surveys are described below:

6.4.2.1.1 The First Work-Sampling Study and Foreman Delay Survey

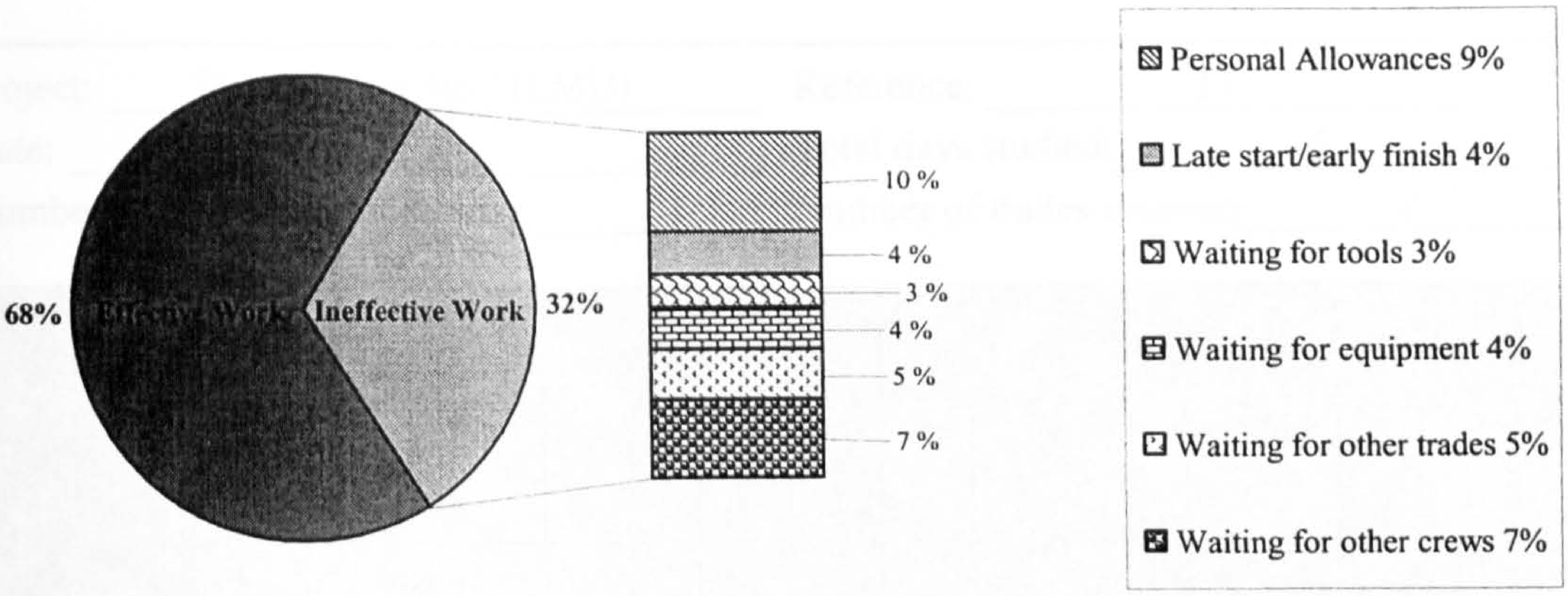
- **Work-sampling study**

The results of the first work-sampling implementation indicated that the average effective work of operatives on site 3 was 68%, equal to 5 hours and 26 minutes. The 32% ineffective work consisted of personal allowances 10%, late start/early finish 4%, waiting for tools 3%, waiting for equipment 4%, waiting for other trades 5% and waiting for other crews 7% (see Figure 6.13 and Figure 6.14).

- **Foreman delay surveys**

Foreman delay surveys at this site were concerned with two trades, fitters and welders. Data were collected by four foremen, two from each trade, and 760 man-hours (45,600 man-minutes) were recorded. 5.48% idle time, equal to 42 man-hours, was reported by the foremen, which is due to the reasons shown below (see Figure 6.15 and Figure 6.16):

- Waiting for material (on-site): steel (fitter) 0.26%;
- Tools and equipment breakdown: air pump ran out of gas (fitter and welder) 3.29%;
- Waiting for other trades: wait for MT and UT (fitter) and waiting for the installation of a heating pad (welder) 0.83%;
- Waiting for other crews (fitter) 0.04%; and
- Waiting for inspection: wait for the client's inspection (welder) 1.05%.



STUDY ANALYSIS SHEET

Project: Thai Nippon Steel (LMU) Reference: 13
No. of rounds observed: 45 Study period: 5 days
Total observation No. : 450 Start date: 26/11/01 Finish date: 15/11/01

Category	Total	Percentage (%)
100 Effective Work	304	67.56
200 Ineffective Work	146	32.44
210 Management Delays	85	18.89
211 Waiting for materials	0	0.00
212 Waiting for tools	14	3.11
213 Waiting for equipment	18	4.00
214 Waiting for instruction	0	0.00
215 Waiting for inspection	0	0.00
216 Waiting for other trades	21	4.67
217 Waiting for other crews	32	7.11
220 Personal Allowances	43	9.56
221 Taking a break	38	8.44
222 Personal needs	5	1.11
230 Miscellaneous Delays	18	4.00
240 No Contact	0	0.00
Total	450	100.00

Figure 6.13 Data analysis sheet of the first work-sampling study for site 3

Figure 6.14 Graphical presentation of the first work-sampling study for site 3

FORMEMAN DELAY SURVEY
FINAL SUMMARY SHEET

Project: Thai Nippon Steel (LMU)
Reference: 13
Date: 26-30/11/01
Total days studied: 5
Number of foremen participating: 4
Number of trades invoved: 2

Problems causing delay	Trade	Fitter	Welder						Total	Percentage (%)
	Manhours worked	24000	21600						45600	
1 Waiting for material (on-site)		120	0						120	0.26
2 Waiting for material (vendor delay)		0	0						0	0.00
3 Waiting for tools and equipment		0	0						0	0.00
4 Tools and equipment breakdown		150	1350						1500	3.29
5 Waiting for information		0	0						0	0.00
6 Waiting for other trades		120	260						380	0.83
7 Waiting for other crews		20	0						20	0.04
8 Waiting for inspection		0	480						480	1.05
9 Changes/redoing work (design error or change)		0	0						0	0.00
10 Changes/redoing work (prefabrication error)		0	0						0	0.00
11 Changes/redoing work (field error or damage)		0	0						0	0.00
12 Unnecessary move (move to other work area)		0	0						0	0.00
13 Weather		0	0						0	0.00
14 Other (specify):		0	0						0	0.00
15 Other (specify):		0	0						0	0.00
Total		410	2090						2500	5.48
Percentage (%)		0.90	4.58						5.48	

Figure 6.15 FDS final summary sheet of the first study for site 3

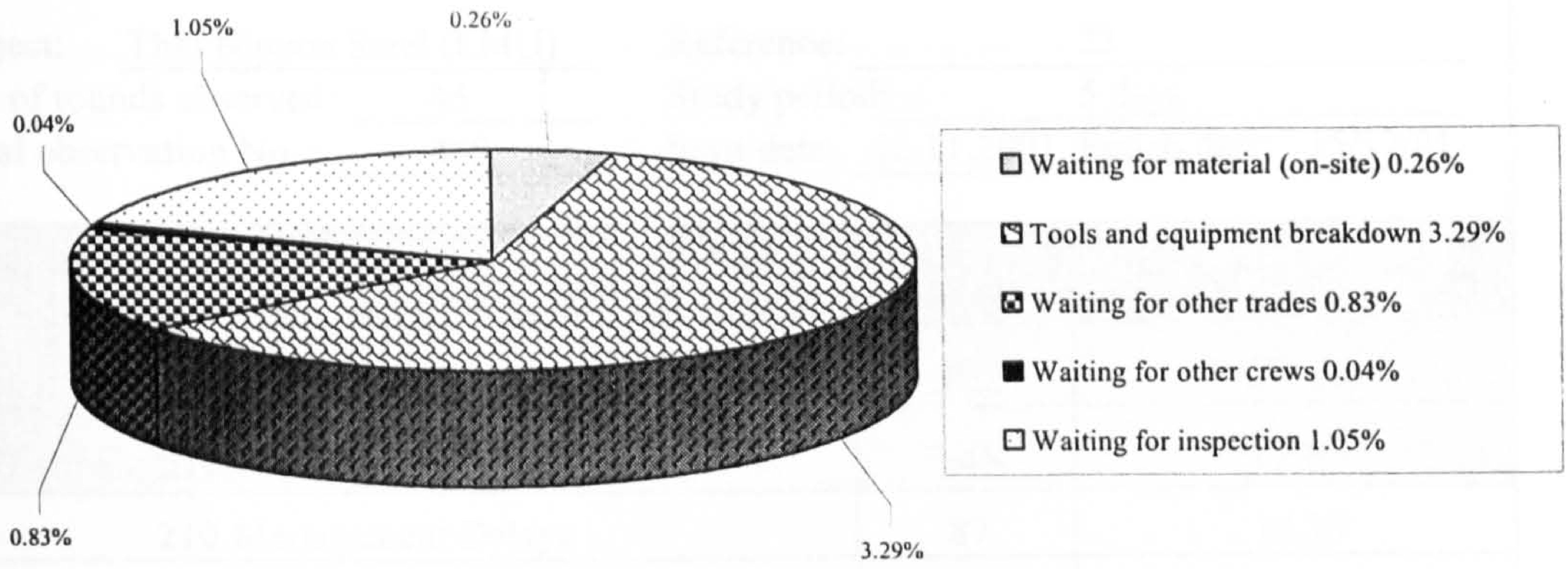


Figure 6.16 Graphical presentation of the first foreman delay surveys for site 3

6.4.2.1.2 The Second Work-Sampling Study and Foreman Delay Survey

❖ **Work-sampling study**

Effective time indicated in the second study was 67%, while ineffective time was 33%. The ineffective time included waiting for equipment 3%, waiting for instruction 2%, waiting for inspection 1%, waiting for other trades and crews 9% and 5%, respectively, and also personal allowance 9% and late start/early finish 5% (see Figure 6.17 and Figure 6.18).

❖ **Foreman delay surveys**

The second survey recorded a total of 880 man-hours (52,800 man-minutes) and there were only 4.32% of delays specified, which are clarified as follows (see Figure 6.19 and Figure 6.20):

- Tools and equipment breakdown: 50 tons crane (fitter) 1.70%;
- Waiting for other trades: wait for MT and UT (welder) 0.80%; and
- Waiting for inspection 1.82%.

STUDY ANALYSIS SHEET

Project: Thai Nippon Steel (LMU) Reference: 23
No. of rounds observed: 45 Study period: 5 days
Total observation No. : 450 Start date: 12.11.2001 Finish date: 15/12/01

Category	Total	Percentage (%)
100 Effective Work	302	67.11
200 Ineffective Work	148	32.89
210 Management Delays	87	19.33
211 Waiting for materials	0	0.00
212 Waiting for tools	14	3.11
213 Waiting for equipment	0	0.00
214 Waiting for instruction	9	2.00
215 Waiting for inspection	3	0.67
216 Waiting for other trades	40	8.89
217 Waiting for other crews	21	4.67
220 Personal Allowances	42	9.33
221 Taking a break	36	8.00
222 Personal needs	6	1.33
230 Miscellaneous Delays	19	4.22
240 No Contact	0	0.00
Total	450	100.00

Figure 6.17 Data analysis sheet of the second work-sampling study for site 3

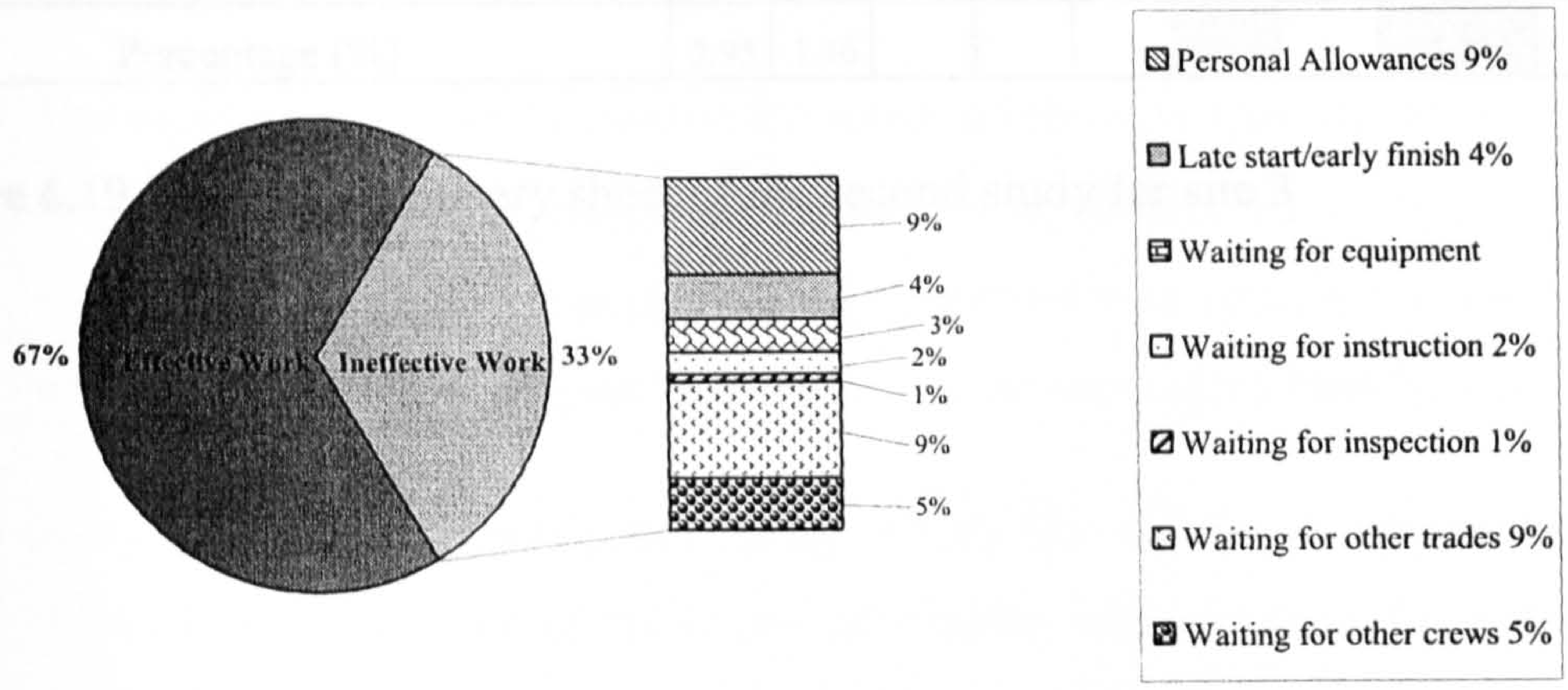


Figure 6.18 Graphical presentation of the second work-sampling study for site 3

FORMEMAN DELAY SURVEY
FINAL SUMMARY SHEET

Project: Thai Nippon Steel (LMU)	Reference: 23
Date: 11-15/12/01	Total days studied: 5
Number of foremen participating: 4	Number of trades invoved: 2

Problems causing delay / Trade	Fitter	Welder						Total	Percentage (%)
Manhours worked	32160	20640						52800	
1 Waiting for material (on-site)	0	0						0	0.00
2 Waiting for material (vendor delay)	0	0						0	0.00
3 Waiting for tools and equipment	0	0						0	0.00
4 Tools and equipment breakdown	900	0						900	1.70
5 Waiting for information	0	0						0	0.00
6 Waiting for other trades	420	0						420	0.80
7 Waiting for other crews	0	0						0	0.00
8 Waiting for inspection	240	720						960	1.82
9 Changes/redoing work (design error or change)	0	0						0	0.00
10 Changes/redoing work (prefabrication error)	0	0						0	0.00
11 Changes/redoing work (field error or damage)	0	0						0	0.00
12 Unnecessary move (move to other work area)	0	0						0	0.00
13 Weather	0	0						0	0.00
14 Other (specify):	0	0						0	0.00
15 Other (specify):	0	0						0	0.00
Total	1560	720						2280	4.32
Percentage (%)	2.95	1.36						4.32	

Figure 6.19 FDS final summary sheet of the second study for site 3

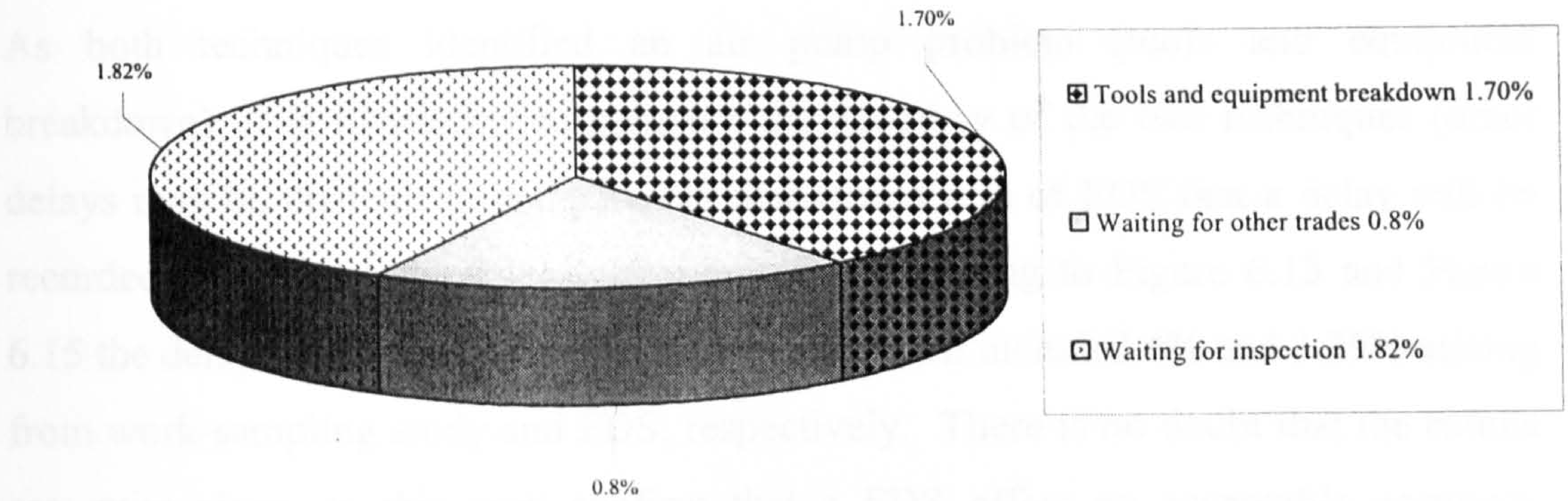


Figure 6.20 Graphical presentation of the second foreman delay surveys for site 3

6.4.2.2 Data Analysis

This project was being fairly well progressed, as the results of the first work-sampling study showed 68% effective time and the FDS identified only 5.48% delays, which confirms this. Although there were some problems revealed, they were retrievable and are explained below (see Figure 6.14):

- Late start/early finish is also a productivity problem of this site, like site 1, that caused 4% delay (19 mpcpd). This problem is not too difficult to alleviate and should be focused on.

- The problem that should receive the most attention is that the air pump ran out of gas (tools and equipment breakdown), which has resulted in 4% unproductive time (19 mpcpd). If this problem was completely alleviated, which is possible, the project would increase its productive time by 4%.

- Another way to improve productivity of this site was to assign other minor works to the craftsmen to do, where applicable, while waiting for something such MT, UT, or installing a heating pad.

- The author also found that during a day, on average, an operative had to spend around 16 minutes getting tools from the store (waiting for tools 3%), as it is quite a long distance from the shop to the store.

As both techniques identified an air pump problem (tools and equipment breakdown), it is interesting to compare the accuracy of the two techniques (other delays may be difficult to compare because it is a rule of FDS that a delay will be recorded only if it lasts at least 15 minutes). Referring to Figure 6.13 and Figure 6.15 the delay due to tools and equipment breakdown included 4% and 3.29% arising from work-sampling study and FDS, respectively. There is no doubt that the results are quite close, so this may confirm that a FDS offers an acceptable accuracy, whereas a work-sampling study provides a fairly high accuracy.

About 10 days after the presentation of the results of the first study, the second study started. The second work-sampling pointed out 67.33% effective time, which is a 0.23% decrease when compared with the first study. Table 6.6 compares the results of both studies (see Figure 6.13 and Figure 6.17).

Table 6.6 Comparison of the first and second work-sampling study for site 3

Category	The fist study	The second study	Different
Effective work	67.56%	67.33%	Loss 0.23% (1mpcpd*)
Waiting for tools	3.11%	3.11%	-
Air pump run out of gas	4.00%	0.00%	Gain 4.00%
Waiting for instruction	0.00%	2.00%	Loss 2.00%
Waiting for inspection	0.00%	0.67%	Loss 0.67%
Waiting for other trades	4.67%	8.89%	Loss 4.22%
Waiting for other crews	7.11%	4.67%	Gain 2.44%
Personal allowances	9.56%	9.11%	Gain 0.45%
Late start/early finish	4.00%	4.00%	-
		Total	**Loss 0.23% (1mpcpd)**
Foreman Delay Surveys	5.48%	4.32%	**Decrease 1.16%**

* mpcpd = minutes per craftsman per day

There is no doubt that, according to Table 6.6, the problem of the air pump running out of gas (tools and equipment breakdown) had been completely solved, which should, therefore, increase the second productive time by 4% (the second study should identify around 70-71% productive time). Unfortunately, the second work-sampling's results, did not result in an increase, but showed a decrease of 0.23%.

This is because the work situation of the second study was obviously different from the first investigation.

During the first work-sampling study, welders and fitters worked independently and rarely needed to cooperate with each other. However, during the second study they were required to work with each other more. The second study's results could clearly confirm this, as it shows that waiting for other crews decreased by 2.44%, while waiting for other trades increased by 4.22% (see Table 6.6), which contributed to the decreased effective time. In addition, the second study highlighted some new productivity problems, which were:

- Waiting for instruction, due to work discontinuity, which was experienced by the fitters and accounted for 2% of total working time; and
- Welders had to wait for an inspection from QC and, as a result, 0.67% of working time was lost.

Although the productive time of the two trades is as high as 67%, the project progress is lagging behind the schedule due to an inadequate number of welders employed on the LMU project. The project manager explained that during the peak time of the project, the period of these studies, that instead of employing 28 welders, as specified in the original plan, the project manager chose to maintain 18 welders and extend the finish date. This is because doing so is easier to manage and there is no effect on the whole project if LMU has been delayed, which was approved by the client.

The results of site 3 investigation confirm that the project was quite well managed, since work-sampling showed productive time as high as 67% and FDS reported delays of only 4-5%. Although some productivity problems were found, they were only minor problems, which were not difficult to overcome or alleviate. However, similar to site 2, the decrease in productive time is not statistically significant.

6.4.3 Feedback from the Project Manager and the Foremen

6.4.3.1 The Foremen's Opinion

The foremen believed that FDS assisted them in carrying out advance planning and coordinating with other foremen in order to decrease idle time. The repeat problem has been solved. A very obvious example, in this case, is that the air pump engine ran out of gas, which they had experienced many times, but now this problem has disappeared. Also, FDS provides evidence that a foreman and his subordinates do not try to avoid working, for example, they are idle because they are waiting for inspection. Finally, the foremen prefer the management to implement FDS, as it makes them feel that the management closely co-operates with them to achieve improved productivity.

6.4.3.2 The Project Manager's Opinion

The project manager was impressed by the accuracy of the results of work-sampling, since it reflected the percentages that he had in mind. With regard to the frequency of implementation, the project manager prefers to have work-sampling done once a month. Although the implementation of WS may require some engineer man-days for preparation, data collection and analysis, the project manager strongly believed that it is worthwhile. This is because the cost saved by productivity improvement, according to the study results, is much more than the cost of the engineer man-days required for work-sampling implementation.

In respect of choosing to implement only one tool, work-sampling or FDS, the project manager would pick work-sampling, as he questioned the accuracy of FDS, due to unfaithful reporting by the foremen. Furthermore, work-sampling, undertaken by a third party, offers more accuracy than FDS and provides a better picture of productivity problems, especially the percentages specified in a particular category, which assist him to respond quickly and correctly to the heart of problem, taking into account which activity requires priority.

6.5 Site 4: MRT Chaloem Ratchamongkhon Line (Khumpangphet Station: S20)

The MRT Chaloem Ratchamongkhon Line is owned by the Mass Rapid Transit System (MRTS) and is designed and constructed by ION Joint Venture. This project, when completed, will be the first underground train line in Thailand, which goes 20 km from Hua Lum Pong train station to Bang Sua train station. In addition, the North Contact, was started on 2 December 1998 and the expected finish date is 5 December 2002. The line, basically, consists of two parallel tubes, with 6.3 m outside diameter and track levels approximately 20 m below ground level. Furthermore, the MTR Chaloem Ratchamongkhon Line presently includes 9 underground train stations, which each have a width between 18-25 m, length between 150-230 m and the deepest floor below ground level is between 16-32 m.

Khumpangphet Station (S20), one of the nine underground train stations, was used for this case study. This station has 3 entrances, 1 subway and 3 levels namely; retail, concourse and station, with the dimensions of 23 m in width, 228 m in length, and the lowest floor is 20 m below ground level. Additionally, S20 is located at the junction of Khumpangphet Road and Khumpangphet 2 Road, Jatujak, Bangkok. The project started on 11 August 1997 and is expected to be completed by 4 August 2002 and has the project value approximately 1,200 MBaht (Contract only).

At the beginning of the first sampling, mechanical and electrical work was 40% complete, architectural work 40% complete and structural work 100% complete, meanwhile the whole project is still right on the schedule. Nevertheless, mechanical and electrical works and architectural works have been delayed for 5 and 3 months, respectively, against the master plan. In addition, the project employs 1 project manager, 13 engineers, 3 administrators, 31 foremen and 418 craftsmen, which consists of 5 main trades, 45 electricians, 34 plumbers, 37 air conditioning installers, 145 plasterers and 157 concrete workers. The 10 samples, therefore, are taken 1 each from the electricians, plumbers and air conditioning installers, 3 from the plasterers and 4 from the concrete workers.

The second sampling commenced on 15 January 2002, when the number of craftsman was 430 in total and consisted of 45 electricians, 34 plumbers, 36 air conditioning installers, 127 plasterers and 188 concrete workers; therefore the ratio of each trade was approximately stable. Therefore, the 10 samples from the first study were maintained. In general, the project progress had been delayed 2 weeks against the master plan, due to, probably, the effect of the New Year holiday, where mechanical and electrical works, and architectural works had both been 50% completed.

6.5.1 Detail of the Study

As with to site 1, only the work-sampling technique was implemented, which was undertaken between 21 December 2001 and 19 January 2002. Every study observed 400 samples, with 80 samples and 8 rounds of observations recorded each day, for 5 consecutive days. This is due to a long observation time, 45 minutes, required to complete an observation round. Table 6.7 illustrates all 80 observations times for this investigation.

Table 6.7 Observation times of work-sampling study for site 4

Study no.	Observation date	Round							
		1	2	3	4	5	6	7	8
1	21/12/01	8.18	9.17	10.16	11.05	13.31	14.35	15.37	16.35
	22/12/01	8.59	10.09	10.55	11.49	13.49	14.36	15.22	16.23
	24/12/01	8.27	9.27	10.47	11.55	13.43	14.26	15.21	16.36
	25/12/01	8.43	9.58	10.55	11.40	13.42	14.37	15.46	16.49
	26/12/01	8.09	9.21	10.23	11.28	13.47	14.33	15.28	16.18
2	15/01/02	8.30	9.23	10.49	11.52	13.58	14.42	15.48	16.35
	16/01/02	8.26	9.27	10.22	11.33	13.31	14.55	15.55	16.40
	17/01/02	8.41	9.35	10.21	11.13	13.26	14.39	15.24	16.43
	18/01/02	8.33	9.34	10.30	11.35	13.30	14.18	15.55	16.48
	19/01/02	8.01	9.41	10.26	11.13	13.07	14.04	15.12	15.57

The first work-sampling study took place from 21 to 26 December 2001 and, about two weeks after the first study, the second study was done (from 15 to 19 January 2002). Referring to the ratio of the numbers of craftsman of each trade to the total numbers of craftsman indicated above, 10 samples were randomly taken 1 each from plumbers, electricians and air conditioning installers, 3 from plasters and the last 4 from the concrete workers.

6.5.2 Results of the Study and Analysis

6.5.2.1 Results of the Study

6.5.2.1.1 The First Work-Sampling Study

The first application identified that the average effective work of the craftsmen of site 4 was only 47% and the other 53% was ineffective work, which consisted of 16% personal allowances, 13% late start/early finish, 2% waiting for materials, 1% each for waiting for equipment and waiting for other trades, and 21% waiting for other crews (see Figure 6.21 and Figure 6.22).

STUDY ANALYSIS SHEET

Project: S20 (Khumpangpetch) Reference: 14
No. of rounds observed: 40 Study period: 5 days
Total observation No. : 400 Start date: 21/12/01 Finish date: 26/12/01

Category	Total	Percentage (%)
100 Effective Work	188	47.00
200 Ineffective Work	212	53.00
210 Management Delays	99	24.75
211 Waiting for materials	8	2.00
212 Waiting for tools	0	0.00
213 Waiting for equipment	1	0.25
214 Waiting for instruction	3	0.75
215 Waiting for inspection	0	0.00
216 Waiting for other trades	4	1.00
217 Waiting for other crews	83	20.75
220 Personal Allowances	63	15.75
221 Taking a break	49	12.25
222 Personal needs	14	3.50
230 Miscellaneous Delays	50	12.50
240 No Contact	0	0.00
Total	400	100.00

Figure 6.21 Data analysis sheet of the first work-sampling study for site 4

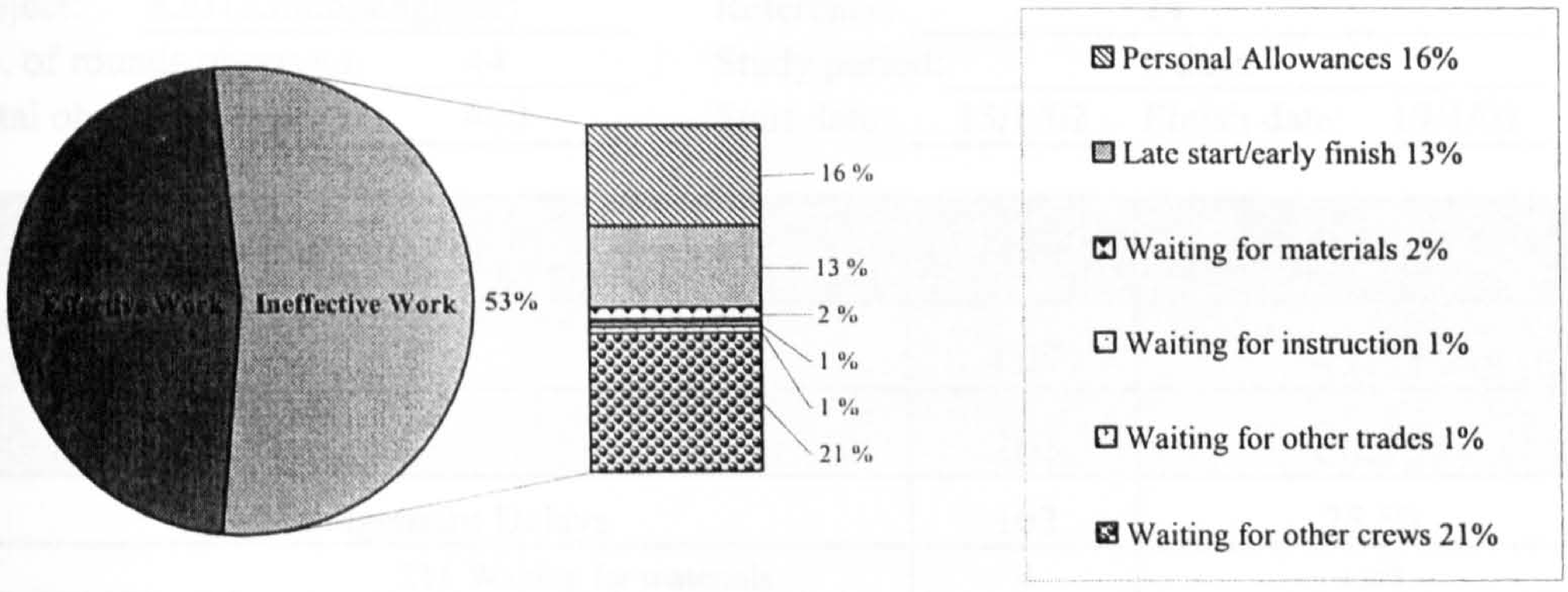


Figure 6.22 Graphical presentation of the first work-sampling study for site 4

8.4.2.1.2. The Second Work-Sampling Study

The second work-sampling study for site 4 highlighted an average for effective work of 49% and 51% for ineffective work that included 15% personal allowances, 10% late start/early finish, 1% each for waiting for materials and waiting for equipment, 2% waiting for instruction and 22% waiting for other crews (see Figure 6.23 and Figure 6.24).

STUDY ANALYSIS SHEET

Project: S20 (Khumpangphet)
Reference: 24
No. of rounds observed: 44
Study period: 5 days
Total observation No. : 400
Start date: 15/1/02 Finish date: 19/1/02

Category	Total	Percentage (%)
100 Effective Work	197	49.25
200 Ineffective Work	203	50.75
210 Management Delays	102	25.50
211 Waiting for materials	4	1.00
212 Waiting for tools	0	0.00
213 Waiting for equipment	3	0.75
214 Waiting for instruction	6	1.50
215 Waiting for inspection	0	0.00
216 Waiting for other trades	0	0.00
217 Waiting for other crews	89	22.25
220 Personal Allowances	61	15.25
221 Taking a break	46	11.50
222 Personal needs	15	3.75
230 Miscellaneous Delays	40	10.00
240 No Contact	0	0.00
Total	400	100.00

Figure 6.23 Data analysis sheet of the second work-sampling study for site 4

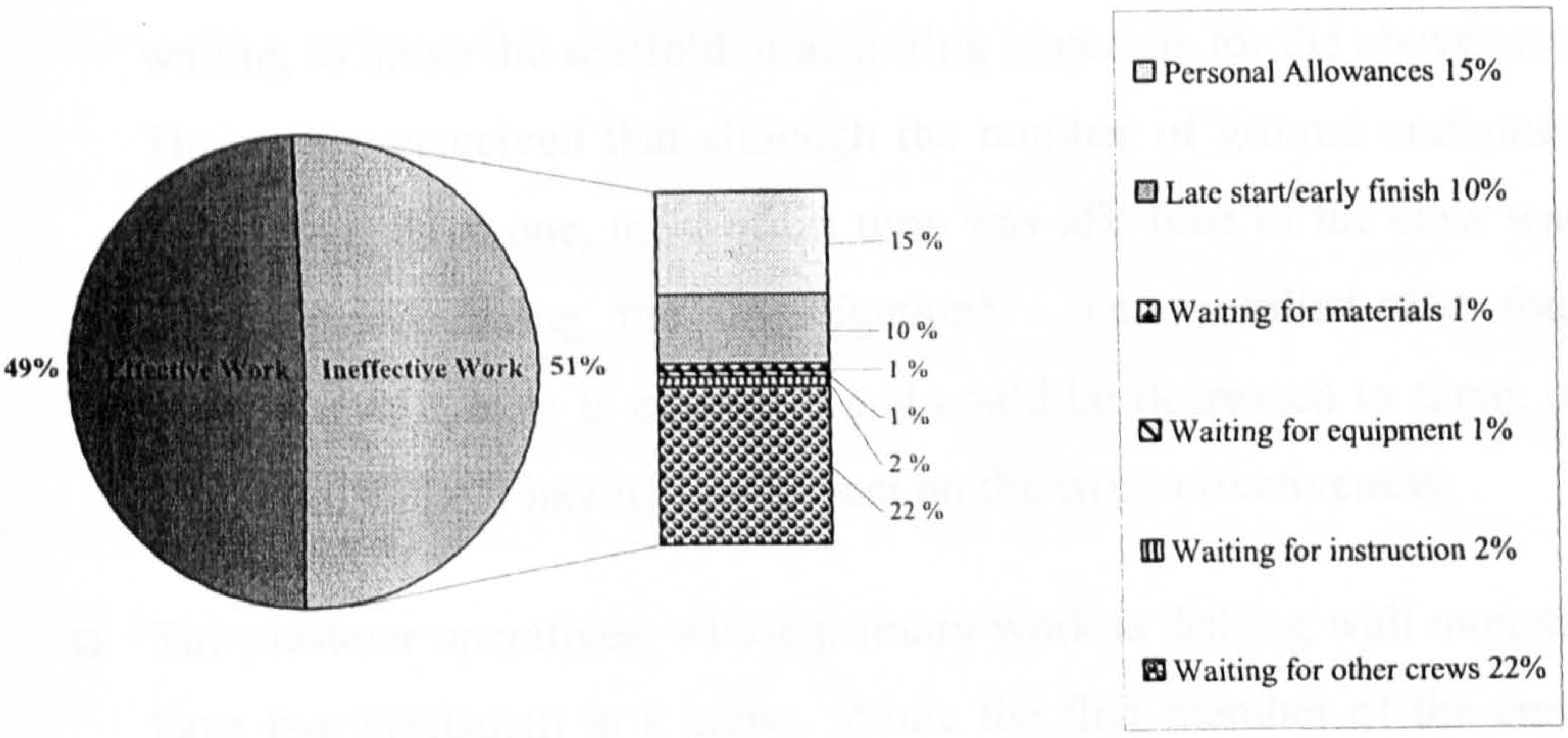


Figure 6.24 Graphical presentation of the second work-sampling study for site 4

6.5.2.2 Data Analysis

The following are productivity problems that the author found during the first study:

- Waiting for materials (ready mixed concrete) was a particular problem of concrete workers, which delayed the operatives who worked on the top floor of the station in area 1, for four hours in total (two hours for two days, both in the afternoon). Furthermore, the craftsmen who worked at the concourse level lost another two hours for the same problem.

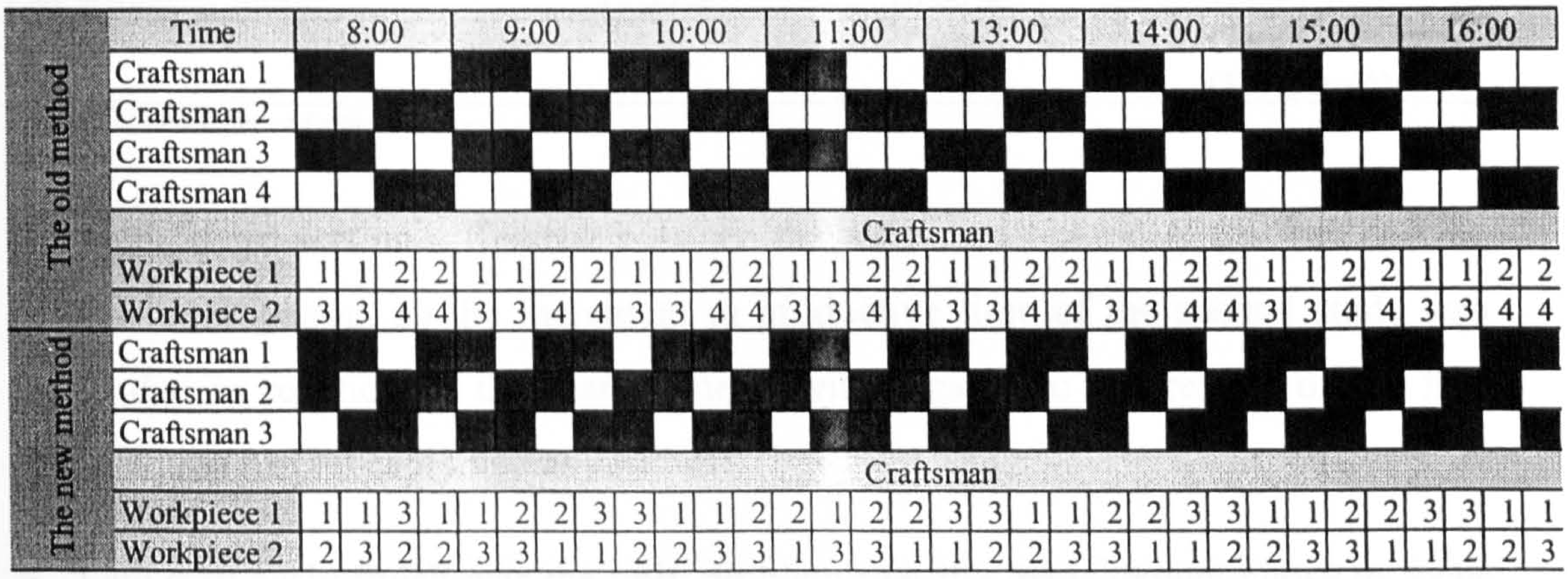
- The concrete workers in area 2 had a low effective time, due in part to non-strict supervision. As a result, the craftsmen here always take a break and wait for instruction. An air pump breakdown was also specified in area 2, but just for a short time, and so had very minor impact.

- There is no doubt that the most ineffective time was waiting for other crews, which accounted for 21% of total working time. All trades faced this problem, with the root of the problem being crew imbalance. According to this study, the trades that were experiencing the most obvious imbalance were the electricians, then the plasterers. Examples of the problem are provided below:

    - Usually, there were four craftsmen in an electrician crew, two of whom worked on the scaffold while the other two were on the ground waiting to move the scaffold or acquiring materials for the above two. The author perceived that although the number of ground craftsmen was decreased to one, most of his time was idle (one of the crew was absent twice during the investigation). This implied that four craftsmen in a crew is excessive and could be decreased to three, or even two, without having any impact on the work effectiveness.

    - The plasterer operatives, whose primary work is drilling wall mounts, have two craftsmen in a crew. While the first member of the crew was working, the second would have a rest and vice versa; this cycle would usually take 30 minutes and partly contribute to making the personal allowance as high as 16%. This problem could be alleviated by rearranging to have three craftsmen in a crew, when two jobs are nearby, instead of having two crews with two operatives each and let them work on each of the two particular jobs separately, as in the original method, and assign the new crew to work with the new method demonstrated in Table 6.8.

Table 6.8 Comparison of the old and the new working method of the plasterer



	Time	8:00				9:00				10:00				11:00				13:00				14:00				15:00				16:00			
The old method	Craftsman 1	■	■			■	■			■	■			■	■			■	■			■	■			■	■			■	■		
	Craftsman 2			■	■			■	■			■	■			■	■			■	■			■	■			■	■			■	■
	Craftsman 3	■	■			■	■			■	■			■	■			■	■			■	■			■	■			■	■		
	Craftsman 4			■	■			■	■			■	■			■	■			■	■			■	■			■	■			■	■
		Craftsman																															
	Workpiece 1	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
	Workpiece 2	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4
The new method	Craftsman 1	■	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■
	Craftsman 2	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■	
	Craftsman 3		■	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■		■	■		■
		Craftsman																															
	Workpiece 1	1	1	3	1	1	2	2	3	3	1	1	2	2	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3	1	1
	Workpiece 2	2	3	2	2	3	3	1	1	2	2	3	3	1	3	3	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3

Please note that ■ represents working period of 15 minutes

It is remarkably clear that, referring to Table 6.8, the new working method could increase productivity, since it offers the same level of work done with less craftsmen (3 instead of 4). In other words, labour productivity of this trade could be increased by 33%, as effective work would increase from 30 to 45 minutes per hour, if the new working method is installed.

- ➢ Another major problem of this site was late start/early finish, which wastes as much as one hour for each operative based on 8 working hours, on average. With this amount, this problem should be responded to immediately, as it far beyond an acceptable limit. In addition, at the first stage, if time lost due to late start/early finish is decreased to 40 mpcpd, it will offer the site an outstanding financial saving.

The second work-sampling study was carried out about two weeks after the results presentation and effective work indicated this time was 49% (see Figure 6.24), which was an increase of about 5%, according to the first study. Table 6.9 compares the results of both studies.

Table 6.9 Comparison of the first and the second work-sampling study for site 4

Category	The fist study	The second study	Different
Effective work	47.00%	49.25%	Gain 2.25%
Waiting for materials	2.00%	1.00%	Gain 1.00%
Waiting for tools and instruction	1.00%	2.25%	Loss 1.25%
Waiting for other trades	1.00%	0.00%	Gain 1.00%
Waiting for other crews	20.75%	22.25%	Loss 1.50%
Personal allowances	15.75%	15.25%	Gain 0.50%
Late start/early finish	12.50%	10.00%	Gain 2.50%
		Total	**Gain 2.25%** **(11mpcpd*)**

* mpcpd = minute per craftsman per day

Basically, there was no difference between the working situation of the first and the second investigation, so the increment in productive time of the second study was solely due to reaction of the management, with regards to the results of the first study, which can be explained as follows:

- Late start/early finish was the only problem that the management chose to focus on and manage to alleviate. Applying stricter supervision and having each craftsmen sign his name 15 minutes before 17.00 hours at the concourse level, then allowing the craftsmen to come up to the ground was how management responded to the problem. As a result, time lost due to late start/early finish was reduced to 48 mpcpd (previously it was 60 mpcpd), representing a 20% decrease, which was a good start. Nevertheless, 48 mpcpd is still over the acceptable limit which should be between 10-15 mpcpd, so further action is required for this site.

Although the effect of late start/early finish was reduced now, there were some other problems such as crew imbalance, which all trades were experiencing, that the management could solve, so that on-site productivity would improve. The author strongly believed that if the late start/early finish and crew imbalance problems were further investigated in order to alleviate their seriousness, the overall productive time of this site could be increased to at least 55%, or improve by 10% from the present.

6.5.3 Feedback from the Project Manager

The project manager was pleased with the results of the study, especially the percentages specified in each category, since he perceived these values, however, without any measurement tools, it is impossible to know exactly how much these percentages are. In addition, the manager strongly believed that the results of the study led him to solve the problems correctly. Work-sampling, not only works as a productivity measurement tool, but also works as a monitor, which helps him to set productivity goals for each particular month, the project manager further explained.

Although work-sampling does not indicate how to overcome productivity problems, it just highlights the problems, the observer, an engineer, could clarify what is occurring on the site, according to what he has seen during data collection, which, as a result, allows work-sampling to be used as a productivity improvement tool. However, one obvious disadvantage of having a foreman doing the observations is that yet the sources of productivity problems may be inaccurate. For example, concrete has not been put into the formwork, because the consultant has not yet approved the drawing, however, the foreman may understand that the concrete has not been delivered. The foreman, therefore, identifies that the cause of delay is due to waiting for material (concrete undelivered), rather than waiting for instruction (drawing approval).

6.6 Summary

This chapter has demonstrated the application of work-sampling and foreman delay surveys (FDS) on four Thai construction sites; both techniques were applied on two sites and the other two implemented only work-sampling and the results are summarised in Table 6.10.

There is no question, according to Table 6.10, that crew imbalance (waiting for other trades and crew) and late start/early finish are likely to be universal construction productivity problems in Thailand, and lack of material is not a significant problem in these work-sampling studies. In addition, it is reasonable to confirm that, in general, the productivity problems are management's responsibility, not labour's, since the problems specified are far beyond the craftsmen's control, but are within the management's control.

Table 6.10 Results of work-sampling studies and FDS

Category	Site 1 (%)		Site 2 (%)		Site 3 (%)		Site 4 (%)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Effective work	46.22	51.78	56.82	59.75	67.56	67.11	47.00	49.25
Waiting for materials	2.67	0.22	0.00	0.25	0.00	0.00	2.00	1.00
Waiting for tools	0.00	0.22	0.00	0.00	3.11	3.11	0.00	0.00
Waiting for equipment	2.44	3.11	2.05	0.25	4.00	0.00	0.25	0.75
Waiting for instruction	11.11	2.00	0.00	0.00	0.00	2.00	0.75	1.50
Waiting for inspection	0.00	0.44	0.00	0.00	0.00	0.67	0.00	0.00
Waiting for other trades	10.89	17.78	1.59	6.50	4.67	8.89	1.00	0.00
Waiting for other crews	13.78	10.89	27.05	22.50	7.11	4.67	20.75	22.25
Personal allowances	7.11	7.11	10.45	8.75	9.56	9.33	15.75	15.25
Late start/early finish	5.78	6.44	1.59	2.00	4.00	4.22	12.50	10.00
Total effective time increase	5.56		2.93		0.23 (decrease)		2.25	
			Site 2 (%)		Site 3 (%)			
			1st	2nd	1st	2nd		
FDS results (%)			3.08	3.04	5.48	4.32		
Total delay decrease (%)			0.04		1.16			

Although each work-sampling application highlighted productivity problems that required correct reactions to alleviate or overcome the problems, there has been only one site, site 1, that could conclude with a 95% confidence level that the productive time of the site had been increased. FDS seems to offer a fairly acceptable accuracy, as its results complied with those obtained from the work-sampling studies. Although both sites 2 and 3 are well managed, site 3 has a higher effective time than site 2, due to the fact that working in a fabrication shop (site 3) is easier than working on a construction site (site 2). The next chapter will clarify the validity and reliability of these studies.

CHAPTER 7

PREDICTION OF WORK-SAMPLING RESULTS

7.1 Introduction

This chapter explains the prediction of work-sampling study results, by the use of the Markov process. Definition and discussion of the necessary elements in the Markov process, initial conditions and transition probabilities, determination of the probability of finding a system in any particular state at any specified time and determination of steady-state probabilities will be clarified here.

The explanation of the Markov process mentioned in this chapter, nevertheless, illustrates only what is concerned with the application of the method to this research. Full details of the Markov process can be further consulted in many textbooks under the general heading of "Management Science" (Anderson, 2000; Anderson *et al.*, 1991; Davis *et al.*, 1986; Dennis and Dennis, 1991; Lee *et al.*, 1990; Stevenson, 1992).

Similar to the validity and reliability tests, only data of site 1 will be used as an illustration. Furthermore, the predictions of the remaining three sites are included in Appendix F.

7.2 An Introduction to Markov Analysis

Markov analysis (also called "*Markov process*") was originally developed, in the early 19th century, by the Russian mathematician Andrei Markov, to describe and predict the behaviour of particles of gas in closed containers. The process is useful in studying the evolution of certain systems over repeated trials. The repeated trials are often successive time periods where the state or outcome of the system in any particular time period cannot be determined with certainty. Rather, transition probabilities are used to describe the manner in which the system makes transitions from one period to the next. Hence, Markov analysis is about the probability of the system being in a particular state at a given time period (Anderson *et al.*, 1991). Table 7.1 provides some illustrations of systems that may lend themselves to Markov analysis.

Table 7.1 Examples of systems that may be described as Markov process

Source: Stevenson (1992, p. 805)

System	Possible System States	Transition Probabilities
Brand switching	Proportion of customers who buy Brand A, Brand B, Brand C, etc.	Probability that a customer will switch from Brand A to Brand B, etc.
TV market share	Proportion of viewers who watch BBC1, ITV, etc.	Probability that a viewer who watched BBC1 news will switch to ITV news, etc.
Rental returns	Proportion who return rentals to various locations.	Probability that a renter will return item to a different location than the one it was rented from.
Machine breakdowns	Proportion of machines running, proportion not running.	Probability that a machine's condition running/not running will change in the next period.

7.2.1 Markov Properties

The application of the Markov process to this research, similar to what has been written in the references above, is restricted to processes that meet the following assumptions:

Property 1. The system being studied has a finite number of discrete states (conditions).

Property 2. The transition probabilities (the probabilities of moving from one state to another) are constant over time.

Property 3. The probability of being in one particular state after a specified period of time is dependent only on the current state and the transition probabilities, and not on any earlier conditions.

It must be noted that whilst the Markov process is appropriate for steady state situations, it does not naturally fit the characteristics of construction. Consequently, the results of Markov process need to be read with caution.

7.2.2 Developing the Transition Probabilities

Dennis and Dennis (1991) specified that developing the transition probabilities requires careful research and record keeping, as well as detailed analysis of the data describing the movement of the system from state to state over time. Lee *et al.* (1990) further explained that understanding the fundamental basis of the transition probability matrix is essential to understanding Markov processes. Therefore, before demonstrating how transition probabilities for this study are developed, a general example will be shown before hand in order to make it easier for the reader to understand.

Suppose that one is interested in analysing the market share and customer loyalty for Tesco, M & S and ASDA, the only three supermarkets in a small town. There are only 12,000 customers in this town, who make one shopping trip each week to one of the three supermarkets. Now let's assume that an extensive market research study has been conducted on shopping behaviour of customers in the town. The study has yielded the number of customers who had shopped at one of the three supermarkets on two different weeks. The status of supermarket customers at the two points in time is given in Table 7.2.

Table 7.2 Net changes in number of customer of the three supermarkets

Supermarket	Number of customers		Net gains/losses
	Time 1	Time 2	
Tesco	5000	4600	-400
M & S	3000	4100	+1100
ASDA	4000	3300	-700

It is obvious that there was a significant shift in customer preference for supermarkets from one point in time to the next. Tesco had a net decrease of 400 customers, while M & S gained 1100 customers and ASDA lost 700 customers. Nevertheless, this analysis is superficial. A thorough analysis requires consideration of the underlying features of the customer movement process.

The market research study also yielded the actual gains and losses of customers for each supermarket. The movement of customers from one supermarket to another is shown in Table 7.3.

Table 7.3 Customers retained, gained and lost at time 2

		To supermarket		
	From supermarket	Tesco (T)	M & S (M)	ASDA (A)
5000	Tesco (T)	3500	500	1000
3000	M & S (M)	300	2400	300
4000	ASDA (A)	800	1200	2000
		4600	4100	3300

According to Table 7.3, there is no doubt that the net lost of 400 customers to Tesco (shown in Table 7.2) was, in fact, the result of a pattern of gains and losses. Tesco retained 3500 customers, gained 300 customers from M & S, gained 800 customers from ASDA, lost 500 customers to M & S and lost 1000 customers to ASDA. Notice that Table 7.3 shows the retention of customers as the intersection of row T and column T, while losses to other supermarkets are shown in the remaining cells in row T, and the gains from other supermarkets are shown in the remaining cells in column T. The table shows this same information for stations M and A.

Assuming that the observed movement of customers among supermarket is *stable* (the same relative movement will continue), the transition probabilities can be developed from these figures. The probability that Tesco will retain current customers is 3500/5000 = 0.7, lose customers to M & S is 500/5000 = 0.1, and lose customers to ASDA is 1000/5000 = 0.2. Interpreting the figures another way, M & S loses 300/3000 = 10% of its customers to Tesco; retains 2400/3000 = 80%; and loses 300/3000 = 10% to ASDA. The same approach can be used for ASDA. The resulting probability transition matrix is given in Table 7.4.

Table 7.4 Transition matrix for the three supermarkets

	To supermarket		
From supermarket	Tesco (T)	M & S (M)	ASDA (A)
Tesco (T)	0.7	0.2	0.1
M & S (M)	0.1	0.8	0.1
ASDA (A)	0.2	0.3	0.5

7.3 The Application of The Markov Process to a Work-Sampling Study

Since, a basic understanding of transition matrix development has been clarified, the following will explain the construction of the matrix for this study. The purpose of the application of the Markov process to the research is mainly to predict the percentage of effective time increase due to the implementation of work-sampling.

Table 7.5 illustrates net changes in the number observed and the movement of craftsmen from one category to another of the three categories. Please note that the data used for this demonstration are taken from site 1 and the categories considered are reclassified, which are effective time (code 100), total management delays (code 210 + code 230) and personal allowances (code 220), in order to make it suitable for application of the Markov process. Furthermore, no contact (code 240) is excluded, as this category includes an extremely small number of observations, as close as 0. For convenience, the categories will now be referred as ET (effective time), MD (total management delays) and PA (personal allowances).

Table 7.5 Net changes in number observed and movement of craftsmen's activity from one category to another of the three categories

Sample	The first study			The second study			Net gains/losses		
no.	ET	MD	PA	ET	MD	PA	ET	MD	PA
1	33	6	6	35	5	5	2	-1	-1
2	23	22	0	32	12	1	9	-10	1
3	35	9	1	35	7	3	0	-2	2
4	17	26	2	25	18	2	8	-8	0
5	21	19	5	27	12	6	6	-7	1
6	13	30	2	2	43	0	-11	13	-2
7	16	23	6	18	25	2	2	2	-4
8	11	30	4	19	24	2	8	-6	-2
9	17	25	3	21	18	6	4	-7	3
10	22	20	3	19	21	5	-3	1	2
Subtotal	208	210	32	233	185	32	25	-25	0
Total		450			450			0	

There is no doubt that there was a dramatic increase in ET, as it was recorded 25 times more than for the first study, while MD appeared 25 times less and PA remained constant at 32 times. Next, the calculation of numbers retained, gained and lost of the three categories will be shown.

Let's start with MD and the number it retained, shown in the MD column of the first and the second study, where, for the first sample, the numbers specified are 6 and 5, respectively. This means that, for sample no. 1, MD could retain 5. Now move to sample no. 2, in the same column, where the numbers are 22 and 12, respectively. Similarly, for this sample, MD retained 12, so, up to now, the numbers that MD retained is 5 + 12 = 17. Then, move to sample no. 3, where the numbers shown in the column are 9 and 7, respectively. Likewise, the number MD has retained to date is 5 + 12 + 7 = 24. Carrying on this approach until all 10 samples have been included, finally, the total numbers MD retained are 5 + 12 + 7 + 18 + 12 + 30 + 23 + 24 + 18 + 20 = 169.

Explained in an easier way, when comparing each individual pair of these numbers, select the least number and add them up together to get the total number. As a result, the same numbers will be obtained 5 + 12 + 7 + 18 + 12 + 30 + 23 + 24 + 18 + 20 = 169. Therefore, the numbers EF retained are 33 + 23 + 35 + 17 + 21 + 2 + 16 + 11 + 17 + 19 = 194 and those of PA is 5 + 0 + 1 + 2 + 5 + 0 + 2 + 2 + 3 + 3 = 23.

Table 7.6 Calculation of the movement of craftsmen's activity from one category to another

Order	Sample no.	Total number
ET gained from MD (MD lost to ET)	1, 2, 4, 5, 8 and 9	1 + 9 + 8 + 6 + 6 + 4 = 34
ET gained from PA (PA lost to ET)	1, 7 and 8	1 + 2 + 2 = 5
MD gained from ET (ET lost to MD)	6 and 10	11 + 1 = 12
MD gained from PA (PA lost to MD)	3 and 7	2 + 2 = 4
PA gained from ET (ET lost to PA)	7	2
PA gained from MD (MD lost to PA)	2, 3, 5 and 9	1 + 2 + 1 + 3 = 7

The next step is to demonstrate the numbers that these categories gained and lost to each other. Let's use MD lost to PA as an example. Now focusing on the net gains/losses column for samples 2, 3, 5 and 9, it is clear that in these samples MD lost numbers to PA of 1, 2, 1 and 3, respectively. As a result, the total number that MD lost to PA is 1 + 2 + 1 + 3 = 7. Another example could be the number that ET gained from PA. According to samples 1, 7 and 8, it can be noted that the ET of the three samples gained 1, 2 and 2 from PA, respectively. Consequently, the total number that ET gained from PA is 1 + 2 + 2 = 5. The same approach can be applied to the remaining samples and the calculations are summarised in Table 7.6.

It is now understandable why categories cannot be broken down further, say into four categories. This is because it will make detection of movement from one category to another three categories impossible. For example, assuming that categories are divided to four groups, which are ET (code 100), MD (code 210), PA (code 220) and late start/early finish (code 230), and ET and MD both gained 1, while late start and PA lost 1 each. There is no way to specify that 1 gained by EF came from PA or late start, or 1 lost from late start contributed to ET or MD. Referring to the above, the movement of craftsmen's activity from one category to another can be now shown in Table 7.7.

Table 7.7 Numbers retained, gained and lost at the second study

		To category		
	From category	ET	MD	PA
208	ET	194	12	2
210	MD	34	169	7
32	PA	5	4	23
		233	185	32

Likewise, assuming that the observed movement of craftsmen's activities is *stable*, the transition probabilities can be developed from these figures. The probability that ET will retain current numbers is 194/208 = 0.9327, lose numbers to MD is 12/208 = 0.0577, and lose numbers to PA is 2/208 = 0.0096. Interpreting the figures another way, MD loses 34/210 = 16.19% of its numbers to ET; retains 169/210 = 80.48%; and loses 7/210 = 3.33% to PA. The same approach can be used for PA. In addition, transition probabilities in each row of a transition matrix sum to 1. The resulting probability transition matrix is given in Table 7.8.

Table 7.8 Transition matrix for the three categories

	To category		
From category	ET	MD	PA
ET	0.9327	0.0577	0.0096
MD	0.1619	0.8048	0.0333
PA	0.1563	0.1250	0.7188

7.3.1 Initial Conditions

Initial conditions, which describe the system as it currently exists, are usually described by a one-dimensional matrix called a row vector. In the case of the research, the working time is divided 51.78% (233/450) to effective work, 41.11% (185/450) to management delays (including miscellaneous delays) and 7.11% (32/450) to personal allowances (see Figure 6.3). The initial conditions are thus described by the row vector.

$$[0.5178 \quad 0.4111 \quad 0.0711]$$

In addition, initial conditions can be used to describe the condition of a single craftsman's activity. For example, using the example, the vector [0 1 0] would indicate that a craftsman is presently categorised as management delays. Thus, a system can represent an entire working time or a single craftsman's activity.

7.4 Predicting Future States

The value of obtaining the transition probability matrix in a Markov process is that it makes prediction of future states possible. Both the long-term and short-term predictions of a system are completely determined by the system transition probabilities. Short-term prediction is merely dependent on the system's state in the present period and the transition probabilities. Consequently, the percentage of working time accounted for by each category in any given period is simply a function of the percentage of working time of each category in the preceding period and the transition probabilities. The percentage of working time of each category in the preceding period, thus, is normally a significant factor that affects the percentage of working time of each category in the next several periods.

The long-term prediction of the system, however, will be unaffected by the initial number of each category; the proportion of percentage of working time of each category over the long run will be the same, regardless of initial conditions. The long-run proportions are referred to as the *steady-state* proportions, or probabilities, of the system. Not every system has a tendency to stabilise, though. Some tend to cycle back and forth, and some tend to converge on a single value called an *absorbing state* (Stevenson, 1992). (Absorbing state is far beyond this research and will not be discussed here. However, information about absorbing state can be consulted in the references indicated at the beginning of this chapter)

Generally, there are two techniques that can be used to predict state probabilities two or more periods in the future – tree diagrams and matrix multiplication. Nevertheless, as the matrix approach is more suitable to the study, it will be the only technique described here.

7.4.1 Matrix Multiplication

The matrix approach employs matrix multiplication of the initial conditions and the transition matrix to predict future states of the system. The state of the system at time 0 is described by a one-dimensional matrix called a *vector.*

$$p(0) = [p_1(0), p_2(0), p_3(0),......p_n(0)]$$

where;
$p(0)$ = vector of initial conditions (all $p_1(0)$ values)
$p_1(0)$ = probability of being in state 1 at time 0
$p_2(0)$ = probability of being in state 2 at time 0
$p_3(0)$ = probability of being in state 3 at time 0
$p_n(0)$ = probability of being in state n at time 0

The transition probability matrix is given by

$$P = \begin{array}{c|ccccc|}
 & & & \text{To state} & & \\
\text{From state} & 1 & 2 & 3 & \dots & j \\
\hline
1 & p_{11} & p_{12} & p_{13} & \cdots & p_{1j} \\
2 & p_{21} & p_{22} & p_{23} & \cdots & p_{2j} \\
3 & & p_{32} & p_{33} & \cdots & p_{3j} \\
 & p_{31} & & & & \\
. & . & . & . & \cdots & . \\
i & p_{i1} & p_{i2} & p_{i3} & \cdots & p_{ij} \\
\hline
\end{array}$$

where;
P = matrix of transition probabilities
p_{ij} = probability of going from state i to state j (for example p_{12} is the probability of going from state 1 to 2)

7.4.1.1 Future State Prediction

This section will demonstrate the method for computing future state predictions using matrix multiplication, which begins by calculating state probabilities after one time period, that is, the probability of being in state j at time 1 when the system is currently in time 0. This is computed by multiplying the initial condition vector by the transition matrix.

$$p(1) = p(0)P$$

That is, the vector of state probabilities at time 1 is equal to the vector of state probabilities at time 0 times the transition matrix (i.e. time 0 is the second implementation of the study). In this case, the percentage of working time accounted by the three categories after the third implementation of work-sampling study can be calculated as below:

$$\begin{bmatrix} 0.5178 & 0.4111 & 0.0711 \end{bmatrix} \begin{bmatrix} 0.9327 & 0.0577 & 0.0096 \\ 0.1619 & 0.8048 & 0.0333 \\ 0.1563 & 0.1250 & 0.7188 \end{bmatrix} = \begin{bmatrix} 0.5606 & 0.3696 & 0.0698 \end{bmatrix}$$

7.4.1.2 Probabilities after Two or More Periods

In order to predict the system state at time 1, multiplying the initial condition vector at time 0 by the transition matrix must be carried out. Then, prediction for time 2 could be obtained by multiplying the state vector for time 1 by the transition matrix. Repeating this process again gives the prediction for time 3. Fortunately, there is a more efficient approach to predict the state at time *n* than the previously described successive multiplication.

Recall that the state of the system at time 1 equals the state of the system at time 0 times the transition matrix:

$$p(1) = p(0)P$$

Also recall that the state of the system at time 2 equals the state of the system at time 1 times the transition matrix:

$$p(2) = p(1)P$$

Introducing the value of p(1) into the equation for p(2) results in the following expression:

$$p(2) = p(1)P = p(0)PP = p(0)P^2$$

Similarly, as the state of the system at time 3 equals the state of the system at time 2 times the transition matrix,

$$p(3) = p(2)P = p(0)PPP = p(0)P^3$$

In general, the system state at any time in the future (in time t) is equal to the state vector at time 0 multiplied by the transition matrix raised to the power t (called a t-step transition matrix):

$$p(t) = p(0)P^t$$

Thus, we can predict the percentage of working time accounted for ET, MD and PA in time 2 as follows:

$$p(2) = p(0)P^2$$

$$P^2 = \begin{bmatrix} 0.9327 & 0.0577 & 0.0096 \\ 0.1619 & 0.8048 & 0.0333 \\ 0.1563 & 0.1250 & 0.7188 \end{bmatrix}^2 = \begin{bmatrix} 0.8806 & 0.1014 & 0.0178 \\ 0.2865 & 0.6611 & 0.0523 \\ 0.2783 & 0.1995 & 0.5223 \end{bmatrix}$$

$$p(2) = \begin{bmatrix} 0.5178 & 0.4111 & 0.0711 \end{bmatrix} \begin{bmatrix} 0.8806 & 0.1014 & 0.0178 \\ 0.2865 & 0.6611 & 0.0523 \\ 0.2783 & 0.1995 & 0.5223 \end{bmatrix} = \begin{bmatrix} 0.5936 & 0.3385 & 0.0679 \end{bmatrix}$$

7.5 Steady State

Basically, as *t* grows larger, the state values tend to stabilise at a steady state, where the operating characteristics are time independent. Steady state occurs when additional transitions do not affect the probability of finding the system in any particular state. That is, when steady state is achieved, multiplication of the state condition by the transition matrix does not change the state condition. This is expressed as:

$$p(t+1) = p(t)P$$

where t = any time after steady state is achieved

Steady state probabilities are average probabilities that the system will be in a certain state after a number of transitions. Within the system there will be continued movement from state to state, but the average probability of being in a given state will remain constant. Only if every element in the t-step transition matrix has no zero elements (every element of $P^t > 0$), will the process reach steady state. There are two basic approaches to determine steady state, namely; matrix approach and algebraic computation.

7.5.1 Matrix Approach

It is possible to determine steady state by multiplying the transition matrix by itself a number of times. When the elements in the matrix no longer change (when the t+1 step transition matrix equals the t-step transition matrix), steady state has been reached. According to Table 10.9, the working time system reaches equilibrium in time 30. Actually, in the case of site 1, $p(t+1) = p(t)P$ (carried to three decimal places) after twenty nine periods, but the transition matrix probabilities do not reach equilibrium until period 30, although the changes between periods 16 and 30 are remarkably small (0.03 or less).

Table 7.9 Reaching steady state

Period (t)	Transition Matrix (P^t)	System state p(t)
0		$\begin{bmatrix} 0.518 & 0.411 & 0.071 \end{bmatrix}$
1	$\begin{bmatrix} 0.933 & 0.058 & 0.010 \\ 0.162 & 0.805 & 0.033 \\ 0.156 & 0.125 & 0.719 \end{bmatrix}$	$\begin{bmatrix} 0.561 & 0.370 & 0.070 \end{bmatrix}$
2	$\begin{bmatrix} 0.881 & 0.101 & 0.018 \\ 0.287 & 0.661 & 0.052 \\ 0.278 & 0.199 & 0.522 \end{bmatrix}$	$\begin{bmatrix} 0.594 & 0.339 & 0.068 \end{bmatrix}$
4	$\begin{bmatrix} 0.810 & 0.160 & 0.030 \\ 0.456 & 0.477 & 0.067 \\ 0.448 & 0.264 & 0.288 \end{bmatrix}$	$\begin{bmatrix} 0.639 & 0.298 & 0.064 \end{bmatrix}$
8	$\begin{bmatrix} 0.742 & 0.214 & 0.044 \\ 0.617 & 0.318 & 0.065 \\ 0.612 & 0.274 & 0.114 \end{bmatrix}$	$\begin{bmatrix} 0.682 & 0.261 & 0.058 \end{bmatrix}$
16	$\begin{bmatrix} 0.710 & 0.239 & 0.052 \\ 0.694 & 0.251 & 0.055 \\ 0.693 & 0.249 & 0.058 \end{bmatrix}$	$\begin{bmatrix} 0.702 & 0.244 & 0.053 \end{bmatrix}$
29	$\begin{bmatrix} 0.705 & 0.242 & 0.053 \\ 0.704 & 0.243 & 0.053 \\ 0.704 & 0.243 & 0.053 \end{bmatrix}$	$\begin{bmatrix} 0.705 & 0.242 & 0.053 \end{bmatrix}$
30	$\begin{bmatrix} 0.705 & 0.242 & 0.053 \\ 0.705 & 0.242 & 0.053 \\ 0.705 & 0.242 & 0.053 \end{bmatrix}$	$\begin{bmatrix} 0.705 & 0.242 & 0.053 \end{bmatrix}$
31	$\begin{bmatrix} 0.705 & 0.242 & 0.053 \\ 0.705 & 0.242 & 0.053 \\ 0.705 & 0.242 & 0.053 \end{bmatrix}$	$\begin{bmatrix} 0.705 & 0.242 & 0.053 \end{bmatrix}$

This example also shows that steady state is independent of the initial state vector. In other words, the steady state matrix demonstrates that the probability of the matrix being in a given state in the distant future is not dependent on where the process started. The steady state depends only on the transition probabilities. For example, the percentage of working time accounted for by ET, MD and PA began at time 0 with 51.78%, 41.11% and 7.11%, respectively. Multiplying these initials percentages by steady state conditions results in the steady state percentages.

$$\begin{bmatrix} 0.5178 & 0.4111 & 0.0711 \end{bmatrix} \begin{bmatrix} 0.705 & 0.242 & 0.053 \\ 0.705 & 0.242 & 0.053 \\ 0.705 & 0.242 & 0.053 \end{bmatrix} = \begin{bmatrix} 0.705 & 0.242 & 0.053 \end{bmatrix}$$

If the beginning working times accounted for were 48.50%, 40.00% and 11.50%, respectively, the working time shares would be:

$$\begin{bmatrix}0.485 & 0.400 & 0.115\end{bmatrix}\begin{bmatrix}0.705 & 0.242 & 0.053\\ 0.705 & 0.242 & 0.053\\ 0.705 & 0.242 & 0.053\end{bmatrix} = \begin{bmatrix}0.705 & 0.242 & 0.053\end{bmatrix}$$

Thus if the management of site 1 maintains its strong support to the work-sampling program, and the transition probabilities remain constant, in the long run, the next 30 months (based on one work-sampling application per month), the effective time of site 1 will increase to 70.5% (from 51.78% presently). However, in the short run, the next 8 months, a dramatic change of working situations should be noticed, as, at that time, the effective time of this site is expected to be around 68.2%, which is close to the 70.5% which will be achieved in its steady state.

7.5.2 Algebraic Computation

The matrix approach for determining the steady state transition matrix is rather complicated. Fortunately, steady state values can also be determined algebraically. To gain a better understanding of the algebraic determination of steady state values, it is helpful to review some of the earlier findings that are used in developing the algebraic solution.

First, the transition from one period to the next is embodied in the following equations:

$$p(t+1) = p(t)P$$

which has been generalised to

$$p(t) = p(0)P^t$$

That is, the state probabilities in period t are equal to the initial state probabilities multiplied by the t-step transition matrix.

At steady state, the state probabilities in a given time period t+1 are the same as in the previous time period, t, and multiplication of the system state by the transition matrix yields the same system state:

$$p(t+1) = p(t)P$$

If the steady-state values are represented by the symbol S, and the steady-state vector as $[S_1 \quad S_2 \quad S_3]$, then at steady state

$$S = p(t+1) = p(t)P \text{ or}$$

$$S = SP$$

That is, the steady-state values remain the same after a one-stop transition. For our case, this results in

$$S = [S_1 \quad S_2 \quad S_3] = [S_1 \quad S_2 \quad S_3]\begin{bmatrix} 0.933 & 0.058 & 0.010 \\ 0.162 & 0.805 & 0.333 \\ 0.156 & 0.125 & 0.719 \end{bmatrix}$$

Using matrix multiplication, a system of linear equations can be obtained:

$$S_1 = 0.933S_1 + 0.162S_2 + 0.156S_3 \quad ....(1)$$

$$S_2 = 0.058S_1 + 0.805S_2 + 0.333S_3 \quad ....(2)$$

$$S_1 = 0.156S_1 + 0.125S_2 + 0.719S_3 \quad ....(3)$$

Recall that the sum of the state probabilities must be 1:

$$1 = S_1 + S_2 + S_3 \quad ....(4)$$

Solving for S_1, S_2 and S_3 using equations (1) – (4) simultaneously yields:

$$S_1 = 0.705$$

$$S_2 = 0.242$$

$$S_3 = 0.053$$

which are the steady-state conditions. These are the same values we obtained earlier in Table 7.9 in the 30th time period.

7.6 Results Analysis

The prediction of the results of work-sampling study of all four sites are summarised in Table 7.10. Please note that the full details of the calculations can be seen in Appendix F.

Table 7.10 Prediction of the results of work-sampling study of this research

Period (t)	System state p(t) of			
	Site 1	Site 2	Site 3	Site 4
0	[0.518 0.411 0.071]	[0.598 0.315 0.088]	[0.671 0.236 0.093]	[0.493 0.355 0.153]
1	[0.561 0.370 0.070]	[0.614 0.308 0.078]	[0.667 0.241 0.092]	[0.510 0.341 0.148]
2	[0.594 0.339 0.068]	[0.627 0.302 0.071]	[0.664 0.244 0.091]	[0.524 0.330 0.145]
4	[0.639 0.298 0.064]	[0.647 0.292 0.061]	[0.659 0.250 0.091]	[0.544 0.315 0.140]
8	[0.682 0.261 0.058]	[0.669 0.280 0.051]	[0.654 0.255 0.091]	[0.564 0.300 0.135]
:	:	:	:	:
Steady state	[0.705 0.242 0.053] (t = 30)	[0.684 0.270 0.045] (t = 37)	[0.649 0.259 0.092] (t = 43)	[0.577 0.291 0.132] (t = 34)

In order to highlight the significant financial savings a work-sampling program can provide to a company, referring to the Markov analysis, the monetary term in GBP will be shown. Likewise data from site 1 will be selected as a demonstrator.

Since there are 181 craftsmen working on site 1, assume that on an average a craftsman earns £1100 monthly and final productive time will increase 24.3%, when compared with the productive time of the first study (originally 46.22%, according to the first study, and expected to be 70.5% at the steady state, referring to the Markov analysis). Consequently, potential financial saving is £48,381 (181 x £1100 x 24.3%).

There is also, however, an implementation cost for an engineer to act as an observer and study leader. In total, in order to undertake a work-sampling study, seven engineer man-days are required, according to the author's experience (assume one engineer man-day is worth £100). Therefore, the implementation cost is £700 per month (based on one application per month). Nevertheless, a period of 31 months is needed to reach the steady state, so the implementation cost will add up to £21,700

(£700 x 31). The total saving, therefore, is £26,681 (£48,381 - £21,700), during the whole period of 31 months. In other words, site 1 could expect to save around £10,700 per annum through the monthly application of work-sampling.

7.7 Validity of the Markov Process: The Project Managers' Perception

Structured interview via telephone, where the interviewees are asked the same predetermined questions, is employed for this purpose. The interview provides some obvious advantages to this research, which are, first, it allows questions to be explained, so it is less likely that the questions will be misunderstood (Kumar, 1996) and also facilitates *face validity* (Bryman, 2001; Denscombe, 2000; Seale, 1998; Kumar, 1996; Sarantakos, 1988; Struening, 1975). Face validity can be defined as the measure that apparently reflects the content of the concept in question (Bryman, 2001).

Secondly, it offers validity, as the direct contact at the point of the interview means that data can be checked for accuracy and relevance as they are collected (Denscombe, 2000). Fröbel (2001) and Ramirez (2001) have also provided examples of successful interviews to ascertain validity at PhD level.

In order to validate the prediction of Markov process, therefore, two project managers were asked to provide their general opinion about the results. Please note that the data of site 1 is primarily used in these interviews.

With regard to the increased percentage of effective time predicted by the Markov process, the interviewed project managers agreed that changes in the increase in the percentage of effective time should gradually decrease, as the number of applications increases, rather than constantly increasing at the same rate for all studies. For example, they believed if the first study shows an increase in effective time of 10%, then it is reasonable that the increase rate decreases to, say 9.5%, in the second study and keeps decreasing until reaching the steady state, rather than constantly increasing at 10% for each study. They further explained that this is due to some particular problems that should be overcome, or alleviated, in responding to results of the study, so the barriers that prevent craftsmen from working productively are less and less. Consequently, the room for improvement decreases and the increase in effective time improvement decreases.

The project managers did not totally agree with the final effective time predicted (steady state) which could be over 70% (see Table 7.9), based on the assumption that management always fully respond to the problems revealed by every work-sampling study. This is because one project manager foresaw no problem of achieving over 70%, if all manageable problems are overcome, while the others are under control.

The other project manager, however, debated that although most of the problems can be controlled or completely solved, it is still difficult to reach 70%, as, by nature, construction work is unpredictable, so unexpected problems could appear anytime. As a result, the productive time should be less, due to these problems, so the steady state should be around 65%-67%, but he also revealed that it is possible to achieve 70% or over. Nevertheless, these two project managers agreed that 100% effective time is unachievable and additionally identified that even 80% effective time is impossible, due to the nature of construction work.

In respect of economic gain/loss from the implementation, both, without any doubt, confirm that it is worthwhile to carry out work-sampling studies. One of these project managers provided a very interesting point of view. He classified the implementation of work-sampling into two groups, according to the periods of application, which are short-term implementation and long-term implementation. The project manager, moreover, referred to short-term implementation and long-term implementation as site and shop implementation, respectively.

He explained, as is clearly shown in Table 7.9, that an organisation would enjoy more benefits from a short-term application rather than a long-term application, since, when compared to the whole period of implementation, the early state provides the highest improvement compared to other states, especially the steady state. For a construction project lasting eight months, then the company would save more from two eight month projects compared to a sixteen month implementation over the same period in the fabrication shop.

In other words, a series of eight work-sampling studies would gain 14.8% in effective time (from 51.8% at the beginning to 66.6% at 8th application, see Table 7.9), so two eight month projects should offer a 29.6% increase. Meanwhile, a sixteen month application would offer 17.3%, according to Table 7.9. Consequently, short-term implementation offers more saving than long-term implementation.

This project manager, furthermore, believed that, if he carried out work-sampling studies until the steady state has been reached, then he will consider less frequent implementation than a monthly basis, probably, once every two or three months, depending upon that particular situation. He explained that although the effective time would drop slightly (it should be less than 0.2%, referring to Table 7.9), it is not worthwhile to sacrifice engineer man-days to undertake the study. For example, there are 86 craftsmen, who earns 164 Bath daily (approximately 3600 Bath per month, based on 22 working days per month), working in his fabrication shop, so 0.2% loss in effective time will cost 620 Bath[2] (0.2% x 86 x 3600). Nevertheless, 7 engineer man-days required to carry out a work-sampling study costs 5,600 Bath (one engineer man-day is worth 800 Bath). As a result, it is not worthwhile to pay 5,600 Bath to secure a maximum gain of 620 Bath.

The other project manager, however, responded to this question, with no hesitation, that it is worthwhile to implement the work-sampling technique, if the final effective time of 70.5% is achievable, as this would clearly offer a dramatic financial saving to his organisation, even though expenses due to engineer man-days are inevitable, but that is not a problem.

The participating project managers mentioned that the predictions of a work-sampling study allowed them to perceive the overall advantage they would obtain from implementing this technique and assisted them in deciding whether to undertake a work-sampling. This is because the work-sampling study identified their current performance and the Markov process highlighted what the percentage should

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[2] 1 GBP = 69.40 Bath (on 5 May 2003)

be at any particular period, including the steady stage. For example, referring to Table 7.9, the present effective time percentage is 51.8%, but it will be as high as 70.5% in the 30th application, which provides a distinct image of the benefits of implementation of work-sampling to their organisations.

Apart from that, the project managers raised the point that the percentage of effective time for any particular times predicted by the Markov process are also useful, as they work like milestones that are available for them to compare the actual result with the predicted one. Therefore, they would know how well they are doing. For example, if the actual percentage is too far below the prediction, an investigation might be carried on in order to find out causes of this low percentage. Furthermore, since the predicted results are in percentage (numerical form), it facilitates a clear goal setting for the following month.

The predictions, nevertheless, could have an effect on the master schedule because, when the schedule was first done, the work-sampling technique has not yet been introduced, so the production rates were based on constant rates. However, when a work-sampling study is carried out, the productive time will increase, so does the productivity (Handa and Abdalla, 1989). Consequently, jobs should be completed in a shorter period, so the master schedule may need to be rearranged.

For example, site preparation and formwork were previously assigned for 45 days. However the engineer may examine the results of the prediction of the Markov process, and find that these two jobs can be completed three days earlier. As a result, resources such as equipments, materials and plants must be updated in order to ensure the job will be carried on smoothly.

Since work-sampling can improve productive time, which allows tasks to be completed in less time, that, as a result, should decrease the time to complete the whole project. Therefore, the project manager believed that this could suggest, in some cases, how much incentive his company will receive, due to early completion of the contract, from the client. (Sometimes, in Thailand, a client would offer financial incentive to the contractor for early completion of the project. The sooner the contractor finishes, the more incentive he receives)

7.8 Summary

Steps of application of the Markov process to this research have been specified in chapter 7. The purpose of the application is to predict the effective time of a particular site at any particular times. Nevertheless, only one demonstration, employing data from site 1, has been shown. The predictions for all sites are indicated in Appendix F. The last section of this chapter describes potential financial savings from a work-sampling study. The next chapter will describe the conclusion of this research.

CHAPTER 8

DISCUSSION OF THE RESULTS

8.1 Introduction

Chapter 8 discusses the results of this research and identifies how the four Research questions can be answered. Since the work-sampling technique is the main idea of the study, these results will be discussed first. Then, the results of work-sampling will, one by one, be compared and contrasted with the other techniques, which include the results of the questionnaires survey, FDS and Markov process. However, to assist the reader, Table 8.1 illustrates techniques that are applied to a particular site.

Table 8.1 Techniques applied to a particular site

Technique applied	Site No.			
	1	2	3	4
Work-sampling	x	x	x	x
Foreman delay surveys		x	x	
Markov process	x	x	x	x

8.2 Discussion of Work-Sampling's Results

For every implementation of work-sampling technique in this research, at least 400 samples were observed in order to secure 95% accuracy and ±5% limit of error. In addition, categories are classified to reflect the objective of the study, which are to identify time utilisation by all craftsmen, and to identify the delays and, from this, to try to eliminate these delays in order to improve on site productivity. These categories are effective work, waiting for materials, waiting for tools, waiting for equipment, waiting for instruction, waiting for inspection, waiting for other trades, waiting for other crews, personal allowances, late start/early finish (miscellaneous delays) and no contact.

Consequently, the results identified an overview of the problems of that particular site such as waiting for material, waiting for instruction and late start/early finish, but this was sufficient to suggest where to improve productivity with the contribution of the causes of these problems noted, when taking observations. Generally, the percentage count in a category indicates the severity of the problem. In other words, the higher percentage counts in a category, the more serious the problem is. Therefore, priority should be given when action is to be taken. As categorisation can be tailored to suit the investigation of any particular trade or problem, the work-sampling technique is a very flexible tool that offers a number of advantages and should be implemented in the construction industry (the advantages and appropriateness of work-sampling have been discussed previously in Table 3.2 and 3.3.1, respectively).

In order to achieve the most effectiveness, the technique requires full support from management to respond to the productivity problems revealed from the study. Work-sampling itself can only specify the problems, but to overcome or rectify them is the management role. The more management support, there is the higher the productive time increase. Evidence for this is the case of sites 1 and 4, where both of the results of their first studies identified 47% productive time, with a list of productivity problems revealed.

However, the management of site 1 responded to all of the problems, except for the late start/early finish issue. On the other hand, the management of site 4 chose to focus only on the late start/early finish element. As a result, the productive time improvement rate of site 1 is as high as 11% ((51.78-46.22)/51.78x100 = 11%) and 5% for site 4 (see Figure 8.1). Please note that the productivity improvement rate for site 3, specified in Figure 8.1, is based on productive time increases sponsored by management actions. In responding to the result of the first study (i.e. air pump breakdown) and discarding the new productivity problems revealed in the second study (i.e. waiting for instruction and inspection) (see Figure 6.13 and Figure 6.17). Accordingly, it is reasonable to conclude that management has the greatest potential to influence productivity improvement, which is the solution for Research question no. 3.

This concept can be applied to any particular sites at any particular period of construction, no matter what the situation of that particular site. For example, in sites 1 and 4, which are typical cases of the industry, work-sampling can highlight a list of productivity problems, which, if rectified, would lead to increase in productivity. Furthermore, for sites 2 and 3, where works were carried out very smoothly, work-sampling certified how well the project was being managed. However, it can also suggest where the management could improve their productivity. Crew imbalance was one such example.

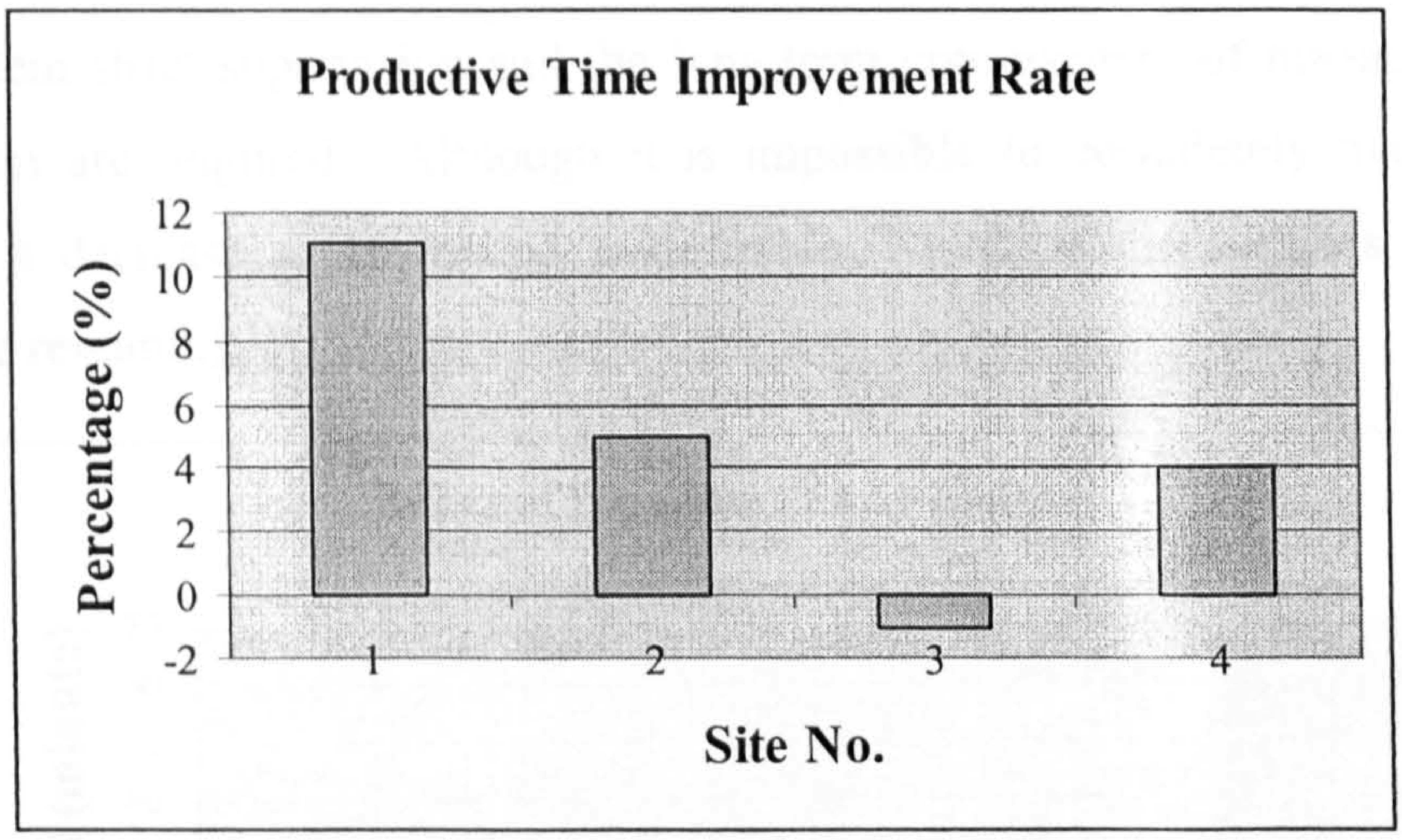

Figure 8.1 Productivity improvement rate for the four case studies

In general, the results of work-sampling indicated that sites 1 and 4 are normal cases for the construction industry, where the effective times are not high, only 47%, and there are a number of problems waiting to be attended to. Site 1, however, has a better chance to be successful in productivity improvement than site 4, as the management of this site take action in responding to the result of work-sampling more serious than the management of site 4. For site 2, work-sampling confirmed the effectiveness of its management and the smoothness of the project being progressed, since its productive time is quite high, about 60%, and the only crew imbalance is a hindrance problem.

The results of the study for site 3, not only certified that the management was doing fairly well, but also detected changes in working situation and problems, as the effective time revealed decreased from 67.56% to 67.33% (see Table 6.6). Although the effective time was decreased, the percentage of almost 70% confirms how well the management was doing and the decrease in effective time in the second study showed that there had been changed in the working situation.

The results of work-sampling studies, in addition, implied that the late start/early finish and crew imbalance could be universal construction productivity problems in Thailand. Nevertheless, further research needed to be undertaken to confirm this. The effect of late start/early finish varies from 10 minutes per craftsman per day (mpcpd) to as much as 60 mpcpd (before alleviation) (see Figure 8.2). To alleviate this problem strict supervision and the long-term commitment of management and supervision are required. Although it is impossible to completely overcome the problem, a decrease to 15 mpcpd is desirable (based on the author's experience during the research).

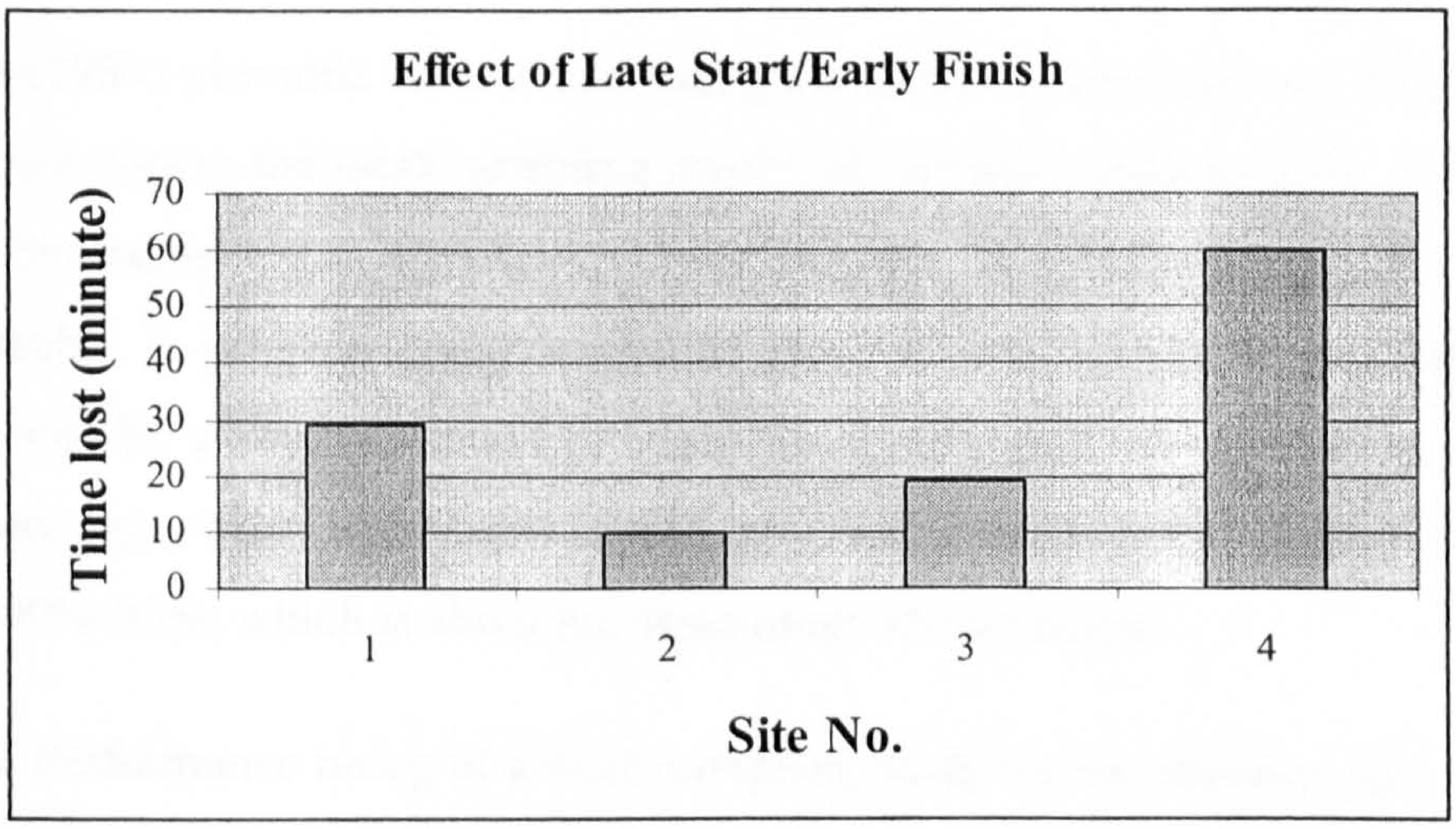

Figure 8.2 Effect of late start/early finish

The crew imbalance problems, as shown in Figure 8.3, usually cause a craftsman a minimum delay of 100 mpcpd. Although it is impossible to convert all these lost times to productive time, a number of effective is retrievable, depend upon the situation. In other words, productive time of a construction site could be increased by at least 3%, if the crew imbalance problem is alleviated. According to these results, it is clear that, in respective of working conditions, work-sampling can highlight productivity problems, which also indicates the potential for productivity improvement. As a result, it contributes to the answer for the Research question no.4.

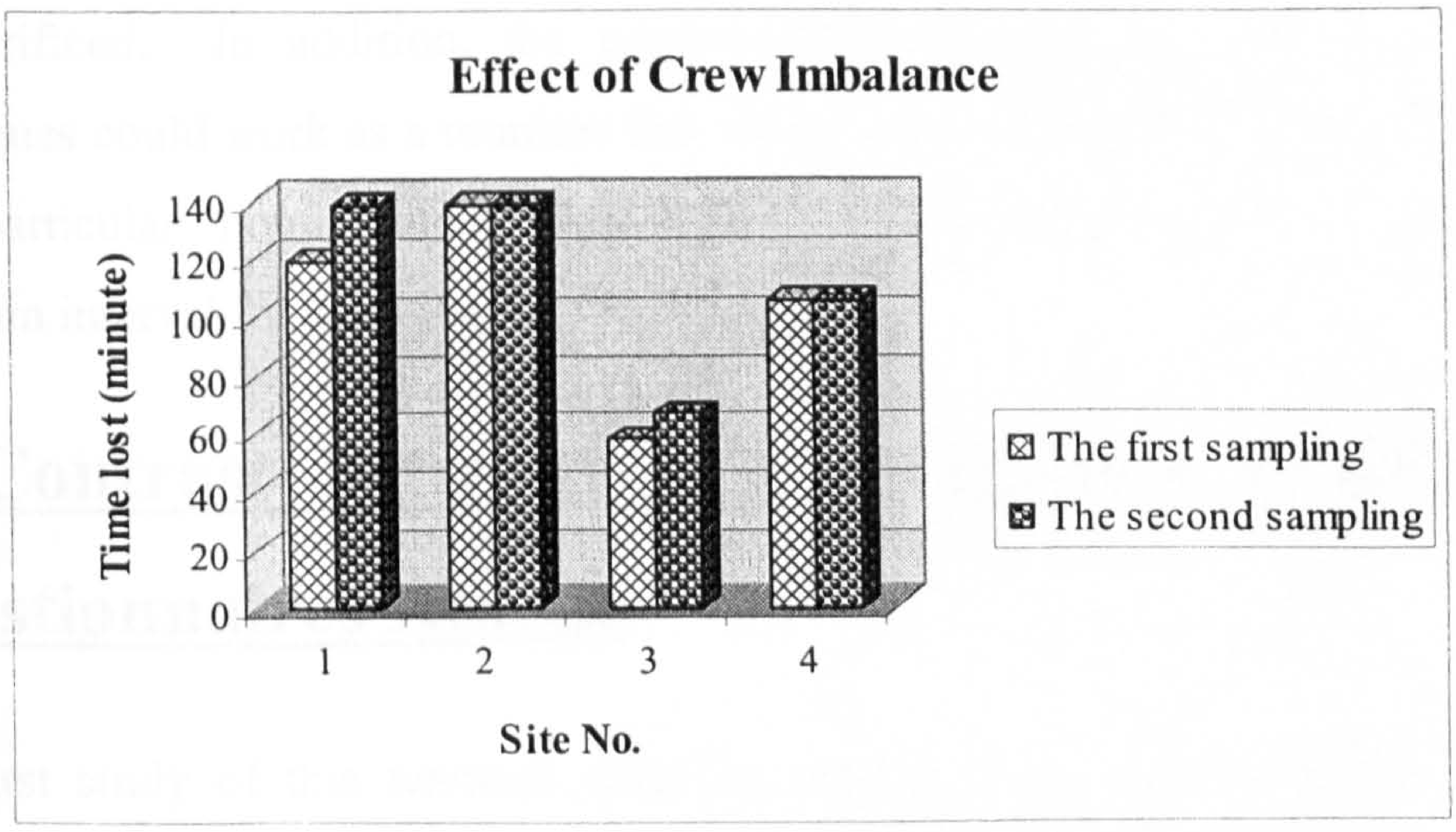

Figure 8.3 Effect of crew imbalance

Benjamin (1987) provided various interesting points of view to conclude that it is not possible to compare the work-sampling results of one plant with another. However, it should be reasonable to set a level of performance for a work-sampling study for this research. A possible interpretation of performance ratings for the productive time obtained by a work-sampling program for construction sites is shown in Table 8.2. In any case, Price and Harris (1985) specified that the effective time can vary between 40%-90%, which is about the same range shown below.

Table 8.2 Performance rating of a work-sampling study for construction sites

Percentage	Rank	Character
50% and below	Poor	A typical construction performance, unacceptable, with a large numbers of problems that are waiting for rectification.
51%-55%	Moderate	Fair performance with a number of problems that should be responded to.
56%-60%	Fairly good	Well managed with some particular problems to overcome.
61%-70%	Good	Very well managed with specific problems to cope with. Most construction sites will have their best performance in this range.
Over 70%	Excellent	Ideal case. All productivity problems are completely overcome or controlled within acceptable limit.

Every responding project manager is highly satisfied with the results of this technique. These impressions of work-sampling study arise from its accuracy and its ability to highlight productivity problems like crew imbalance. They further felt that this technique is a good tool for managing labour productivity that can be applied to both fabrication shops and construction sites, with regard to minimising delays and they believe that it is worthwhile to implement, although engineer man-hours must be sacrificed. In addition, the project mangers suggested that work-sampling techniques could work as a monitor that assists them in setting productivity goals for each particular month, which implies they believed that a monthly basis is the optimum interval for carrying out the technique.

8.3 Contrast between Work-Sampling Results and Questionnaires Results

The first study of this research employed questionnaires, with project managers, foreman and craftsmen as target groups, having the objective to identify the factors affecting construction productivity in Thailand. The results indicated, with 99% confidence that there is a consensus on the factors between the three respondent groups, the top five most influential factors affecting the construction productivity are lack of materials, incomplete drawing, lack of tools and equipment, poor site conditions and incompetent supervisors. Consequently, the Research questions no. 1 and 2 have been clarified.

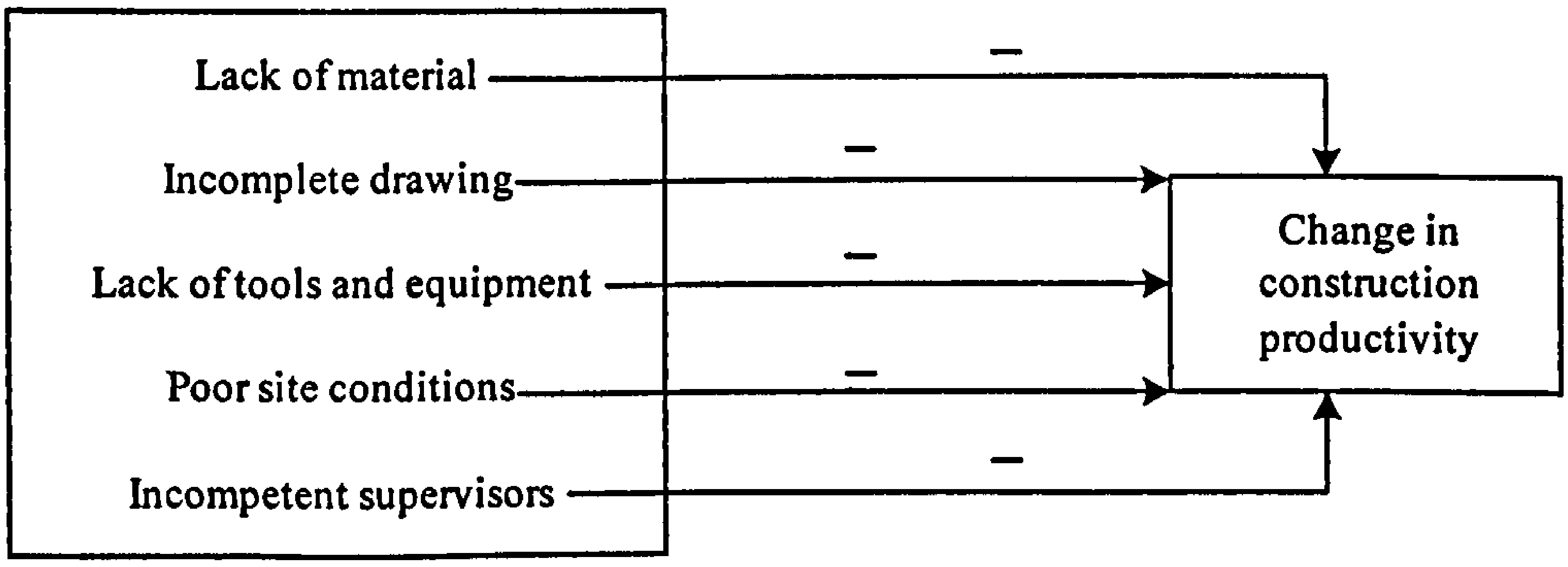

Figure 8.4 Descriptive model illustrating the relationship between the top five factors and the construction productivity improvement

The descriptive model shown in Figure 8.4 is the expansion of the research model depicted in Figure 4.2. The results of the questionnaire surveys revealed that all these five factors prevent projects being progressed smoothly. Consequently, there is no doubt that Figure 8.4 indicates those factors, which are negative related to construction productivity.

The lack of material, which had the highest effect on construction productivity in the pilot study, does not seem to be a very significant productivity problem as revealed by the work-sampling studies carried out on the four cases in the second phase of this study, as this problem accounted for a small percentage of working time (no more than 3%) (see Table 6.10). This is because the major cause of a lack of materials is a shortage of funds. However, it has been over five years since the economic crisis began in Thailand, so the construction companies that still survive to date must have had sufficient financial strength. As a result, these four sites can afford the necessary materials for their jobs, so material shortage is not a big problem.

8.4 Contribution of FDS Results to Work-Sampling Results

This research has found that the accuracy of FDS is fairly high, as high as that of work-sampling, at least in the case of long delays, since the two long delays reported by FDS from the two sites are close to the results of the particular two work-sampling studies. The first case is the first study of site 2, where weather (rain) was reported by work-sampling and FDS as accounting for 2.22% and 2.32%, respectively. The other case occurred in the first study of site 3 when work-sampling specified 4% and FDS indicated 3.29% for the air pump breakdown. Having FDS results close to those arising from work-sampling implies having FDS accuracy as high as that arising from work-sampling.

Generally, one would expect the results of work-sampling and FDS to comply with each other, which means, if the results of the work-sampling study identify an increase in effective time, then FDS should report a decrease in percentage delay, and vice versa. For example, site 2, where the effective time increases from 57% to 60% in the first and second study, respectively, delays specified by FDS decrease from 3.08% to 3.04% (see Table 6.4).

Unfortunately, the results of site 3 are contradict to this idea, as the effective time revealed by the work-sampling study decreased from 68% in the first study to 67% in the second study, but FDS also showed a decrease, instead of an increase, in delays from 5.48% to 4.32% (see Table 6.6). An explanation of this event can be drawn from a principle of FDS that all delays will be recorded only when they last at least 15 minutes and 'waiting for other trades,' due to change in patterns of work that makes the fitters and welders relied on each other more. This was the major cause that decreased effective time in the second work-sampling study.

Although 'waiting for other trades' accounts for 9%, in the second implementation of work-sampling (see Figure 6.18), this percentage accumulated from many short incidents of waiting for other trades for less than 15 minutes, so the FDS would not record them, but work-sampling did. The results of the study of site 3 obviously support this, since the percentage of 'waiting for other trades' reported by work-sampling studies increased from 4.67% to 8.89%, which is a dramatically increase of approximately 90% (see Figure 6.13 and Figure 6.17). Meanwhile, waiting for other crews revealed by FDS increased by only about 11% (from 380 man-minutes to 420 man-minutes) (see Figure 6.15 and Figure 6.19). Therefore, due to the nature of FDS, it cannot detect most of the waiting for other trades, which, unfortunately, in this case, was the major cause of a decrease in productive time that work-sampling could detect. As a result, FDS indicated a decrease in delay, while work-sampling highlighted an increase in delay, which is contrary. However, sites 2 and 3 are good examples from which to conclude that it is not necessarily the case that the results of work-sampling and FDS must always reverse each other, it depends upon the situation.

With regard to the feedback from the participating foremen, all of the foremen agreed that the implementation of FDS created a positive feeling, since they feel that the management was interested in assisting them solve their problems. The foremen also said that FDS is a useful tool that makes their work easier, encourages them to plan in advance and motivates them to co-operate with other foremen in order to decrease delays. Furthermore, FDS provides evidence that a foreman and his subordinates do not try to avoid working, for example, they are idle because they are waiting for inspection.

However, no conclusion can be drawn with regard to whether a work-sampling study or FDS is the better technique. This is because one project manager specified that FDS provided him with a better perception of problems than work-sampling, while another project manager doubted the accuracy of FDS, due to unfaithful reporting by the foreman, and he believed that work-sampling gave him a better view of productivity problems. Both parties, nevertheless, agreed that both techniques complement each other and they preferred to implement these techniques together.

The obvious advantage of work-sampling over FDS, according to this research, is that it could identify those crew imbalance problems that FDS could not, probably due to its basic principle that any delays would be reported only if they lasted at least 15 minutes. On the other hand, the outstanding advantage of FDS over work-sampling is that the survey directly points out what and where are the sources of the problems lie, whereas work-sampling study requires some time to sort this out. It is, consequently, reasonable to conclude that work-sampling and FDS contribute to each other, since the advantage of these techniques over each other can compensate for the weakness of the others, so when they are implemented together, one would have a better perception of the problems than when either tool is implemented individually.

8.5 Contribution of Markov Analysis to Work-Sampling Results

The objective of the application of the Markov process to the work-sampling study in this research is to predict the results of a work-sampling study, especially the percentage of effective time, at any particular period (as the results is depicted in Figure 8.5). The predictions, fortunately, not only comply with the results of work-sampling, but also contribute to a basic requirement of the work-sampling technique, which is that the success of a work-sampling study depends upon the seriousness of the action taken in responding to the results of the study. In addition, these predictions confirm that it is worthwhile to undertake work-sampling, in terms of financial savings, and could also assist with setting a productivity goals for each month. Consequently, these are a contribution to the solutions for Research question no. 3.

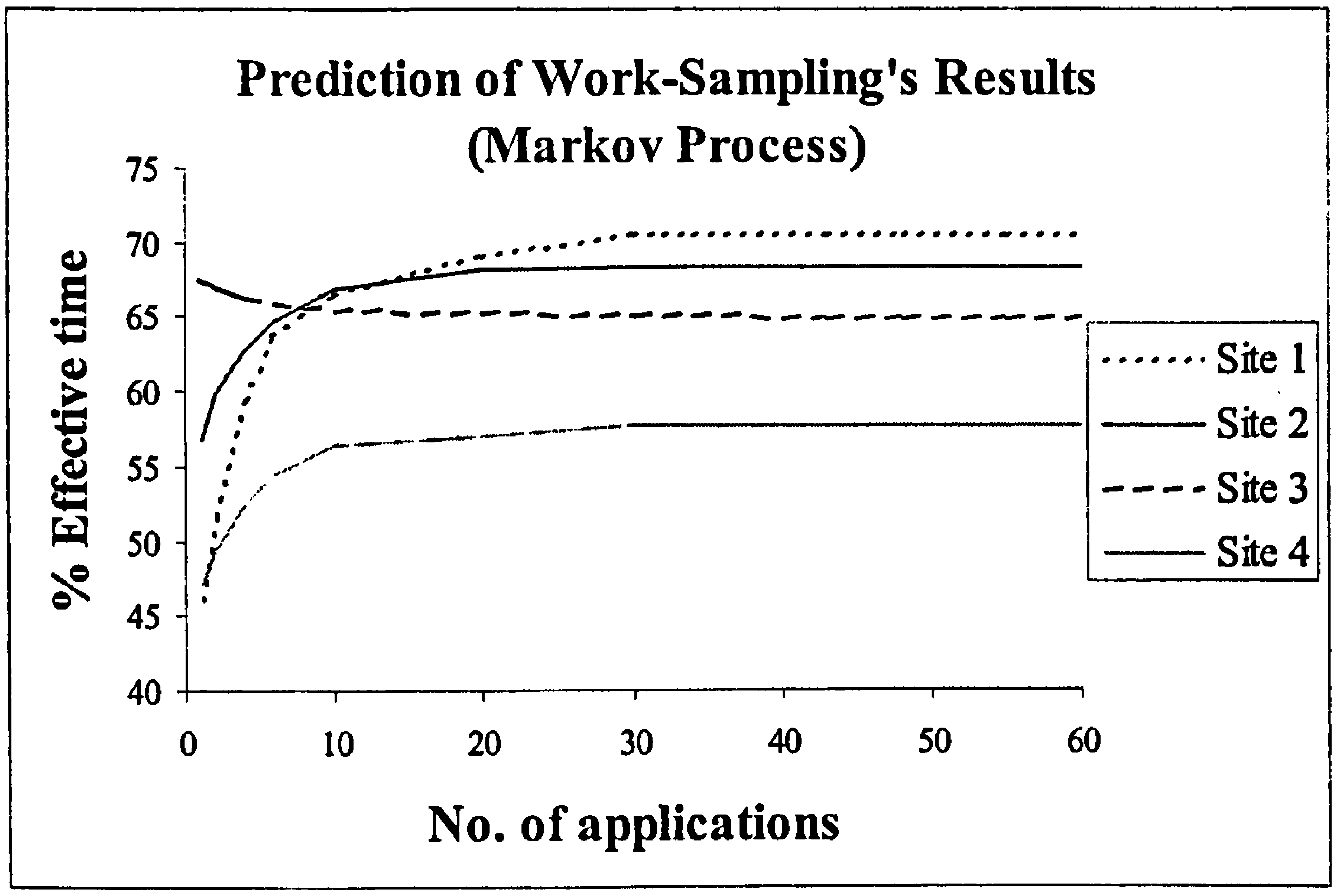

Figure 8.5 The prediction of the effective time of work-sampling results on the 4 sites by the Markov Process

A good example, which illustrates the contribution of the Markov Process to the principle of work-sampling, is the case of sites 1 and 4. These two sites have their first effective of time around 47%, with a list of productivity problems revealed. However, for site 1, where the most support was obtained, the management responded to all of the problems, except for 'late start/early finish,' so the final effective time predicted was 70.5%. On the other hand, the management of site 4, where the least action was taken, chose to focus only on 'late start/early finish,' so the final effective time expected was only 57.7% (see Appendix F). The difference between the final effective time expected is due to the different level of management support for the implementation of the findings of the work-sampling studies, although these two sites have the same starting point. This confirms the importance of management as a potential for productivity improvement, which responds to Research question no. 4.

In respect of the conformation of the Markov Process to the results of work-sampling, the case of site 3 provides a clear demonstration. Since site 3 is the only case, where the effective time decrease from the first study was due to a change in the nature of the works, the predictions reflect this fact, by also specifying the percentage of the final effective time of 64.9% (see Table 7.10), which is lower than the initial effective time of 68%. The Markov Process, nevertheless, still certifies that site 3 was being fairly well managed, even though the percentage of effective time was decreased, since the final effective time of 65% is high.

It is interesting to examine the cases of sites 1 and 2, as site 1 has the most support from the management, but has the least percentage of effective time at the beginning (46%). Meanwhile, site 2 has good support from the management and a higher percentage of effective time (57%). However, the Markov process identifies that, at the end, sites 1 and 2 will have 70.5% and 68.4% effective time, respectively. This confirms that the successful of implementation of work-sampling relies heavily upon the seriousness of the management response to the results of the study. There is also a relationship between the potential for productivity improvement and the severity of the problems. Probably, a number of small problems (the case of site 1) are easier to deal with than one big problem, as in the case of site 2.

Figure 8.6 is a descriptive model representing the research model shown in Figure 4.3. Referring to the results of work-sampling and the Markov process, there is no doubt that the greater the management support and the greater the power of the observer to convince his/her boss and subordinates, the higher is the potential for productivity improvement, which will lead to successful work-sampling implementation. While an incompetent observer may ruin the study, by collecting invalid data that makes the retaking of data again and again inevitable. As a result, the potential for improvement decreases. Similar to the incompetent observer, the severity of problems has a negative relationship to the potential. The more severe the problem is, the less the potential for productivity improvement.

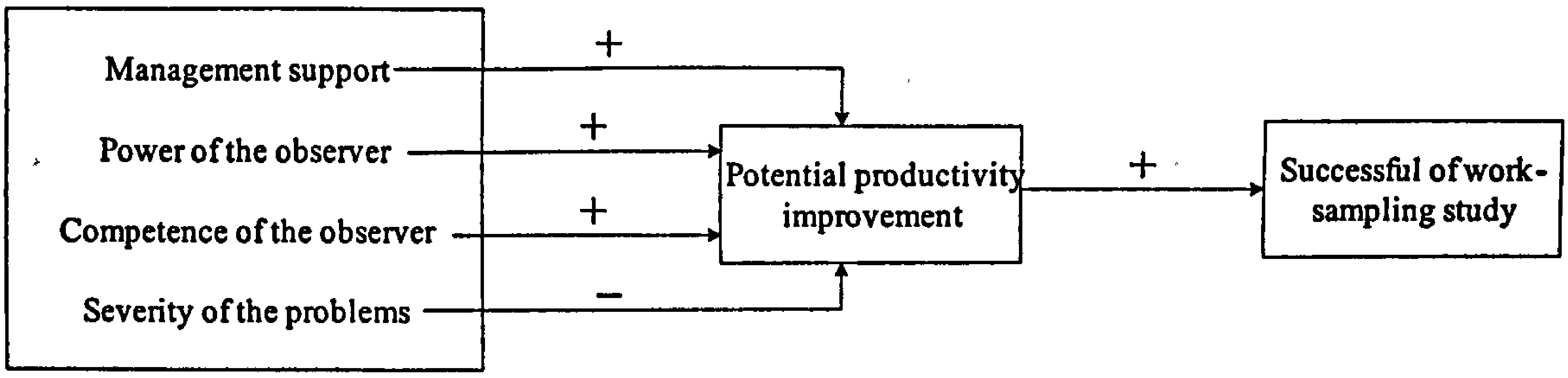

Figure 8.6 Descriptive model illustrating the relationship between contributors to the success of a work-sampling study

8.6 Summary

The results of the work-sampling study confirmed that it is a useful management tool that could assist productivity improvement. Although the results of work-sampling are contrary to those of the questionnaires survey, an explanation has been provided. Unlike the questionnaires, work-sampling study and FDS clearly contributed to each other, so it is recommended to implement them both together. Similarly, the results of the Markov process also comply with the results of work-sampling. However, all Research questions can be answered.

CHAPTER 9

CONCLUSION AND RECCOMENDATION

9.1 Introduction

The objective of this chapter is to draw conclusions from the work described in the previous chapters. To do so, reference is made to the aims and objectives specified in the first chapter, and in particular, to the acceptance or rejection of the hypothesis postulated. Additionally, findings from to the field study are discussed and the thesis ends with recommendations for further research.

9.2 Conclusion

Chapter 1 identified the aim of this research, which is "To improve the present steps in the implementation of work-sampling to make them more practical and rigorous, while maintaining their effectiveness, as a productivity improvement tool, with and without the supplementary foreman delay surveys (FDS)." In order to achieve this aim, nine objectives were stated and the following hypothesis postulated:

"The current work-sampling procedure used in the construction industry can be improved to make it more practical and rigorous, and to increase its effectiveness, as a productivity improvement tool, that can highlight on-site construction productivity problems, with and without supplementary foreman delay surveys (FDS). This will lead to a correct reaction to alleviate or overcome the problems identified and, consequently, after this technique has been applied, the productive time of the construction site will increase."

There is no question that the aim of the thesis has been cautiously accepted, as there is only site 1 that is statistically approved that there has been increased in productive time. The contribution to knowledge made by the work discussed in this thesis may be summarised as follows:

- This research has made factors that affecting construction productivity and causes of lack of material more complete by gathering these factors from various literatures (Borcherding and Sebastian, 1980; Hanna and Heale, 1994; Kaming *et al.*, 1998; Kaming *et al.*, 1997b; Okpala and Aniekwu, 1988; Olomolaiye and Ogunlana, 1989; Olomolaiye *et al.*, 1987; Zakeri *et al.*, 1996) and systematically presenting the results obtained from the questionnaires distributed in Thailand. In addition, the causes of incomplete drawing and the causes of lack of tools and equipment are first introduced in this study.

- The top five factors that have the most influential effect on the productivity of the construction industry in Thailand are lack of materials, incomplete drawing, lack of tools and equipment, incompetent supervisor and poor site conditions. These factors were ranked as the first five by all of the target groups, namely; project managers, foremen and craftsmen, in the first pilot study of this research. In addition, the study confirms that lack of materials is the most crucial productivity problem in several countries, as this factor was ranked first in every country surveyed.

- The three main steps of work-sampling implementation have not only been explicitly set out, namely; Prepare work-sampling, Perform work-sampling, and Evaluate and present results, but also the full practical details for each step have been clarified to make sure that a work-sampling study will be carried out properly. In addition, some steps have been added to the current procedures that are applied to the construction industry, and the whole procedure has been rearranged in order to improve work-sampling technique to make it more practical and rigorous:

    - Sell work-sampling has been included in the first step of Prepare work-sampling, since this step suggests a proper introduction of the technique to the people concerned;

  - Record correlated quantitative measures has also been added to Prepare work-sampling, as the measures would provide evidence of any improvement, with regard to a particular work-sampling study;

  - Sampling procedures have been established to develop and validate observation times (a step in Perform work-sampling) to provide an appropriate sampling interval, which, as a result, will introduce the proper development of observation times;

  - Evaluate validity of data, which consists of the validity of the data and the validity of the observation times, has been inserted in evaluate and present results and Perform work-sampling, respectively. There is no doubt that, without validity, data can not be classified as reliable; and

  - Plan for future studies has been included in Evaluate and present results, since this stage would complete the procedure which allows the work-sampling study to be carried out as a series of studies.

- The results of the work-sampling studies implied that late start/early finish and crew imbalance could be universal construction productivity problems in Thailand. The effect of late start/early finish varies from 10 minutes per craftsman per day (mpcpd) to as much as 60 mpcpd (before alleviation) (see Figure 8.2). To alleviate this problem strict supervision and the long-term commitment of management and supervision are required. Although it is impossible to completely overcome the problem, a decrease to 15 mpcpd is desirable (based on the author's experience during the research).

- The crew imbalance problem, as shown in Figure 8.3, usually causes a craftsman a minimum delay of 100 mpcpd. Although it is impossible to convert all these lost times to productive time, a number of opportunities for productive time to be retrieved, depend upon the specific situation. In other words, the productive time of a construction site could be increased by at least 3%, if the crew imbalance problem is alleviated.

- Benjamin (1987) provided various interesting points of view to conclude that it is not possible to compare the work-sampling results of one plant with another. However, it should be reasonable to set a level of performance of a work-sampling study for this research. A possible interpretation of performance ratings for the productive time obtained by a work-sampling program for construction sites is shown in Table 8.2. In any case, Price and Harris (1985), specified that effective time can vary between 40%-90%, which is about the same range as shown in the table.

- The Markov process can be applied to the construction industry, at least in the case of this research, to predict work-sampling results, with a particular interest in the percentage of effective time accounted for in any particular period. The predictions also confirm that the success of a work-sampling study depends upon the seriousness of the actions taken in responding to the results of the study. For example, for site 1, where the most support was obtained, the final effective time will be 70.5%. On the other hand, for site 4, where the least action was taken, the final effective time will be only 57.7% (see Appendix F). Although, these two sites have approximately the same percentage of effective time at the beginning, 46% and 47%, respectively, the difference between the final effective time expected is due to the different level of management support to implement the results of the work-sampling studies. Furthermore, this concept implies that the success of a work-sampling program depends on the severity of the problems. Probably, a number of small problems (the case of site 1) are easier to deal with than one big problem, like the case of site 2.

The main conclusion of this research, therefore, is that the major part of the decline in productivity in the construction industry is the responsibility of management, not labour, since productivity problems such as waiting for instruction or crew imbalance are beyond the control of labour, but controllable by management. However, in order to improve productivity, management must know what to improve and how to improve it.

Lack of material, which was identified as the most crucial construction productivity problem in Thailand in the first pilot study of this research seems not to be a very significant productivity problem as revealed by the work-sampling studies carried out on the four cases in the second phase of this study, as this problem accounted for a small percentage of working time (no more than 3%) (see Table 6.10). This is because the major cause of the lack of material is a shortage of funds. However, it has been over five years since the economic crisis began in Thailand, so the construction companies that still survive to date must have had sufficient financial strength. As a result, these four sites can afford the necessary materials for their jobs, so a materials shortage is not a big problem.

This thesis has proven that work-sampling provides one answer to these questions and is an invaluable tool that can improve productive time, which leads to the productivity improvement, of any construction works, as it can highlight productivity problems, which identify the correct required response. Nevertheless, in order to be successful, gaining collaboration from every party is essential.

Successful work-sampling application requires full co-operation from all parties, management, supervision and labour. However, the productive time improvement rate of the application depends heavily upon reaction taken in responding to the results of the study by the committee, which in the case of this research is the management. The more serious the reaction is taken, the more is the improvement rate. Evidence for this is the case of sites 1 and 4, where both of the results of their first studies identified 47% productive time, with a list of productivity problems, like waiting for materials or late start/early finish. However, the management of site 1 responded to all of the problems, except for late start/early finish. On the other hand, the management of site 4 chose to focus only on late start/early finish. As a result, the productive time improvement rate of site 1 is as high as 11% and 5% for site 4 (see Figure 8.1). Therefore, this is a reason why all four sites have different rates of productive time improvement.

This research complies with Oglesby *et al.* (1989) that one application of work-sampling study usually increases productive time by 5%-10%. However, the author would like to add that the increase depends on how management decides to react to the problems revealed. Therefore, this is a further reason why the author recommends that engineers do the observations, rather than foreman, as doing so offers a better opportunity to obtain the best result, which is the possible maximum productive time achievable for that particular application.

In respect of preparing work-sampling, the author definitely suggests that establishing the objectives is considered as the most crucial step, which was also suggested by Thomas and Holland (1980). The objectives must be set to reflect what the committee (the management) expect from the study. Next, categories must be designed to reflect the objectives of the program. Finally, all the parties involved must be clearly informed in advance about the details of the study.

At the stage of performing work-sampling, it is important to make sure that observation times are validated by the use of a *c* chart before their applications. Otherwise, the data recorded may not be valid. When collecting data, the observers must be punctual in their observation times, avoid any biased habit patterns in making observations and be precise in categorising observed activity. Heinze (1984) and Thomas *et al.* (1982) wrote that the observer should be open and communicative with the craftsmen and their supervisors, and, as a result, the observer will be able to perceive the difficulties encountered by the craftsmen and can serve in a capacity other than just a number collector (Thomas, 1980). The author found that these two statements are remarkably true.

The only suggestion with regard to evaluating and presenting results, the final step, is that the results should be presented in terms of the original objectives of the study and should be analysed in a careful and conscientious manner, so that all have confidence in the results.

Some authors have recommended that a foreman acts as an observer (Heiland and Richardson, 1957; Richardson, 1976). However, according to the author's experience, as discussed above, the author would recommend that an engineer plays the observer's role, since an engineer has sufficient power to command his subordinates and has adequate communication channels to the top management to persuade them to get things done.

The author agrees with Benjamin (1987) who said that work-sampling does not provide the management with the information needed to detect and correct productivity problems. However, if an engineer plays an observer's role, he would perceive and appreciate what, where and how serious the problems are, so that the observer could provide the information required for alleviating the problems.

All participating project managers have reached the consensus that they were satisfied with the results of the work-sampling study and FDS. These impressions of work-sampling study arise from its accuracy and its ability to highlight productivity problems like crew imbalance. They further felt that this technique is a good tool for managing labour productivity that can be applied to both fabrication shops and construction sites, with regard to minimising delays and believe that it is worthwhile to implement, although engineer man-hours must be sacrificed. In addition, the project mangers suggested that work-sampling techniques could work as a monitor that assists them in setting productivity goals for each month, which implies that they believed that a monthly basis is the optimum interval for carrying out the technique.

Every responding foreman agreed that the implementation of FDS created a positive feeling, since they felt that the management was interested in assisting them to solve their problems. The foremen also said that FDS is a useful tool that makes their work easier, encourages them to plan in advance and motivates them to co-operate with other foremen in order to decrease delays. Additionally, FDS provides evidence that a foreman and his subordinates do not try to avoid working, for example, they are idle because they are waiting for inspection.

However, no conclusion can be drawn with regards to whether work-sampling study or FDS is the better technique. This is because one project manager specified that FDS provided him with a better perception of problems than work-sampling, while another project manager doubted the accuracy of FDS, due to unfaithful reporting by the foreman, and he believed that work-sampling gave him a better view of productivity problems. Both parties, nevertheless, agreed that both techniques complement each other and that they preferred to implement these techniques together.

The obvious advantage of work-sampling over FDS, according to this research, is that it could identify crew imbalance problems that FDS could not, probably due to its basic principle that any delays should be reported only if they last at least 15 minutes. This principle can also be a reason to explain why it is not necessary that the results of work-sampling and FDS must always reverse each other. In other words, in some situations, if the effective time decreases, FDS can also decrease in percentage delay, and vice versa. On the opposite side, the outstanding advantage of FDS over work-sampling is that the survey directly points out what and where is the source of the problems, whereas work-sampling study requires some time to sort this out. In addition, the author agrees with Rogge and Tucker (1982) who said that FDS offers the advantages of speed, economy and the absence of adverse relationships, while work-sampling provides more detail and complete information.

This research has found that the accuracy of FDS is fairly high, as high as that of work-sampling, at least in the case of long delays (minimum 30 minutes), since the two long delays reported by FDS from the two sites is as close as the results of the particular two work-sampling studies. The first case is the first study of site 2, where weather (rain) was reported by work-sampling and FDS as accounting for 2.22% and 2.32%, respectively. The other case occurred in the first study of site 3 when work-sampling specified 4% and FDS indicated 3.29% for air pump breakdown. Having FDS results close to that arising from work-sampling implies that FDS has an accuracy as high as that arising from work-sampling.

Referring to this thesis, it is implied that late start/early finish and crew imbalance could probably be universal productivity problems in the construction industry in Thailand. However, in order to confirm this, further research must be carried out. Late start/early finish accounts for 19 mpcpd to 60 mpcpd. This problem requires stricter supervision and the long-term commitment of management and supervisors in order to decrease this lost time. Crew imbalance usually takes at least 100 mpcpd. Although parts of that are unavoidable, productive time could be increased, if the problem is focused upon.

In order to confirm that the aims have been achieved, conclusions will be drawn under the following headings, which summarise the objectives initially stated.

9.2.1 An Overview of Productivity (Chapter 2)

- *To perceive a general idea of productivity such as its definition, classification, importance, etc.*

The word "Productivity" is a familiar word to everyone and has a large number of definitions, however, the most well known one is:

$$\text{Productivity} = \frac{\text{Output}}{\text{Inputs}}$$

Although productivity has various definitions, when carefully examined, three major types of productivity can be classified, which are partial productivity, total factor productivity and total productivity.

A construction industry usually contributes between 4-10% to GDP and the industry can stimulate the growth of other industrial sectors. Additionally, its productivity can improve quality of life and living standards, so it is reasonable to state that construction is the key to development; and productivity is the key to construction. Unfortunately, management practices are a significant factor behind declining productivity in the industry, since the degree of management control has a strong effect on productivity.

To improve productivity, management must remove any constraints hampering crews in the performance of their tasks. In any case, productivity improvement cannot be achieved without management recognition of the causes of the problem; what to improve and how to improve it. Therefore, these matters were the inspiration for the author's first pilot study, which was an identification of the factors affecting construction productivity in Thailand. A structured questionnaire survey, with project managers, foremen and craftsmen working in the industry as the target groups, was selected to be main research strategy.

9.2.2 Productivity Management(Chapter 3)

- *To provide a basic idea of work-sampling and to specify why work-sampling is suitable for construction work.*

Work-sampling, also called *ratio delay study, snap shot studies* or *activity sampling,* was originated by Tippett, L. H. C. in the early 1930's and is classified as field ratings, productivity ratings and the 5-minute rating technique. A literature review showed that various author (Barnes and Andrews, 1955; Baxendale, 1987; Dale 1976; Heiland and Richardson, 1957; NEDO, 1989; Peer, 1986; Picard 1991; Richardson, 1976; Tsai, 1996) have supported the appropriateness of the application of work-sampling to construction work.

- *To explain all statistical fundamentals concerned with work-sampling.*

The fundamentals of work-sampling have their origin in sampling. When doing a number of samplings, a basic form of frequency distribution of samples, which is known as the *normal distribution curve,* will be obtained. The area under the normal curve is used to develop an equation to identify the number of observations required and the accuracy of the work-sampling study. In addition, p and c charts, should be used to validate study data, and hypotheses tests can be used to determine if the productive time has increased by a statistically significant amount.

- *To specify the problems with the present application of the steps of work-sampling, then to suggest an improved process and to clearly specify every single step of improved work-sampling implementation from the early stages to completion.*

The improved implementation of work-sampling divides itself into three parts; preparing work-sampling, performing work-sampling and evaluating and presenting the results. The crucial step of preparing work-sampling is selling work-sampling, as the success of this application requires full co-operation from all parties such as management, supervision and labour. Furthermore, during the second part, performing work-sampling, it is important to ensure that the observation times developed are valid before their application. In addition, while recording data, the observer must strictly adhere to the observation times, avoid any biased habit patterns in making observations and be precise in categorising any observed activity. In the last section, finally, the presentation and analysis of data is a critical step. The author recommends the use of graphical means of presentation of the results and that the data should be reported with regards to the original objectives of the study, so that confidence in the results can be obtained.

- *To assign a clear approach to the application of foreman delay surveys (FDS).*

There are five major steps of implementation of FDS, introduction to foreman, form distribution and collection, results summarisation, feedback session and remedial action.

9.2.3 Research Methodology (Chapter 4)

- *To identify research questions, research methodology and research variables.*

This research aims to find out the answers to its four main questions, including their variables, by employing structured questionnaires, case studies and the application of the Markov process, as research strategies.

- *To validate the reliability of the results of the studies.*

p and *c* charts were employed to validate the data from this research. *p* charts were used based on the daily and observation rounds and it was found that only the observation round for the first study of site 1, 2 and 3 and the second study of site 3 contained abnormal patterns. The *c* chart was applied based on 10 and 15 minute intervals and indicated no abnormal patterns. In respect of the reliability test, it is an advantage of the work-sampling technique that the reliability of the result can be specified before hand and this research has identified 95% level of confidence and ±5% limit of error and shown that all categories are within these limits.

9.2.4 Factors Affecting the Productivity of the Construction Industry in Thailand (Chapter 5)

- *To identify the factors affecting the productivity of the construction industry in Thailand.*

The result of the first pilot study revealed that there are productivity problems in Thailand, since the study has revealed the impact of factors influencing construction productivity. The top five factors affecting productivity, according to the project managers, foremen and craftsmen, are lack of material, incomplete drawing, lack of tools and equipment, incompetent supervisors and poor site conditions.

9.2.5 The Applications of Work-Sampling and Foreman Delay Surveys (Chapter 6)

- *To implement the improved work-sampling technique and foreman delay survey (FDS) to 4 construction sites in Thailand to find out how well these techniques work.*

This research has been applied to 4 cases, which consists of two construction sites and two fabrication shops. For one case from both categories (Sites 1 and 4) only work-sampling was implemented, while both work-sampling and FDS were implemented on the remaining two (Sites 2 and 3).

Site 1, a fabrication shop, was studied between 15 October and 12 November 2001. The results indicated that the productive time increased from 46% to 52% (about 11% increase), as the management seriously responded to the productivity problem highlighted in the first study. Such problems included waiting for material for the fitter (mark/cut), crew imbalance (fitter) and waiting for instruction (rigger). In respect of the percentage of productive time increase, this site can be classified as the most successful, when compared with the other three sites. This is because not only did it experience the highest percentage of productive time increase, but also site 1 is the only site that statistically could confirm with 95% confidence level that the productive time of the site has been truly increased from 46% to 52%.

The second site, where both work-sampling and FDS were carried out, was accessed between 31 October and 14 November 2001. The productive times disclosed from the first and the second study were 57% and 60%, respectively, while the FDS of both studies only revealed avoidable delays in the order of 3%. Although there is no statistically significant improvement for site 2, this series of studies has confirmed that this site has a high productive time (57%-60%) and this high rate can be maintained even when the number of craftsmen has approximately doubled from the first study (40 at the first and 85 at the second). The results of both studies, in addition, confirm the professional management of this site.

Site 3, the other fabrication shop, implemented both work-sampling and FDS between 26 November and 15 December 2001. The results of the studies specified 67.56% and 67.33% of productive time for the first and the second work-sampling study, respectively, and 5.48% for the first and 4.32% for the second, inavoidable delays obtained via the FDS. Although the air pump problem, which is the most obvious problem and includes a 4% delay, was completely solved in the second study, the effective time did not increase, due to the fact that the working situation between the first and the second study had been changed and led to the introduction of the new productivity problems, such as waiting for inspection. Nevertheless, according to the result of this study, the project was being fairly well managed. Both sites 2 and 3 are classified are well managed, but site 3 has an effective time significantly higher than site 2, due to the nature of the work environment. Working in a fabrication shop is easier to control than working in a site.

Work-sampling was carried out on the last site, site 4, between 21 December 2001 and 19 January 2002. The productive times revealed in the first and the second investigations were 47% and 49%, respectively. Although there were a couple of productivity problems specified in the first study, the management decided to take action only on the late start/early finish problem. As the result, the productive time increased to 49% in the second study, or about 5% increase when compared with the first study.

9.2.6 Prediction of Work-Sampling Results (Chapter 7)

❖ *To predict the results of future work-sampling studies.*

The application of the Markov analysis is used for this purpose. The results confirm that this analysis could fulfil the objective and support the conclusion specified above that the success of work-sampling study relies heavily on the support of management. On site 1, which had the most management support, it is predicted that its optimum effective time will be 70.5%, while on site 4, which have the least management support, it is expected to have a maximum of 57.7% effective time (see appendix F).

9.2.7 Discussion of the Results (Chapter 8)

The answers to all of the four Research questions are clarified, referring to the results of the study. Work-sampling is a good productivity management tool and works even better with the contribution of FDS, as the advantages of each technique complement the disadvantages of the other. The application of the predictions of the Markov process supports the principle of work-sampling that management has a high degree of influence on the success of the applications.

9.3 Recommendations for Further Research

During the development of this original piece of work, the author has found some interesting points that should be followed up in order to contribute to the body of knowledge:

- Referring to this thesis, the framework can be applied to any other country where the factors affecting construction productivity have not been determined and work-sampling studies have never been carried out. The author strongly believes that there must be a number of such countries.

- As the steps of work-sampling implementation have been clearly specified and as this research has found that the construction industry in Thailand is experiencing crew imbalance, the author would suggest that work-sampling is applied first to appreciate the problem, just as in this research, then that a crew balance chart is employed to find out how well this technique works, with regard to decreasing delay, due to crew imbalance.

- Apart from the foreman delay surveys (FDS), which asks the foreman to report delays, there is another survey called the "*craftsman questionnaire*," which allows craftsmen to report delays. As this research has highlighted the consensus between the contribution of work-sampling and FDS together, it would be interesting to find out how well the combination of the two techniques and the craftsman questionnaire work out in practice.

- The validity of the Markov process has never been undertaken elsewhere. The most appropriate way to do so is to compare the actual results with the predicted results. Therefore, a series of work-sampling studies should be carried out, for example, for 8 consecutive months, on two construction sites. Then, the actual percentage obtained and the predicted percentages of effective time are comparable. As a result, the validity of the Markov process can be clarified.

- In any work-sampling study, if it requires over 30 minutes to complete an observation round (eight rounds are taken a day), the author would recommend the employment of two observers, rather than one. Doing so could prevent the observer from experiencing too much strain and fatigue. The author experienced this problem himself, during this research.

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Appendix A: "The Project Managers' Questionnaire"

University of Manchester Institute of Science and Technology (UMIST)

G10 Pariser Building, P.O. Box 88 Sackville Street Manchester, M60 1QD

Factors Affecting Productivity of Construction Industry in Thailand – the Project Manager's Perception

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<u>Section A:</u> General characteristics of project manager.
<u>Instruction:</u> Please tick the items that may apply to you.

1. Gender:
   ○ Male ○ Female

2. Age (years):
   ○ 25-34 ○ 35-44 ○ 45-55 ○ > 55

3. Level of education:
   ○ First Degree ○ Diploma ○ Master Degree ○ PhD
   ○ Other (please specify): ____________________

4. Working experience in construction industry (years):
   ○ < 5 ○ 5-10 ○ 11-20 ○ > 20

5. Working experience in respect of construction types:

   5.1. Residential (years):
   ○ None ○ < 5 ○ 5-10 ○ > 10
   5.2. Building (years):
   ○ None ○ < 5 ○ 5-10 ○ > 10

5.3.Industrial (years):

○ None ○ < 5 ○ 5-10 ○ > 10

5.4. Civil Engineering (years):

○ None ○ < 5 ○ 5-10 ○ > 10

6. Length of stay with current employer (years):

○ < 2 ○ 2-5 ○ 6-10 ○ 11-20 ○ > 20

<u>Section B:</u> General characteristics of your organisation
<u>Instruction:</u> Please tick the items that may apply to you.

1. Nature of work:

○ Residential ○ Building ○ Industrial ○ Civil Engineering

2. Type of contractor:

○ Main contractor ○ Sub-constractor ○ Sub-contractor labour only

3. Average annual turnover (Million Baht):

○ < 10 MB ○ 10-100 MB ○ 101-500 MB ○ 501-1000 MB
○ > 1000 MB

4. Number of permanent employees:

○ < 50 ○ 50-200 ○ 201-500 ○ 501-1000
○ > 1000

5. Number of temporary employees:

○ < 50 ○ 50-200 ○ 201-500 ○ 501-1000
○ > 1000

6. Amount of work (by Baht value) subcontracted on average job:

○ < 25% ○ 25%-50% ○ 50%-75% ○ > 75%

7. Geographic location of organisation:

○ Bangkok and boundary ○ Middle ○ North

○ Northeast ○ East ○ West ○ South

Section C: General opinion of organisation

Instruction: Please tick the items may apply to you.

1. Opinion of employer:

○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

2. Opinion of subordinates:

○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

3. Opinion of working environment:

○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

4. Opinion of level of payment:

○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

5. Opinion of method of construction:

○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

(Please turn to the next page for section D)

Section D: Your perception of factors affecting on site construction productivity, and their potential for improvement.

Instruction: Below are a number of factors, which can have an impact on site productivity. ***From your overall experience,*** *please express your opinion on how important each factor can be in influencing productivity by circling the appropriate influence number, where:*

0 = No influence, or N/A *1 = Very little influence* *2 = Some influence*
3 = Moderate influence *4 = Much influence* *5 = Very much influence*

Example: Suppose, lack of tools and equipment has significant effect on productivity, and occurs often, so the factor should be given a high score, 4 or 5. On the other hand, heavy rain (a weather factor), causes severe damage to productivity, as we can't work at that particular period, but, fortunately, heavy rain does not come very often. Therefore, we should not rate the factor as having a great influence, let's say 4 or 5. The influence number for each factor, consequently, should be assigned according to its severity in respect of productivity, and its frequency of occurrence.

Please also express your opinion *on how much potential with respect to opportunity for productivity improvement each factor has by circling the appropriate potential improvement number, where:*

0 = No potential, or N/A *1 = Too little to deserve attention* *2 = Medium potential*
3 = High potential *4 = Very high potential*

Factor	Influence number	Potential improvement number
Lack of material	0 1 2 3 4 5	0 1 2 3 4
Lack of tools and equipment	0 1 2 3 4 5	0 1 2 3 4
Tools/equipment breakdown	0 1 2 3 4 5	0 1 2 3 4
Rework	0 1 2 3 4 5	0 1 2 3 4
Workers turnover and changing crewmembers	0 1 2 3 4 5	0 1 2 3 4
Interference from other trades or other crew members	0 1 2 3 4 5	0 1 2 3 4
Absenteeism	0 1 2 3 4 5	0 1 2 3 4
Instruction time	0 1 2 3 4 5	0 1 2 3 4
Inspection delay	0 1 2 3 4 5	0 1 2 3 4
Changing of foremen	0 1 2 3 4 5	0 1 2 3 4
Incompetent supervisors	0 1 2 3 4 5	0 1 2 3 4
Overcrowding	0 1 2 3 4 5	0 1 2 3 4
Weather	0 1 2 3 4 5	0 1 2 3 4
Poor site conditions	0 1 2 3 4 5	0 1 2 3 4
Poor site layout	0 1 2 3 4 5	0 1 2 3 4
Incomplete drawing	0 1 2 3 4 5	0 1 2 3 4
Change orders	0 1 2 3 4 5	0 1 2 3 4
Safety (accidents)	0 1 2 3 4 5	0 1 2 3 4

Factor	Influence number	Potential improvement number
Poor communication	0 1 2 3 4 5	0 1 2 3 4
Specification and Standardisation	0 1 2 3 4 5	0 1 2 3 4
Occasional working overtime	0 1 2 3 4 5	0 1 2 3 4
Scheduled working overtime	0 1 2 3 4 5	0 1 2 3 4
Shift work	0 1 2 3 4 5	0 1 2 3 4
Other (please specify): ____________	0 1 2 3 4 5	0 1 2 3 4

Thank you very much for your kind participation

Appendix B: “The Foremen’s Questionnaire”

University of Manchester Institute of Science and Technology (UMIST)
G10 Pariser Building, P.O. Box 88 Sackville Street Manchester, M60 1QD

Factors Affecting Productivity of the Construction Industry in Thailand – the Foreman's Perception

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Section A: General characteristics of operative.
Instruction: Please tick the items that may apply to you.

1. Gender:

○ Male ○ Female

2. Age (years):

○ 15-20 ○ 21-30 ○ 31-40 ○ 41-50 ○ > 50

3. Level of education:

○ Primary School ○ Junior High-school ○ High-school

4. Working experience in construction industry (years):

○ < 2 ○ 2-5 ○ 6-10 ○ 11-20 ○ > 20

5. Working experience in respect of construction types:

5.1. Residential (years):
○ None ○ < 2 ○ 2-5 ○ 6-10 ○ > 10
5.2. Building (years):
○ None ○ < 2 ○ 2-5 ○ 6-10 ○ > 10

5.3. Industrial (years):

○ None ○ < 2 ○ 2-5 ○ 6-10 ○ > 10

5.4. Civil Engineering (years):

○ None ○ < 2 ○ 2-5 ○ 6-10 ○ > 10

<u>Section B:</u> *General characteristics of employment*

<u>Instruction:</u> *Please tick the items or fill in the blanks that may apply to you.*

1. Nature of employer's works in respect of construction type:

   ○ Residential ○ Building ○ Industrial ○ Civil engineering

2. Type of employer:

   ○ Main contractor ○ Sub-contractor ○ Sub-contractor labour only

3. Mode of employment:

   ○ Full time ○ Part time ○ Casual ○ Daily pay

4. Trade, job title, and main responsibility: ______________________________

   ____

5. Length of stay with current employer (years):

   ○ < 2 ○ 2-5 ○ 6-10 ○ 11-20 ○ > 20

6. Please state the number of foreman who have left the organisation since you were recruited:

   ○ Don't know ○ 0-2 ○ 3-5 ○ 6-10 ○ > 10

7. How did you quit your previous job?:

   ○ Quit by myself ○ Employer proposal ○ This is my first job

Section C: General opinion of organisation
Instruction: Please tick the items that may apply to you.

1. Opinion of employer:
   ○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

2. Opinion of working environment:
   ○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

3. Opinion of working environment:
   ○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

4. Opinion of level of payment:
   ○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

Section D: Your perception of factors affecting construction productivity.

Instruction: Below are a number of factors, which can have an impact on site productivity. ***From your overall experience, please express your opinion on how important each factor can be in influencing productivity by circling the appropriate number, where:***

0 = No influence *1 = Very little influence* *2 = Some influence*
3 = Moderate influence *4 = Much influence* *5 = Very much influence*

Example: ***Suppose, lack of tools and equipment has significant effect on productivity, and occurs often, so the factor should be given a high score, 4 or 5. On the other hand, heavy rain (a weather factor), causes severe damage to productivity, as we can't work at that particular period, but, fortunately, heavy rain does not come very often. Therefore, we should not rate the factor as having a great influence, let's say 4 or 5. The influence number for each factor,*** *consequently, should be assigned according to its severity in respect of productivity, and its frequency of occurrence.*

Factor	Number
Lack of material	0 1 2 3 4 5
Lack of tools/equipment	0 1 2 3 4 5
Tools/equipment breakdown	0 1 2 3 4 5
Rework	0 1 2 3 4 5
Workers turnover and changing crew members	0 1 2 3 4 5
Interference from other trades or other crew members	0 1 2 3 4 5
Absenteeism	0 1 2 3 4 5
Instruction time	0 1 2 3 4 5
Inspection delay	0 1 2 3 4 5
Changing of foremen	0 1 2 3 4 5
Incompetent supervisors	0 1 2 3 4 5
Overcrowding	0 1 2 3 4 5
Weather	0 1 2 3 4 5
Poor site conditions	0 1 2 3 4 5
Poor site layout	0 1 2 3 4 5
Incomplete drawing	0 1 2 3 4 5
Change orders	0 1 2 3 4 5
Safety (accidents)	0 1 2 3 4 5
Poor communication	0 1 2 3 4 5
Specification and Standardisation	0 1 2 3 4 5
Height of the work site above ground	0 1 2 3 4 5
Work overload	0 1 2 3 4 5
Other (please specify): ______________________	0 1 2 3 4 5

__Section E:__ Your perception of causes of factors affecting construction productivity.

__Instruction:__ Below are a number of causes, which can be the origin of factors affecting construction productivity. ***From your overall experience, please express*** *your opinion on how important each cause can be in influencing those factors by circling the appropriate number, where:*

0 = No influence *1 = Very little influence* *2 = Some influence*
3 = Moderate influence *4 = Much influence* *5 = Very much influence*

1. Causes of material unavailability

Factor	Number
Waste due to negligence/sabotage	0 1 2 3 4 5
On site transportation difficulties	0 1 2 3 4 5
Excessive paper work for request	0 1 2 3 4 5
Improper material handling on site	0 1 2 3 4 5
Improper material usage to specification	0 1 2 3 4 5
Inadequate planning	0 1 2 3 4 5
Improper materials delivery to site	0 1 2 3 4 5
Improper materials storage	0 1 2 3 4 5
Fluctuation in availability	0 1 2 3 4 5
Fund shortage to procure	0 1 2 3 4 5
Other (please specify): ____________________	0 1 2 3 4 5

2. Causes of incomplete drawing

Factor	Number
Inexperience draftsman	0 1 2 3 4 5
Insufficient time assigned to draftsman to complete	0 1 2 3 4 5
Designer provides incomplete details	0 1 2 3 4 5
Impractical design (by designer)	0 1 2 3 4 5
Lack of careful examination of approved drawing	0 1 2 3 4 5
Incomplete site survey	0 1 2 3 4 5
Incomplete proposal (lack of information)	0 1 2 3 4 5
Other (please specify):_____________________	0 1 2 3 4 5

3. Causes of lack of tools/equipment

Factor	Number
Broken tools/equipment have not been reported	0 1 2 3 4 5
Lack of proper maintenance	0 1 2 3 4 5
Improper tools/equipment application	0 1 2 3 4 5
Delay in inter-site loan	0 1 2 3 4 5
Unordered storage	0 1 2 3 4 5
Various sites are being constructed at the same time	0 1 2 3 4 5
Improper planning	0 1 2 3 4 5
Fund shortage to procure	0 1 2 3 4 5
Other (please specify): _____________________	0 1 2 3 4 5

Appendix C: “The Craftsmen’s Questionnaire ”

University of Manchester Institute of Science and Technology (UMIST)

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Factors Affecting Productivity of the Construction Industry in Thailand – the Craftsman's Perception

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<u>Section A:</u> General characteristics of operative.
<u>Instruction:</u> Please tick the items that may apply to you.

1. Gender:

   ○ Male ○ Female

2. Age (years):

   ○ 15-20 ○ 21-30 ○ 31-40 ○ 41-50 ○ > 50

3. Level of education:

   ○ Primary School ○ Junior High-school ○ High-school

4. Working experience in construction industry (years):

   ○ < 2 ○ 2-5 ○ 6-10 ○ 11-20 ○ > 20

5. Working experience in respect of construction types:

   5.1. Residential (years):

   ○ None ○ < 2 ○ 2-5 ○ 6-10 ○ > 10

   5.2. Building (years):

   ○ None ○ < 2 ○ 2-5 ○ 6-10 ○ > 10

5.3. Industrial (years):

○ None ○ < 2 ○ 2-5 ○ 6-10 ○ > 10

5.4. Civil Engineering (years):

○ None ○ < 2 ○ 2-5 ○ 6-10 ○ > 10

Section B: General characteristics of employment
Instruction: Please tick the items or fill in the blanks that may apply to you.

1. Nature of employer's works in respect of construction type:

   ○ Residential ○ Building ○ Industrial ○ Civil engineering

2. Type of employer:

   ○ Main contractor ○ Sub-contractor ○ Sub-contractor labour only

3. Mode of employment:

   ○ Full time ○ Part time ○ Casual ○ Daily pay

4. Trade, job title, and main responsibility: ______________________________

   ____

5. Length of stay with current employer (years):

   ○ < 2 ○ 2-5 ○ 6-10 ○ 11-20 ○ > 20

6. Please state the number of members in your gang who have left the organisation since you were recruited:

   ○ Don't know ○ 0-2 ○ 3-5 ○ 6-10 ○ > 10

7. How did you quit your previous job?:

   ○ Quit by myself ○ Employer proposal ○ This is my first job

Section C: General opinion of organisation
Instruction: Please tick the items that may apply to you.

1. Opinion of employer:
   ○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

2. Opinion of working environment:
   ○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

3. Opinion of level of payment:
   ○ Very good ○ Good ○ Fair ○ Poor ○ Very poor

Section D: Your perception of factors affecting on site construction productivity.

Instruction: Below are a number of factors, which can have an impact on site productivity. ***From your overall experience,*** *please express your opinion on how important each factor can be in influencing productivity by circling the appropriate number, where:*

0 = No influence
1 = Very little influence
2 = Some influence
3 = Moderate influence
4 = Much influence
5 = Very much influence

Example: ***Suppose,*** *lack of tools and equipment has significant effect on productivity, and occurs often, so the factor should be given a high score, 4 or 5. On the other hand, heavy rain (a weather factor), causes severe damage to productivity, as we can't work at that particular period, but, fortunately, heavy rain does not come very often. Therefore, we should not rate the factor as having a great influence, let's say 4 or 5. The influence number for each*

Factor	Number
Lack of material	0 1 2 3 4 5
Lack of tools/equipment	0 1 2 3 4 5
Tools/equipment breakdown	0 1 2 3 4 5
Rework	0 1 2 3 4 5
Workers turnover and changing crew members	0 1 2 3 4 5
Interference from other trades or other crew members	0 1 2 3 4 5
Absenteeism	0 1 2 3 4 5
Instruction time	0 1 2 3 4 5
Inspection delay	0 1 2 3 4 5
Changing of foremen	0 1 2 3 4 5
Incompetent supervisors	0 1 2 3 4 5
Overcrowding	0 1 2 3 4 5
Weather	0 1 2 3 4 5
Poor site conditions	0 1 2 3 4 5
Poor site layout	0 1 2 3 4 5
Incomplete drawing	0 1 2 3 4 5
Change orders	0 1 2 3 4 5
Safety (accidents)	0 1 2 3 4 5
Poor communication	0 1 2 3 4 5
Specification and Standardisation	0 1 2 3 4 5
Height of the work site above ground	0 1 2 3 4 5
Work overload	0 1 2 3 4 5
Other (please specify): ____________________	0 1 2 3 4 5

Section E: Your perception of causes of factors affecting construction productivity.

Instruction: Below are a number of causes, which can be the origin of factors affecting construction productivity. ***From your overall experience****, please express your opinion on how important each cause can be in influencing those factors by circling the appropriate number, where:*

0 = No influence *1 = Very little influence* *2 = Some influence*
3 = Moderate influence *4 = Much influence* *5 = Very much influence*

1. Causes of material unavailability

Factor	Number
Waste due to negligence/sabotage	0 1 2 3 4 5
On site transportation difficulties	0 1 2 3 4 5
Excessive paper work for request	0 1 2 3 4 5
Improper material handling on site	0 1 2 3 4 5
Improper material usage to specification	0 1 2 3 4 5
Inadequate planning	0 1 2 3 4 5
Improper materials delivery to site	0 1 2 3 4 5
Improper materials storage	0 1 2 3 4 5
Fluctuation in availability	0 1 2 3 4 5
Fund shortage to procure	0 1 2 3 4 5
Other (please specify): ____________________	0 1 2 3 4 5

2. Causes of rework

Factor	Number
Poor instruction and supervision	0 1 2 3 4 5
Poor workmanship	0 1 2 3 4 5
Negligence/sabotage	0 1 2 3 4 5
Revisions/change order	0 1 2 3 4 5
Complex/incomplete drawings and specification	0 1 2 3 4 5
Other (please specify): ____________________	0 1 2 3 4 5

3. Causes of labour turnover

Factor	Number
Better pay at other sites	0 1 2 3 4 5
Other sites nearer home	0 1 2 3 4 5
Job more challenging on other sites	0 1 2 3 4 5
Better working atmosphere on other sites	0 1 2 3 4 5
Casual labour force	0 1 2 3 4 5
Delay in payment	0 1 2 3 4 5
Discontinuity of work	0 1 2 3 4 5
Other job opportunities	0 1 2 3 4 5
Disrespectful treatment by supervisors/management	0 1 2 3 4 5
Strenuous working conditions	0 1 2 3 4 5
Poor working conditions	0 1 2 3 4 5
Other (please specify): ____________________	0 1 2 3 4 5

Appendix D: “Validity Test of the Study”

D.1. Site 1

D.1.1. The First Study

D.1.1.1. *p* Chart

D.1.1.1.1. Daily Basis

Table D.1 Delay percentage for the first study for site 1 (by day)

Day	1	2	3	4	5	$\bar{p}$
% Delay	47.78	50.00	53.33	48.89	57.78	53.78

According to Table D.1 and equation 5, UCL = 69.55, CL = 53.78 and LCL = 38.01. Then, we can plot % delay of a particular day on the *p* chart, as shown in Figure D.1.

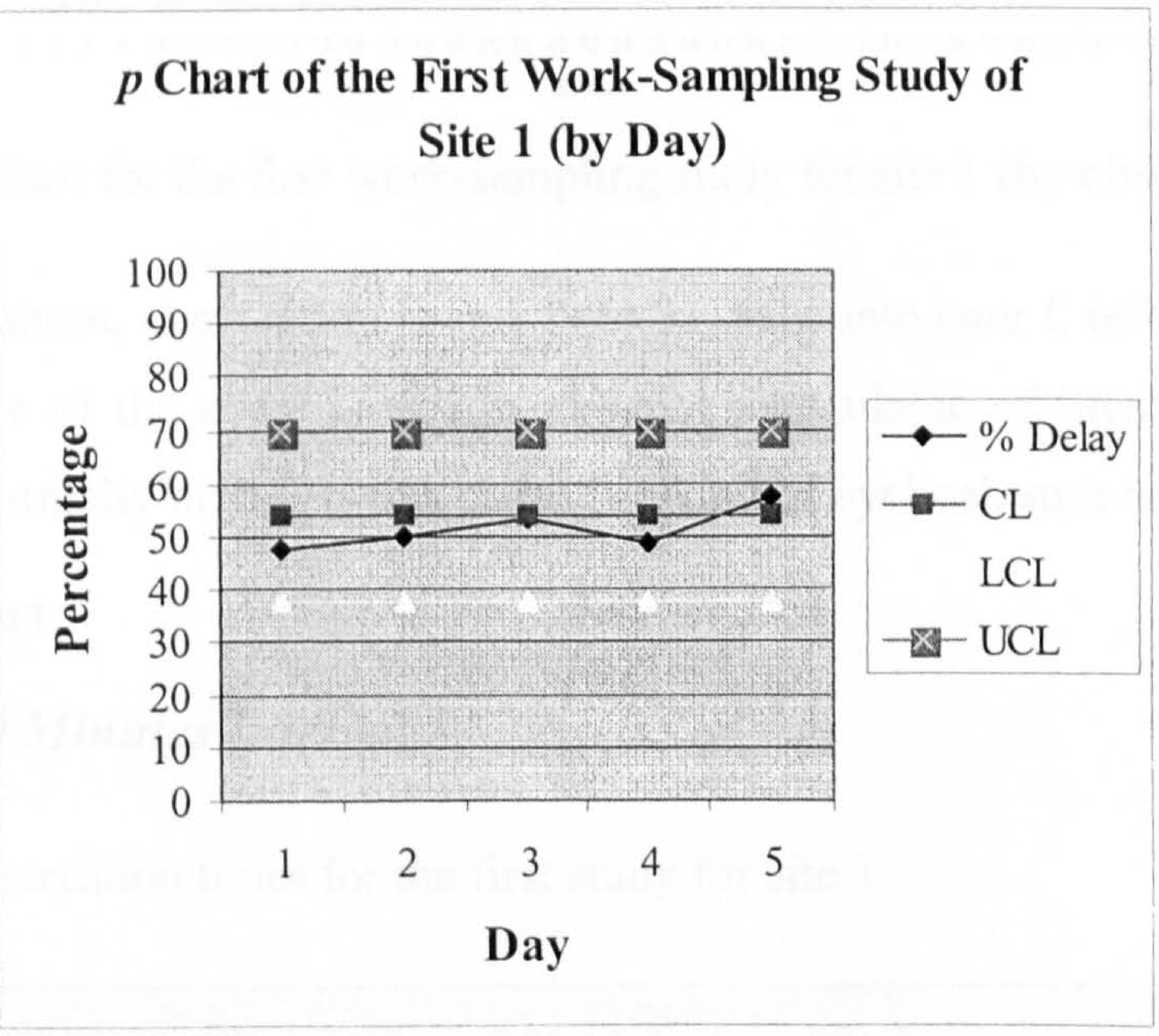


Figure D.1 *p* chart for the first work-sampling study for site 1 (by day)

D.1.1.1.2. Observation Round Basis

Table D.2 Delay percentage for the first study for site 1 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	40	40	70	60	40	40	50	40	50	40	40	70	40	40	50
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	70	60	40	60	40	50	60	70	40	40	60	60	50	70	70
Rounds of observation	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
% Delay	70	70	50	40	60	60	50	50	70	50	40	60	60	70	70

According to Table D.2 and equation 5, UCL = 100.00, CL = 53.78 and LCL = 6.48. Then, we plot % delay of a particular observation round on the *p* chart, as shown in Figure D.2.

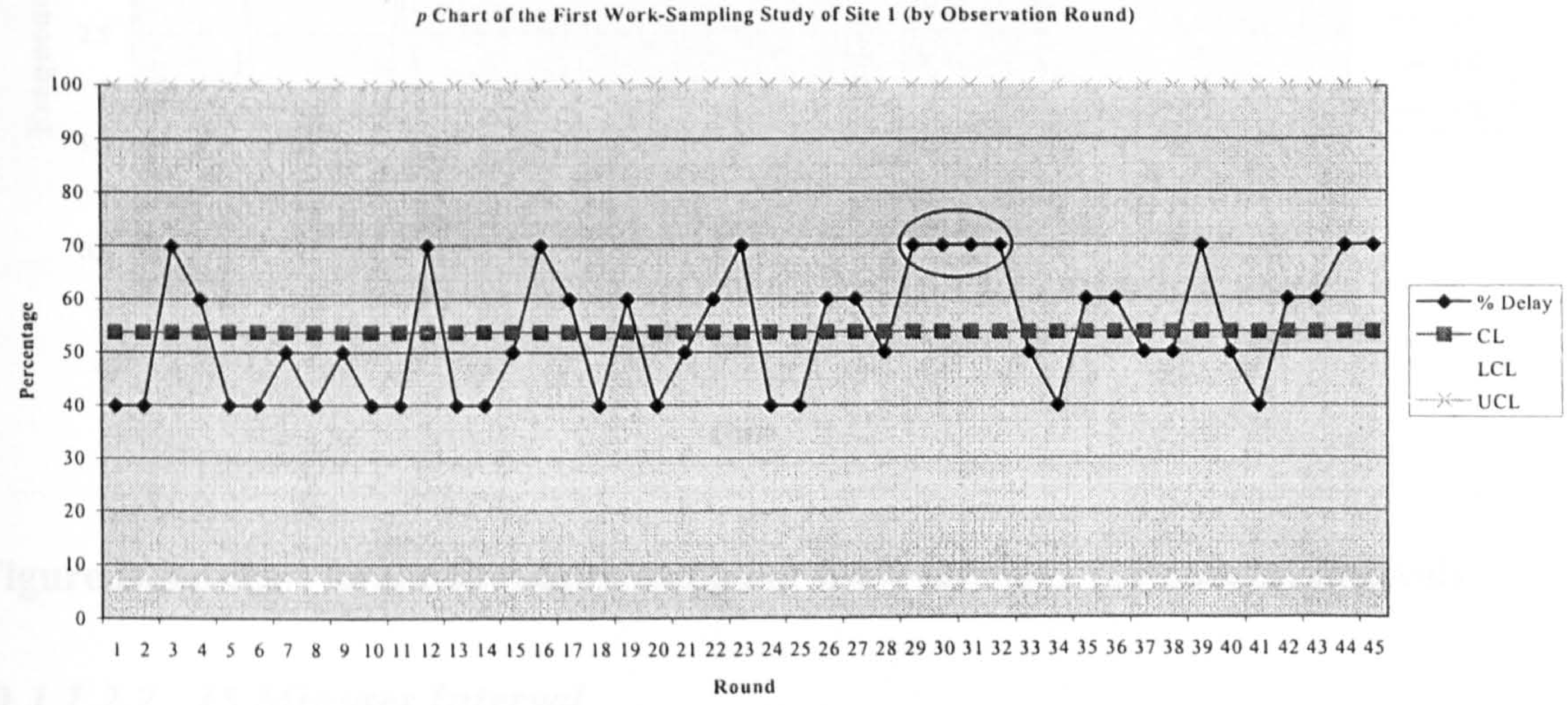


Figure D.2 *p* chart for the first work-sampling study for site 1 (by observation round)

The unusual pattern, observation round 29 to 31, falls into case f, referring to Figure 5.8. The cause of the event is due to material unavailable of fitter (mark/cut), so delays are abnormally high. As this cause is a kind of cyclical, so it is maintained.

D.1.1.2. *c* Chart

D.1.1.2.1. 10 Minutes Interval

Table D.3 Observation times for the first study for site 1

Observation date	Round								
	1	2	3	4	5	6	7	8	9
15/10/01	9.22	9.59	10.32	10.57	13.08	13.42	14.28	14.59	15.53
16/10/01	9.53	10.13	11.19	13.57	14.43	15.33	15.58	16.24	16.55
17/10/01	8.00	8.44	9.41	10.59	11.29	13.17	14.58	14.29	16.19
18/10/01	8.44	9.46	10.34	11.18	11.56	13.44	14.16	14.51	16.52
19/10/01	8.17	8.48	9.42	10.42	13.08	13.45	14.16	14.43	15.03

According to Table D.3 and equation 4, where $\bar{c} = 0.94$, UCL = 3.85, CL = 0.94 and LCL = 0.00, then we have the *c* chart, as shown in Figure D.3.

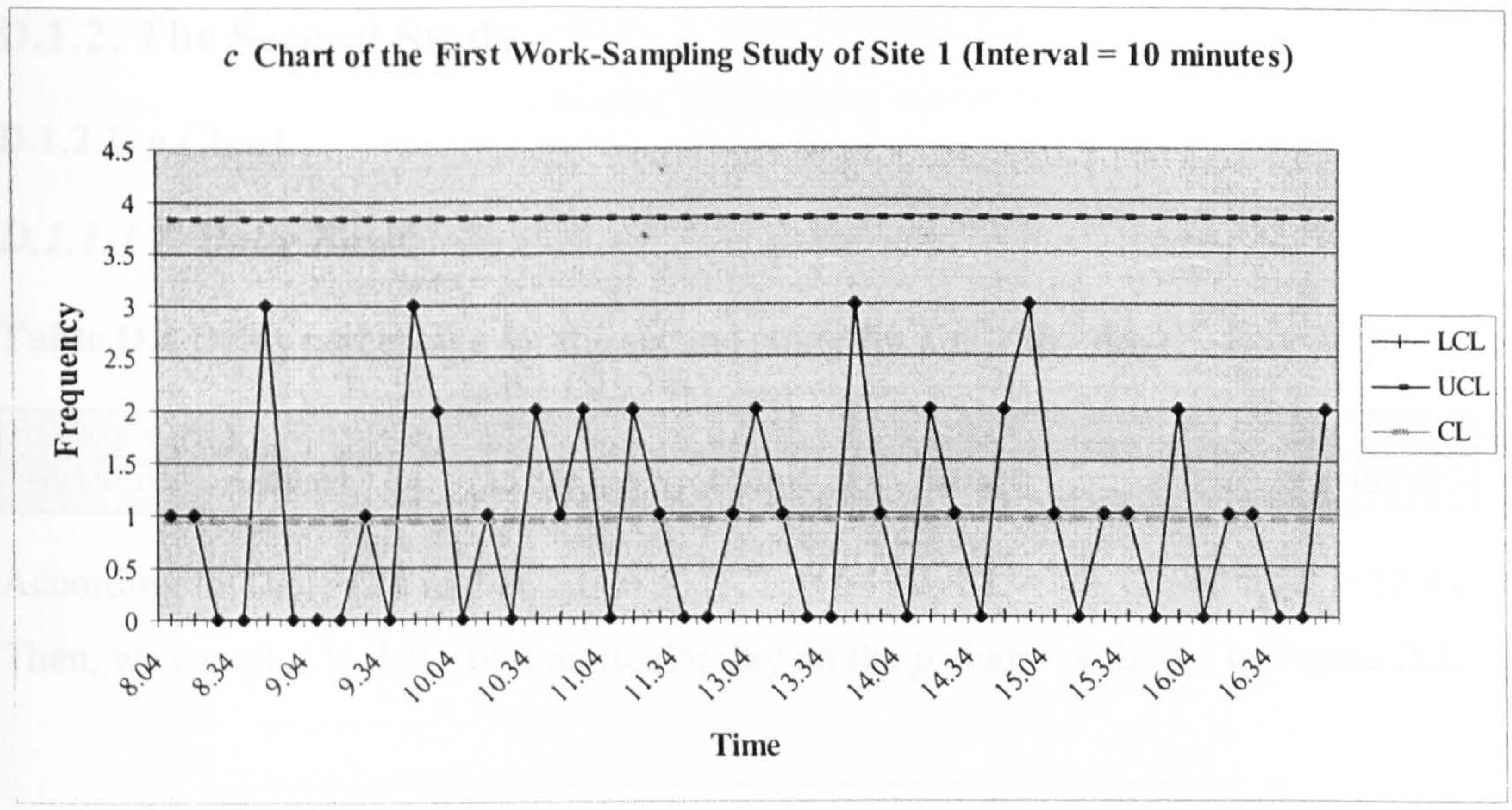


Figure D.3 *c* chart for the first work-sampling study for site 1 (10 minutes interval)

D.1.1.2.2. 15 Minutes Interval

According to Table D.3 and equation 4, where $\bar{c} = 1.41$, UCL = 4.98, CL = 1.41 and LCL = 0.00, then we have the *c* chart, as shown in Figure D.4.

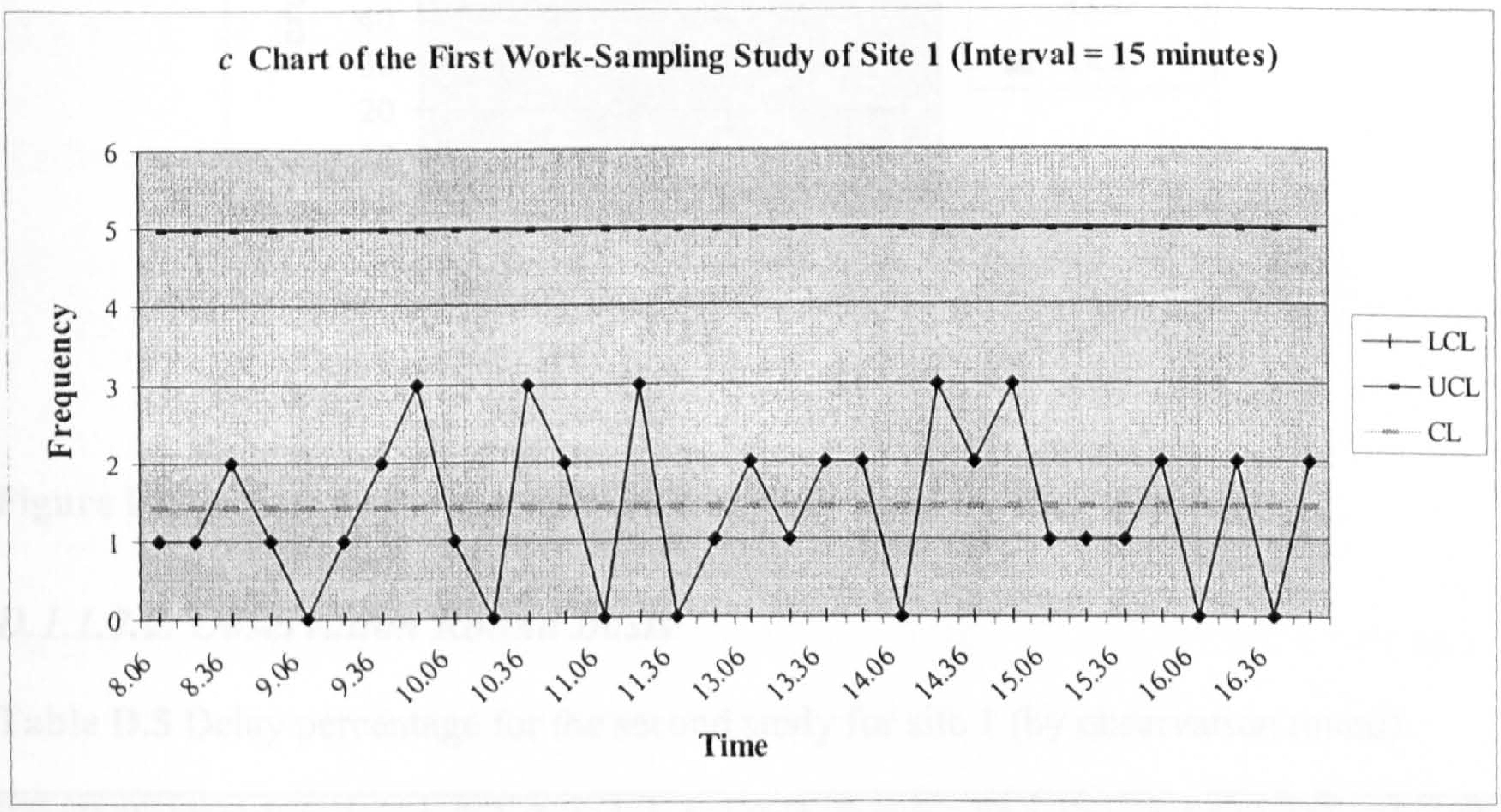


Figure D.4 *c* chart for the first work-sampling study for site 1 (15 minutes interval)

D.1.2. The Second Study

D.1.2.1. *p* Chart

D.1.1.2.1. Daily Basis

Table D.4 Delay percentage for the second study for site 1 (by day)

Day	1	2	3	4	5	$\bar{p}$
% Delay	50.00	45.56	47.78	50.00	47.78	48.22

According to Table D.4 and equation 5, UCL = 64.03, CL = 48.22 and LCL = 32.41. Then, we can plot % delay of a particular day on the *p* chart, as shown in Figure D.5.

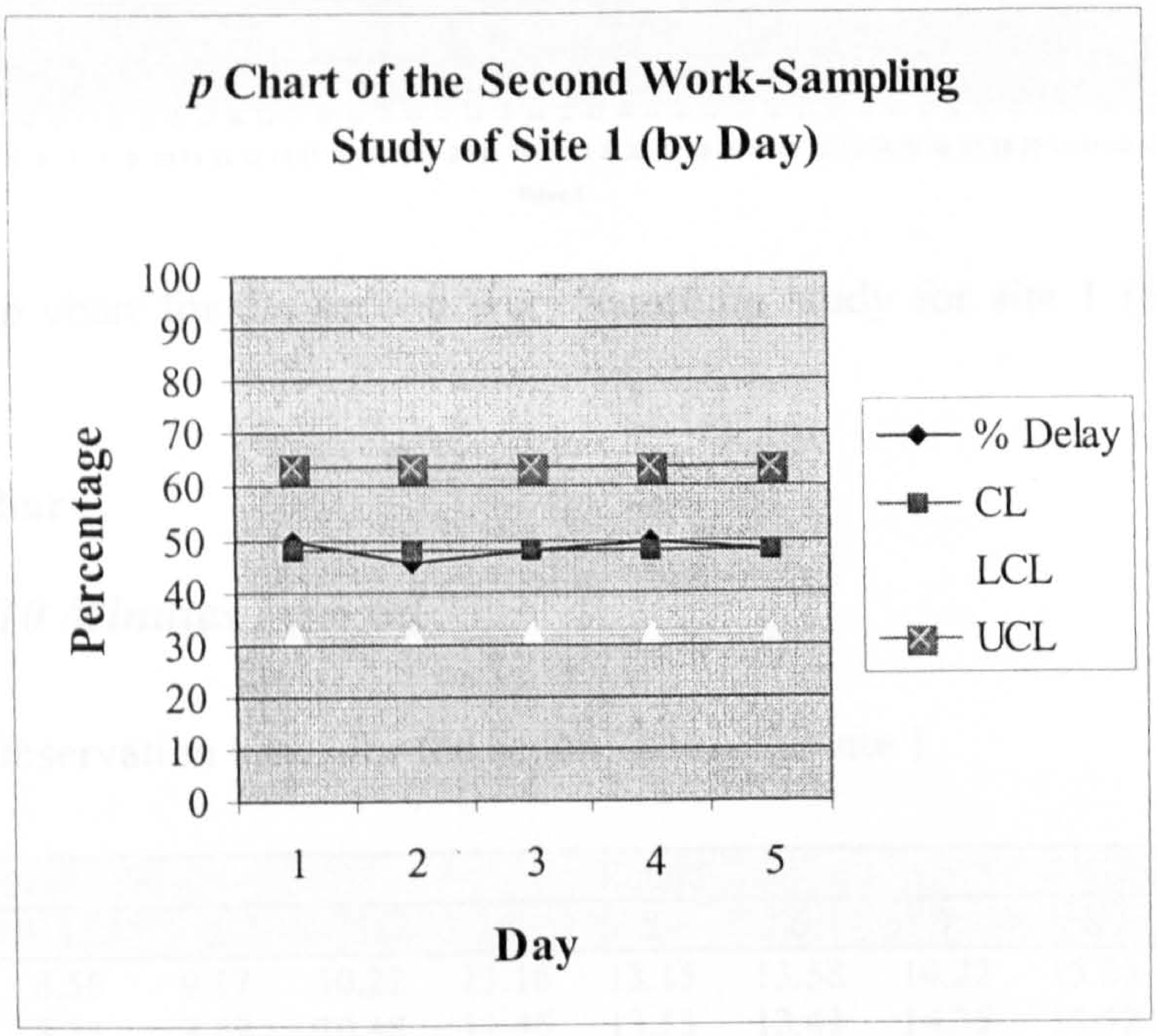


Figure D.5 *p* chart for the second work-sampling study for site 1 (by day)

D.1.1.2.2. Observation Round Basis

Table D.5 Delay percentage for the second study for site 1 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	40	30	70	60	50	70	40	50	40	30	50	50	80	30	40
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	40	50	40	30	50	50	40	90	50	40	40	40	30	60	40
Rounds of observation	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
% Delay	50	90	50	40	30	60	30	30	40	50	20	60	70	70	60

According to Table D.5 and equation 5, UCL = 95.62, CL = 48.22 and LCL = 0.82. Then, we plot % delay of a particular observation round on the p chart, as shown in Figure D.6.

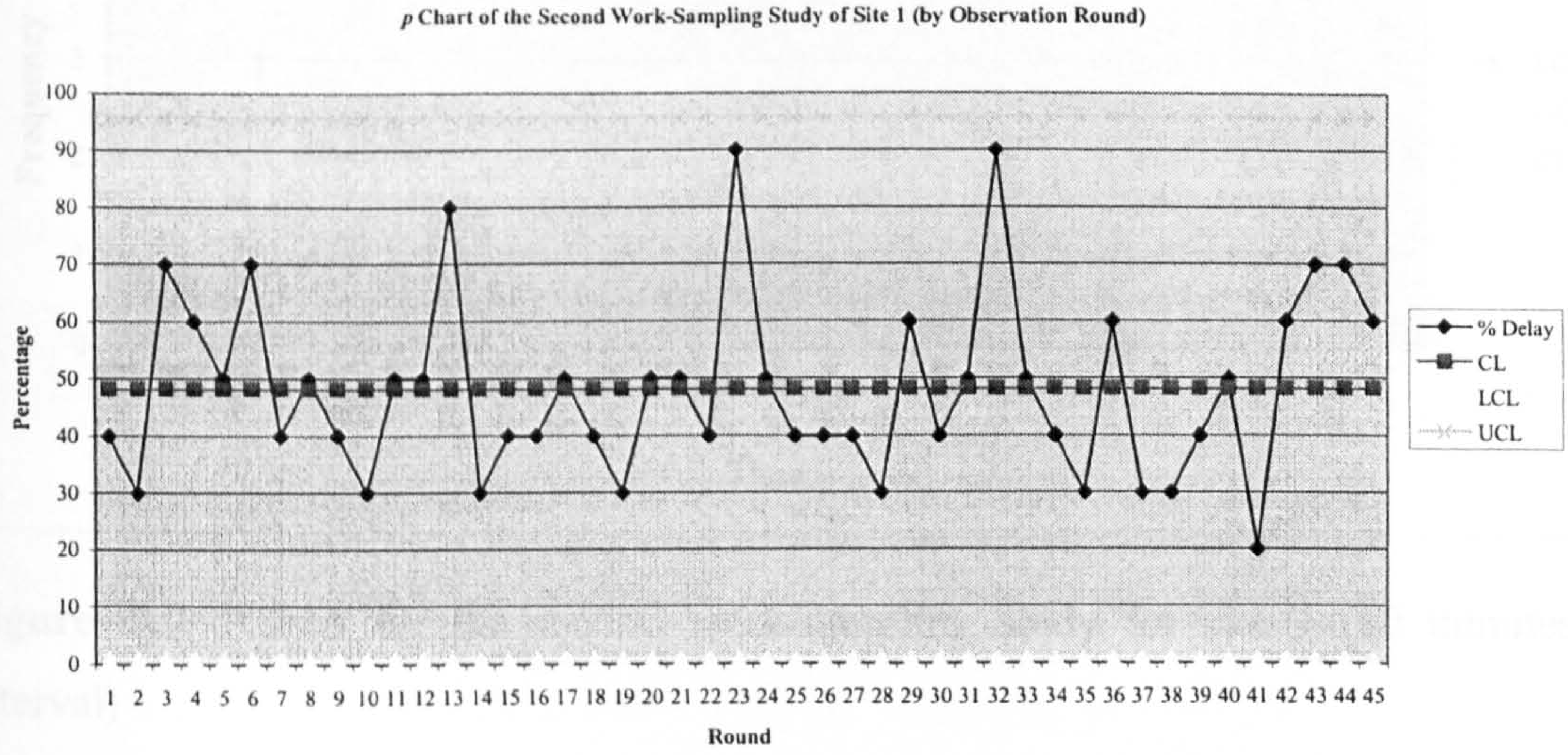


Figure D.6 p chart for the second work-sampling study for site 1 (by observation round)

D.1.2.2. *c* Chart

D.1.2.2.1. 10 Minutes Interval

Table H.6 Observation times for the second study for site 1

Observation date	Round								
	1	2	3	4	5	6	7	8	9
7/11/01	8.56	9.17	10.22	11.16	13.15	13.58	14.22	15.25	15.52
8/11/01	8.34	9.29	10.48	11.46	13.13	13.41	14.35	15.52	16.27
9/11/01	8.27	8.50	10.02	11.23	11.51	14.44	15.07	16.01	16.25
10/11/01	8.18	9.29	10.37	11.19	11.45	13.19	13.48	14.40	15.14
11/11/01	8.13	8.54	9.22	9.44	10.07	10.40	13.00	15.15	16.30

According to Table D.6 and equation 4, where $\bar{c} = 0.94$, UCL = 3.85, CL = 0.94 and LCL = 0.00, then we have the c chart, as shown in Figure D.7.

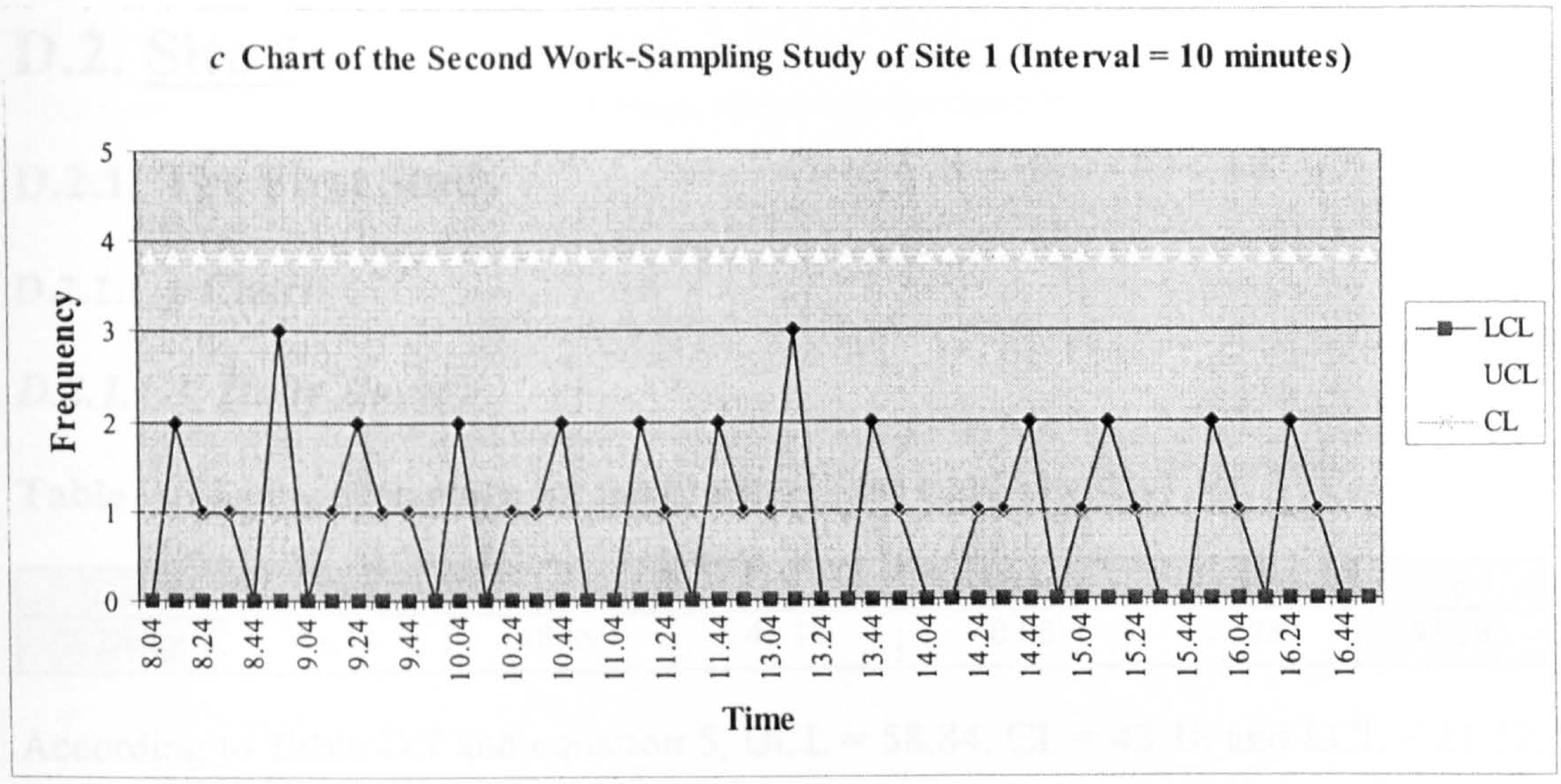


Figure D.7 *c* chart for the second work-sampling study for site 1 (10 minutes interval)

D.1.1.2.2. 15 Minutes Interval

According to Table D.6 and equation 4, where $\bar{c} = 1.41$, UCL = 4.98, CL = 1.41 and LCL = 0.00, then we have the *c* chart, as shown in Figure D.8.

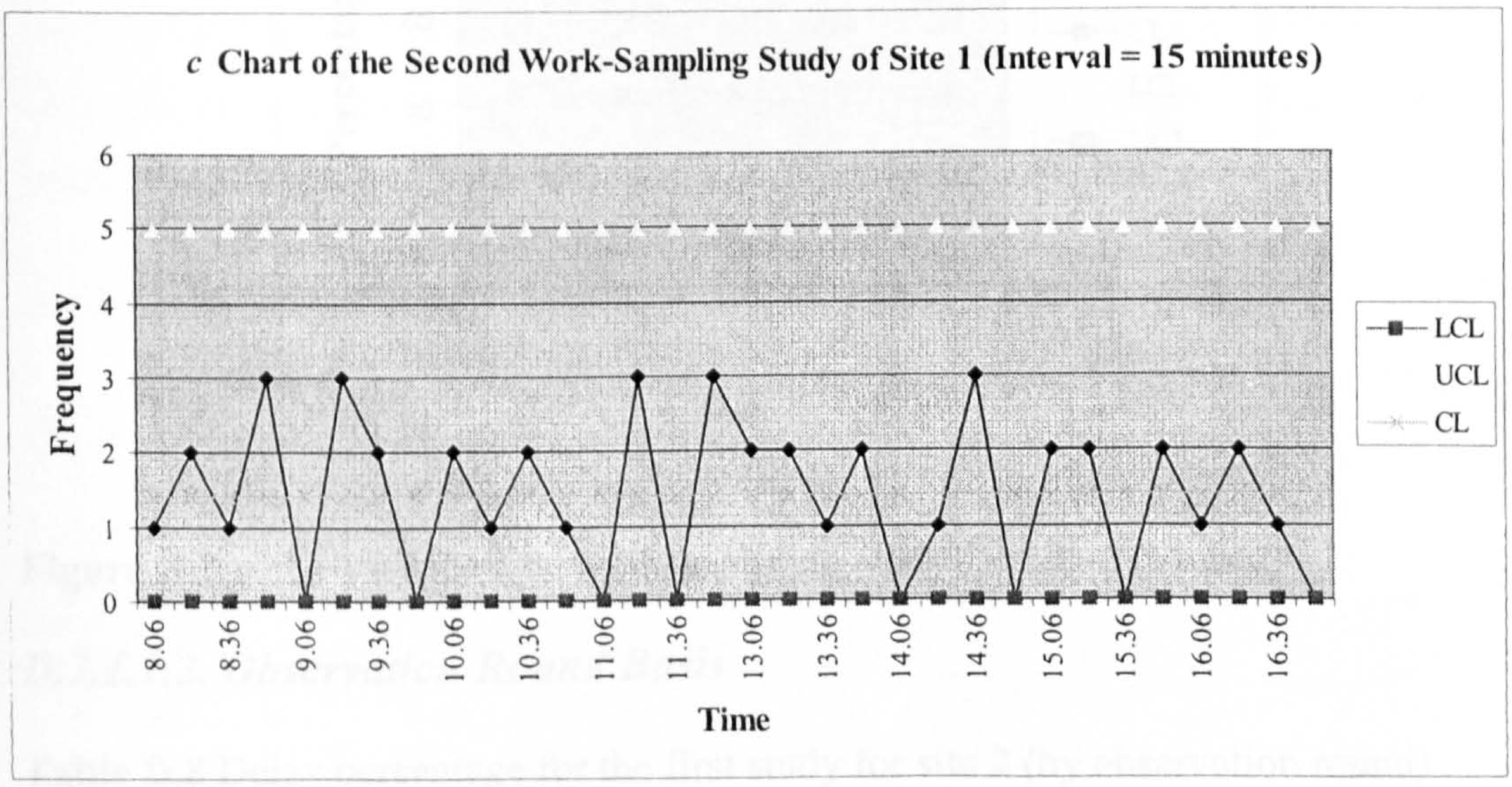


Figure D.8 *c* chart for the second work-sampling study for site 1 (15 minutes interval)

D.2. Site 2

D.2.1. The First Study

D.2.1.1. *p* Chart

D.2.1.1.1. Daily Basis

Table D.7 Delay percentage for the first study for site 2 (by day)

Day	1	2	3	4	5	$\bar{p}$
% Delay	44.44	48.89	41.11	40.00	47.78	43.18

According to Table D.7 and equation 5, UCL = 58.84, CL = 43.18 and LCL = 21.52. Then, we can plot % delay of a particular day on the *p* chart, as shown in Figure D.9.

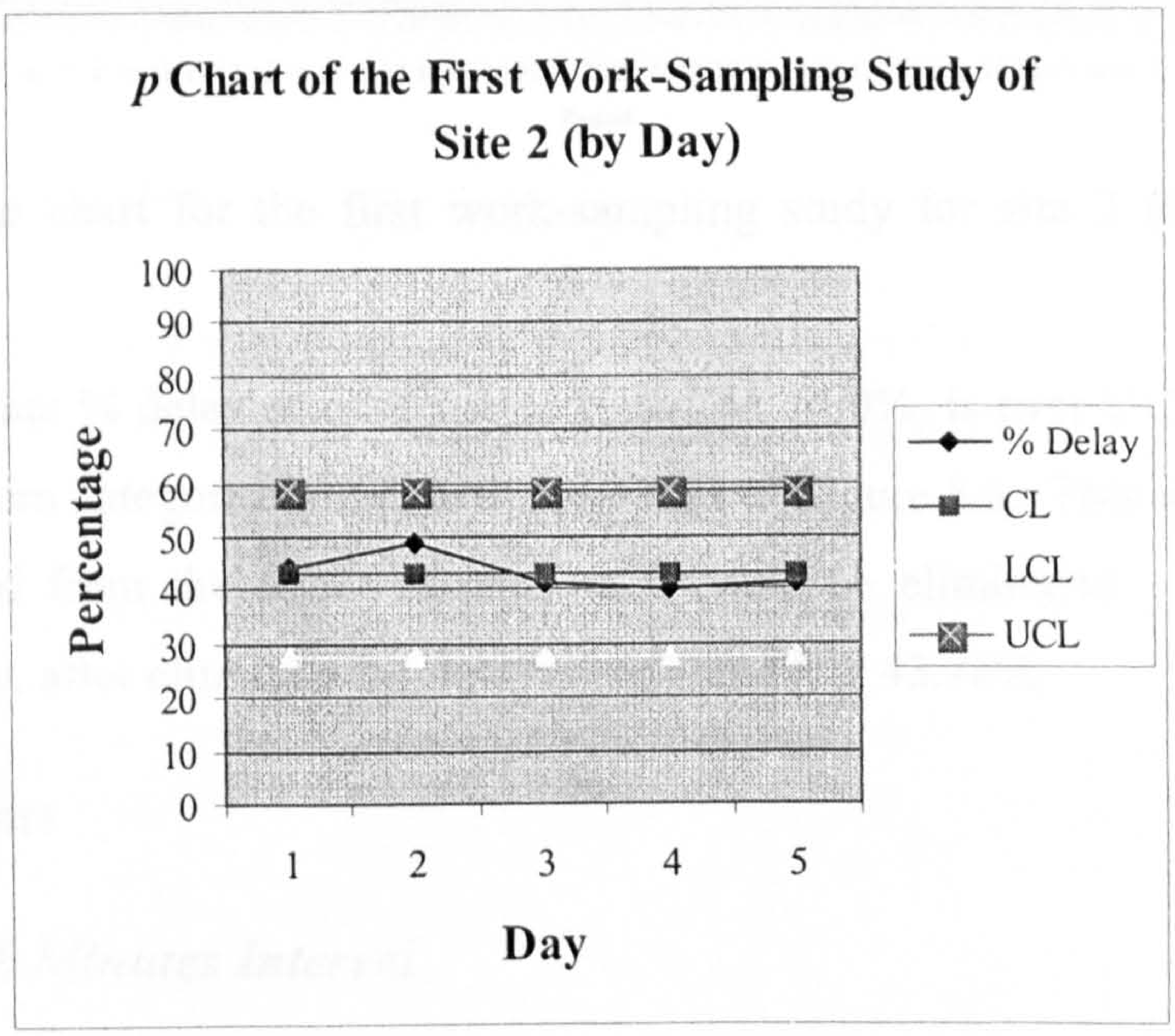


Figure D.9 *p* chart for the first work-sampling study for site 2 (by day)

D.2.1.1.2. Observation Round Basis

Table D.8 Delay percentage for the first study for site 2 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	50	50	60	40	20	40	60	40	40	40	50	70	40	70	30
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	60	40	40	40	60	20	40	30	40	50	50	40	30	50	50
Rounds of observation	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
% Delay	40	50	60	40	30	10	40	60	40	50	50	20	40	100	30

According to Table D.8 and equation 5, UCL = 90.17, CL = 43.18 and LCL = 0.00. Then, we plot % delay of a particular observation round on the *p* chart, as shown in Figure D.10.

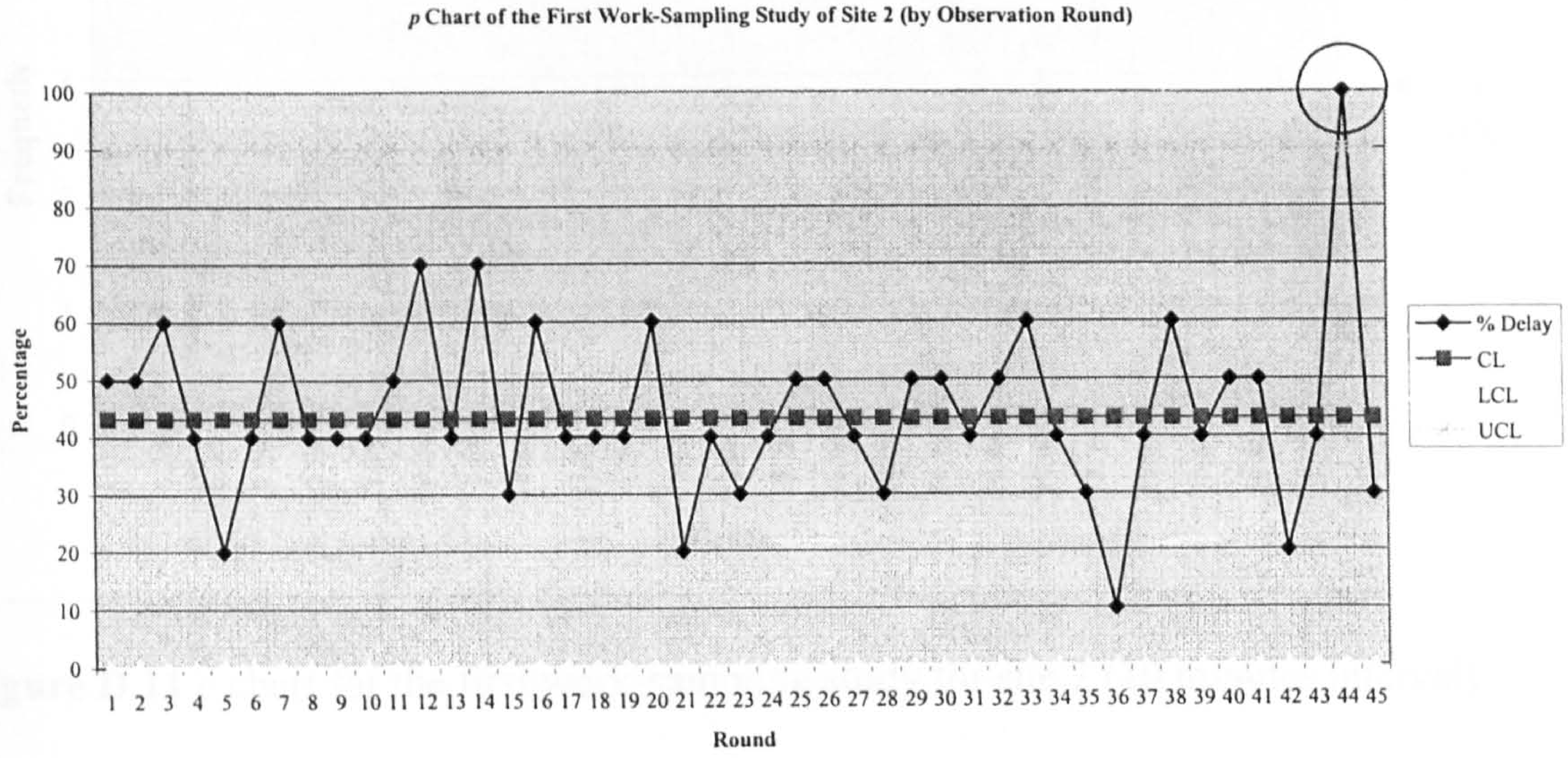


Figure D.10 *p* chart for the first work-sampling study for site 2 (by observation round)

It is obvious that % delay of observation round 44, 100%, is over UCL, which is an abnormal pattern categorised in case a, according to Figure 5.8. This irregularly high delay occurred from the effect of rain, so it could be eliminated. Therefore, the actual % delay, after eliminate the delay of this study, is 43.18%.

D.2.1.2. *c* Chart

D.2.1.2.1. 10 Minutes Interval

Table D.9 Observation times for the first study for site 2

Observation date	Round								
	1	2	3	4	5	6	7	8	9
31/10/01	8.45	9.19	9.42	9.59	10.44	11.36	13.08	14.37	14.59
1/11/01	10.15	10.36	11.27	11.42	14.18	15.08	15.24	16.17	16.53
2/11/01	8.22	8.49	10.49	11.01	13.44	14.32	15.06	16.13	16.38
3/11/01	8.18	9.58	10.11	10.23	13.03	14.48	15.07	15.23	15.37
4/11/01	9.28	10.16	10.34	11.04	13.01	13.18	13.42	15.44	16.05

According to Table D.9 and equation 4, where $\bar{c} = 0.94$, UCL = 3.85, CL = 0.94 and LCL = 0.00, then we have the *c* chart, as shown on Figure D.11.

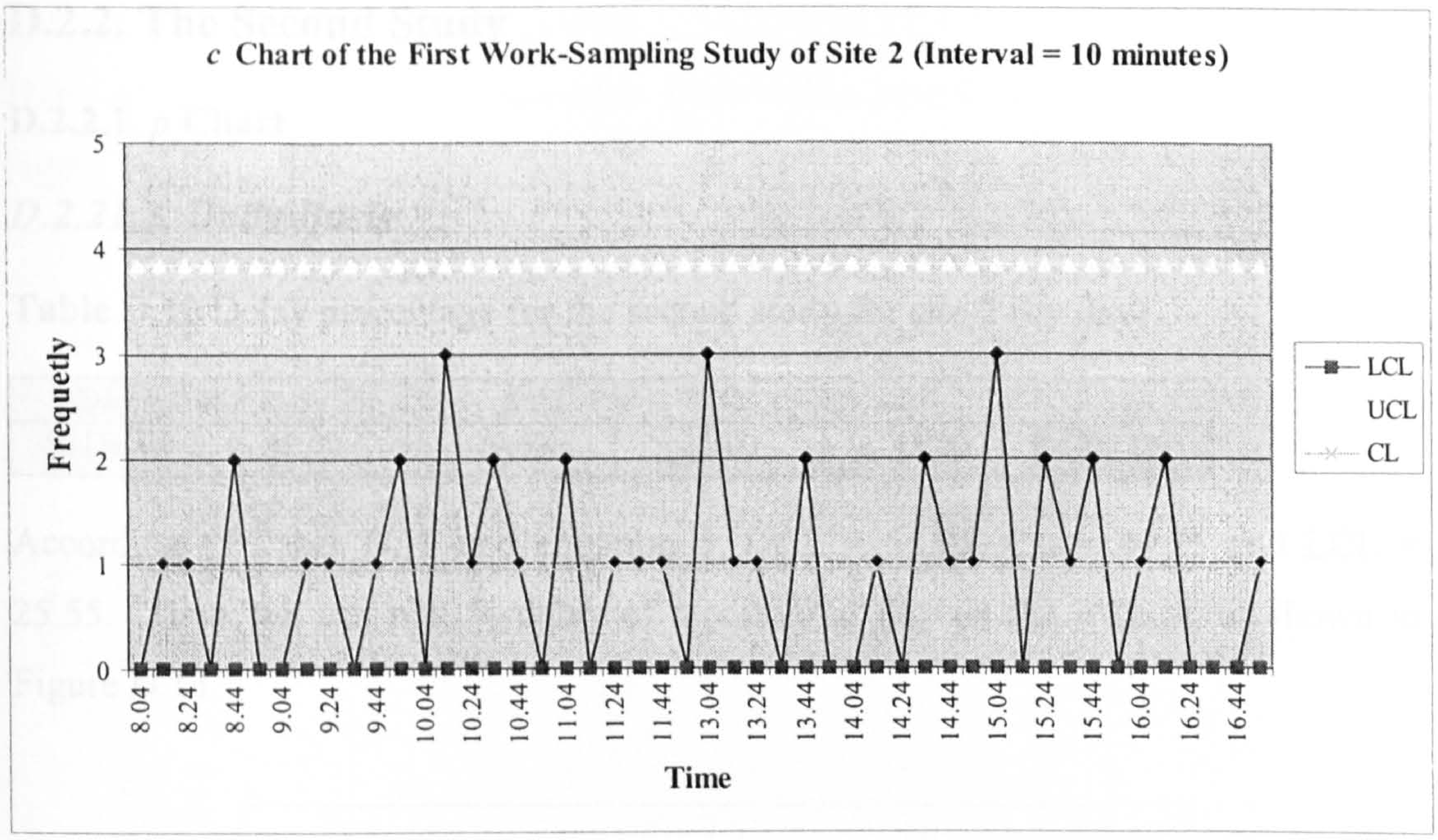


Figure D.11 *c* chart for the first work-sampling study for site 2 (10 minutes interval)

D.2.1.2.2. 15 Minutes Interval

According to Table D.9 and equation 4, where $\bar{c} = 1.41$, UCL = 4.98, CL = 1.41 and LCL = 0.00, then we have the *c* chart, as shown on Figure D.12.

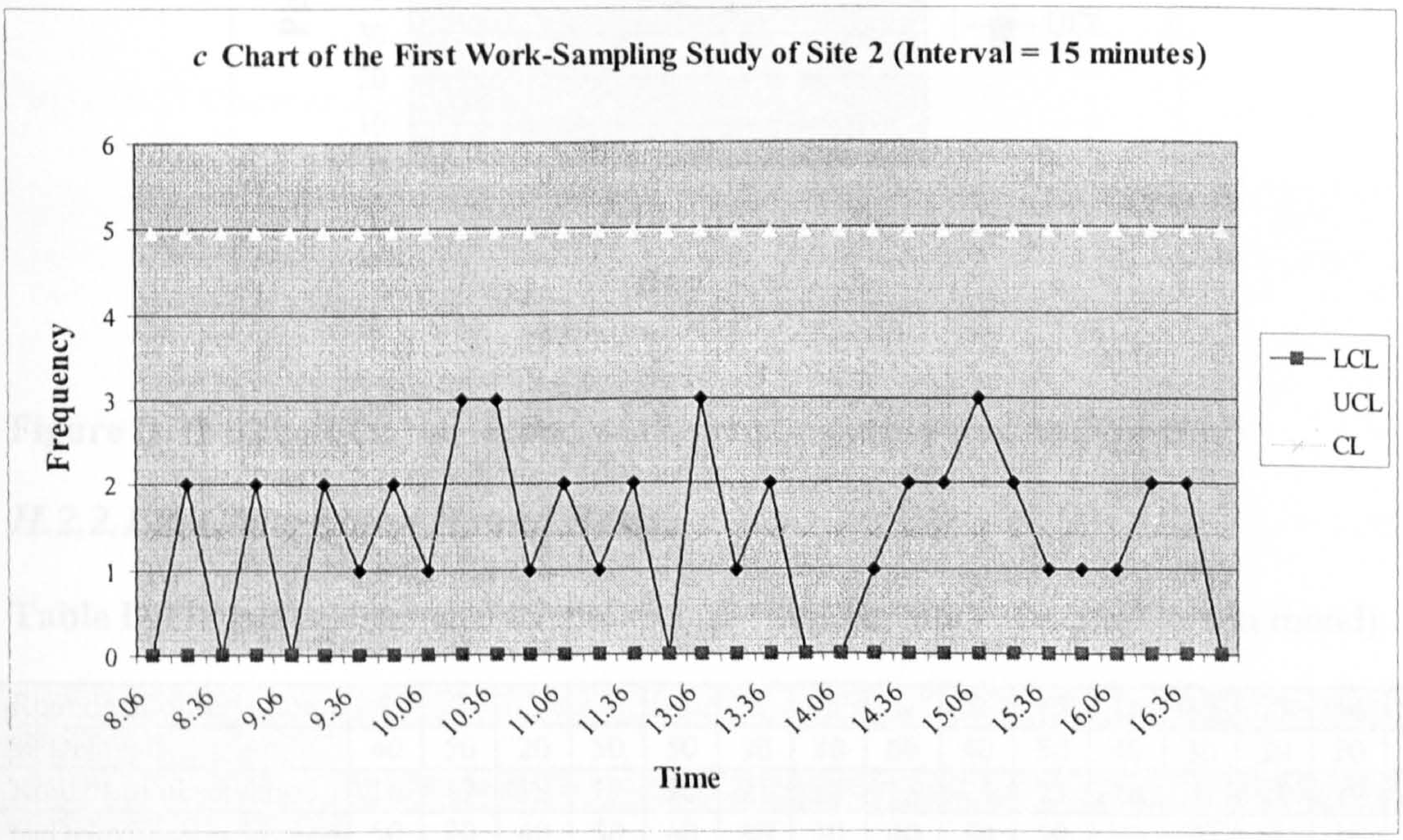


Figure D.12 *c* chart for the first work-sampling study for site 2 (15 minutes interval)

D.2.2. The Second Study

D.2.2.1. *p* Chart

D.2.21.1. Daily Basis

Table D.10 Delay percentage for the second study for site 2 (by day)

Day	1	2	3	4	$\bar{p}$
% Delay	42.00	39.00	35.00	45.00	40.25

According to Table D.10 and equation 5, UCL = 54.95, CL = 40.25 and LCL = 25.55. Then, we can plot % delay of a particular day on the *p* chart, as shown in Figure D.13.

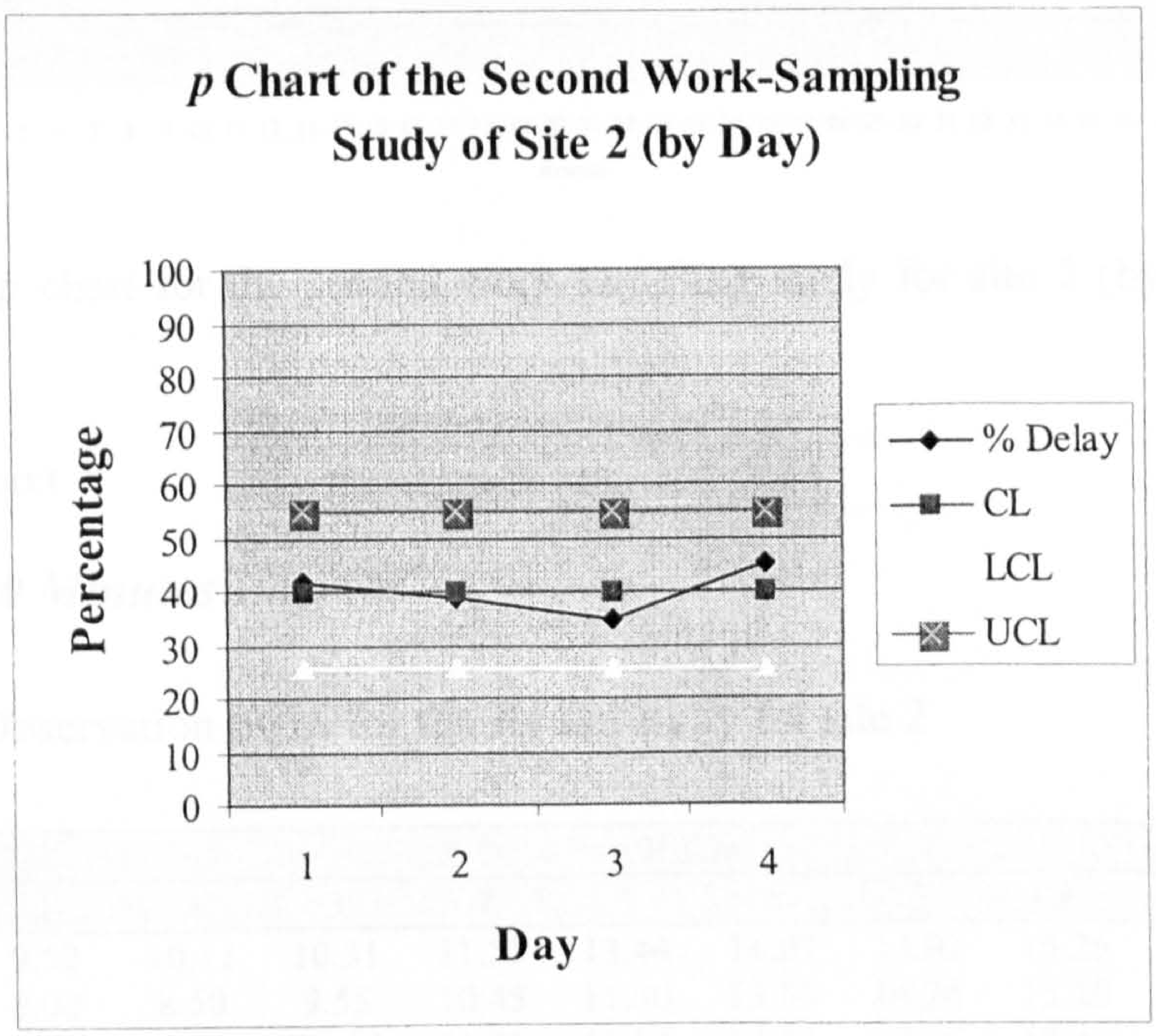


Figure D.13 *p* chart for the second work-sampling study for site 2 (by day)

H.2.2.1.2. Observation Round Basis

Table D.11 Delay percentage for the second study for site 2 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	40	50	20	50	50	30	30	60	40	50	40	30	50	20	30
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	50	20	40	50	60	40	30	40	40	50	20	20	40	10	60
Rounds of observation	31	32	33	34	35	36	37	38	39	40					
% Delay	40	50	50	30	60	40	50	60	20	50					

According to Table D.11 and equation 5, UCL = 86.77, CL = 40.25 and LCL = 0.00 Then, we plot % delay of a particular observation round on the *p* chart, as shown Figure D.14.

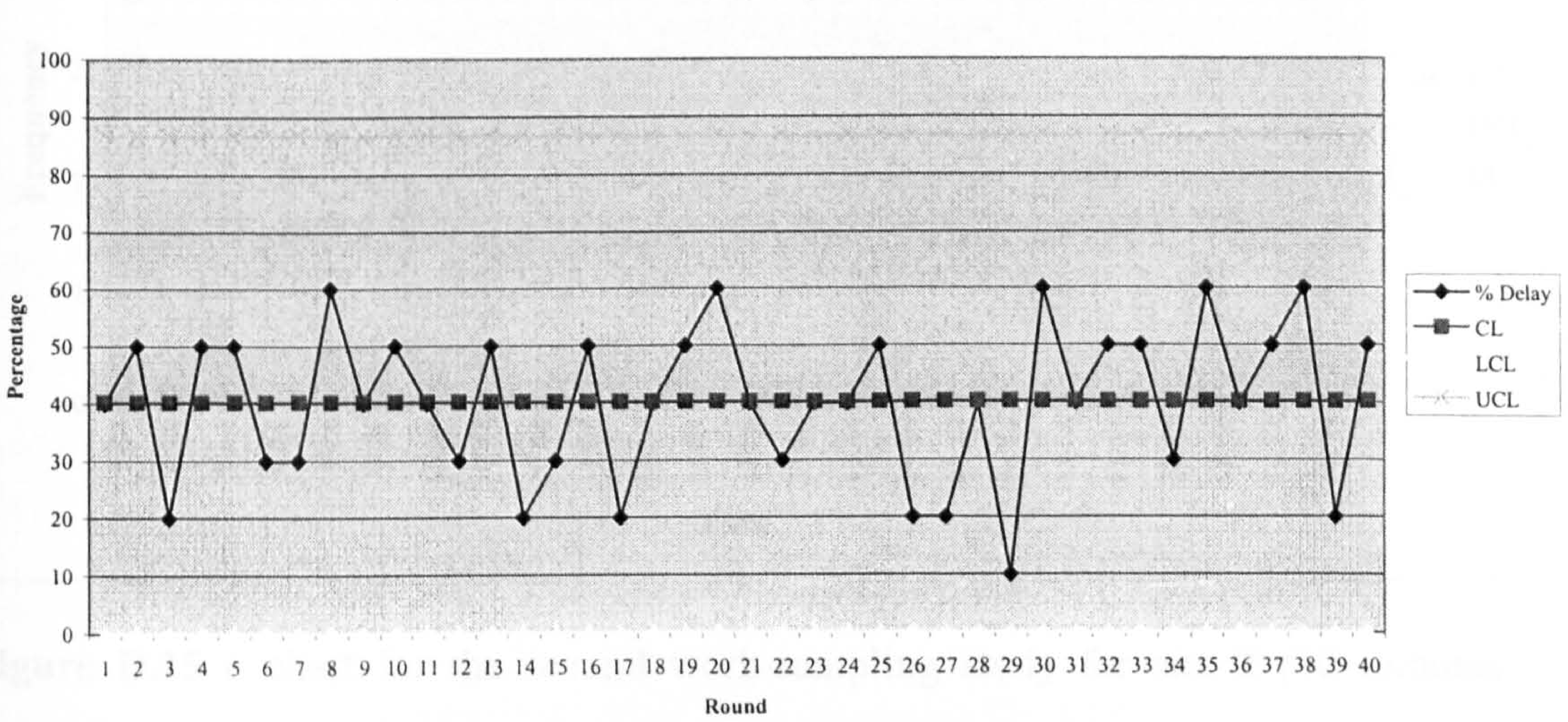


Figure D.14 *p* chart for the second work-sampling study for site 2 (by observation round)

D.2.2.2. *c* Chart

D.2.2.2.1. 10 Minutes Interval

Table D.12 Observation times for the second study for site 2

Observation date	Round									
	1	2	3	4	5	6	7	8	9	10
14/11/01	9.52	10.11	10.31	11.55	13.44	14.07	15.02	15.26	15.48	15.56
15/11/01	8.00	8.50	9.55	10.45	11.30	13.50	14.26	15.20	15.37	16.10
16/11/01	8.10	8.55	10.46	11.36	11.55	14.04	14.56	15.49	16.02	16.29
17/11/01	8.19	8.33	8.59	9.13	10.23	10.49	11.29	13.04	14.03	14.27

According to Table D.12 and equation 4, where $\bar{c} = 0.83$, UCL = 3.57, CL = 0.83 and LCL = 0.00, then we have the *c* chart, as shown Figure D.15.

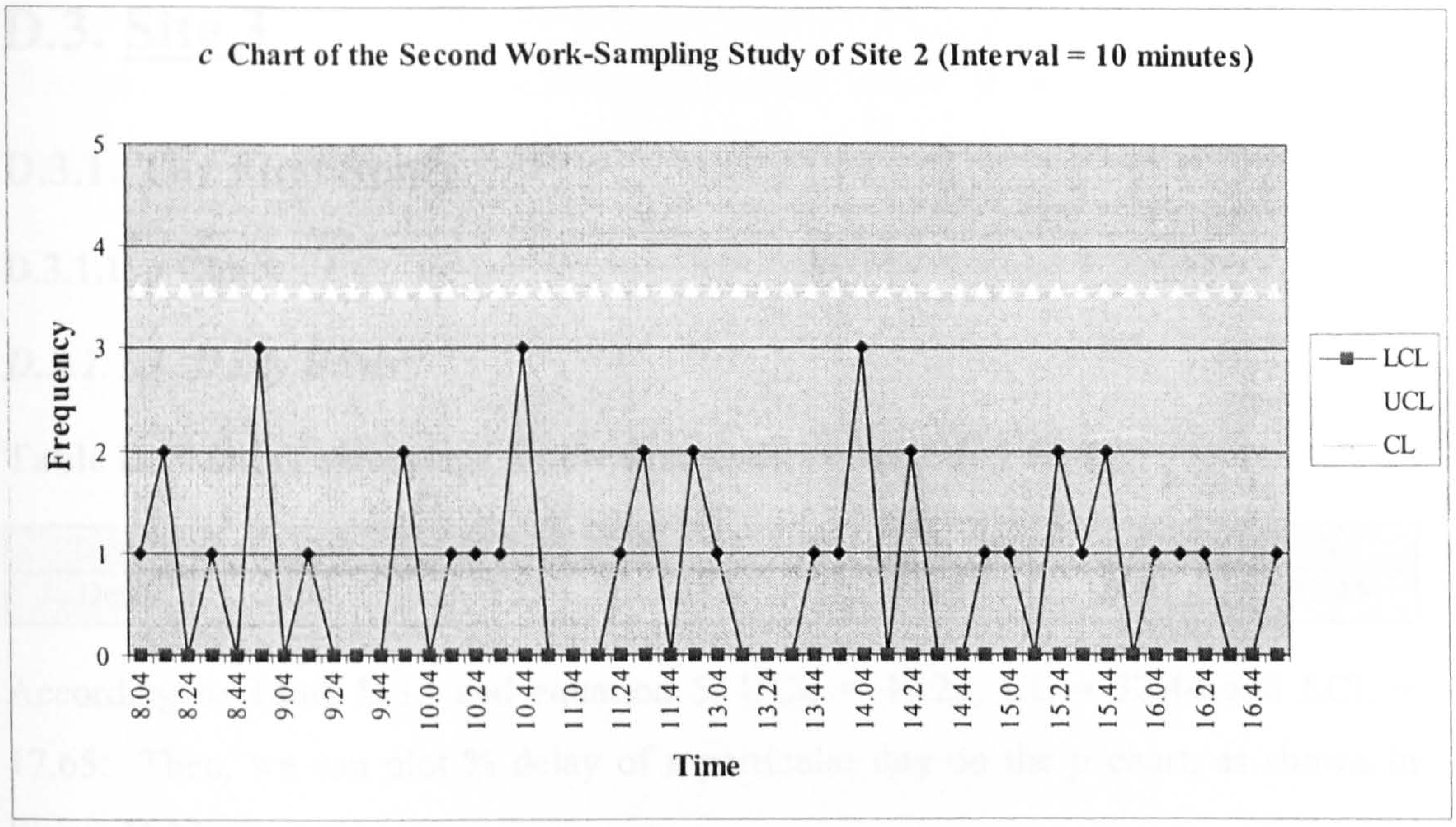


Figure D.15 *c* chart for the second work-sampling study for site 2 (10 minutes interval)

D.2.2.2.2. 15 Minutes Interval

According to Table D.12 and equation 4, where $\bar{c}$ = 1.25, UCL = 4.60, CL = 1.25 and LCL = 0.00, then we have the *c* chart, as shown Figure D.16.

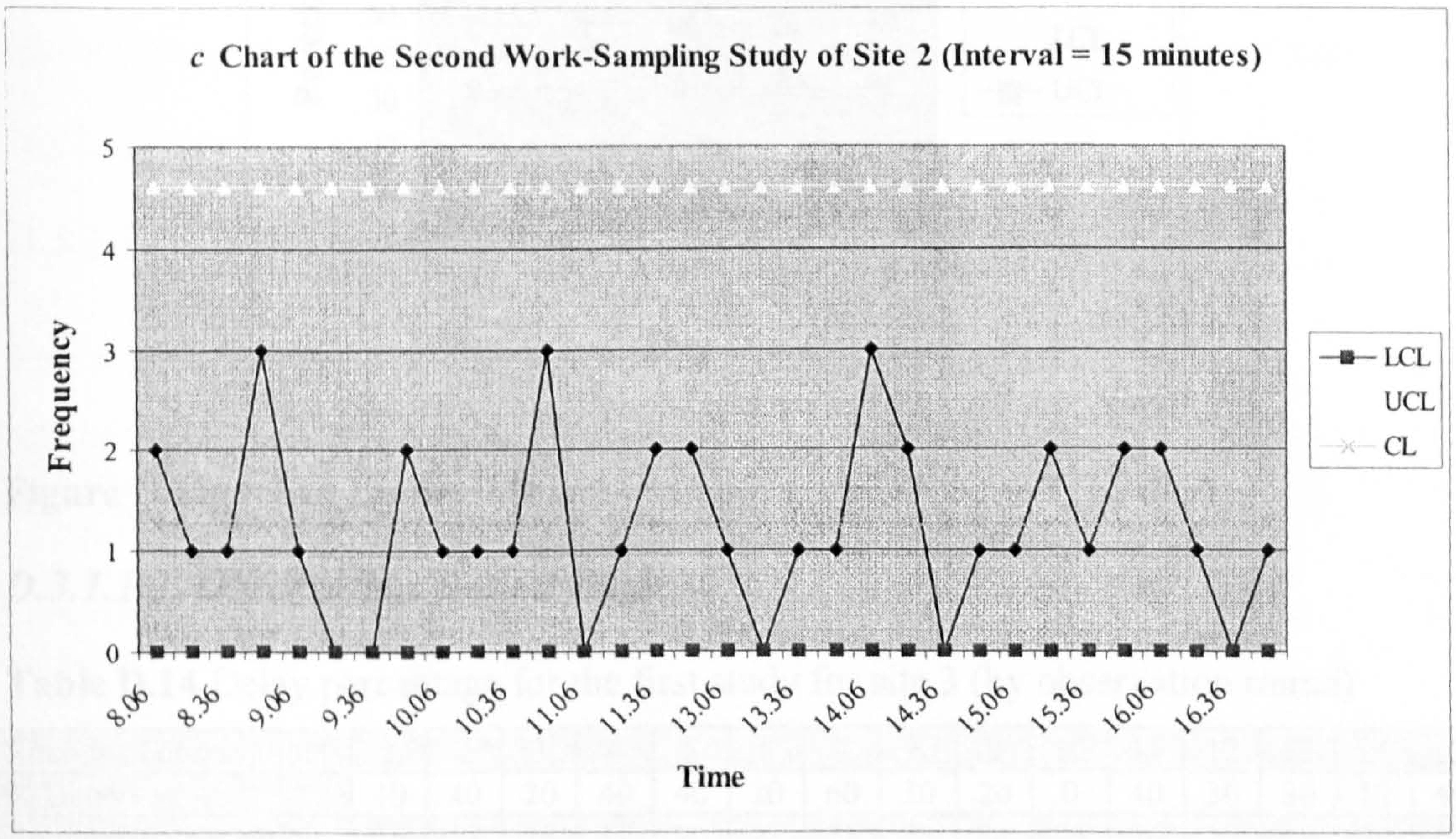


Figure D.16 *c* chart for the second work-sampling study for site 2 (15 minutes interval)

D.3. Site 3

D.3.1. The First Study

D.3.1.1. *p* Chart

D.3.1.1.1. Daily Basis

Table D.13 Delay percentage for the first study for site 3 (by day)

Day	1	2	3	4	5	$\bar{p}$
% Delay	31.11	33.33	35.56	35.56	26.67	32.44

According to Table D.13 and equation 5, UCL = 47.23, CL = 32.44 and LCL = 17.65. Then, we can plot % delay of a particular day on the *p* chart, as shown in Figure D.17.

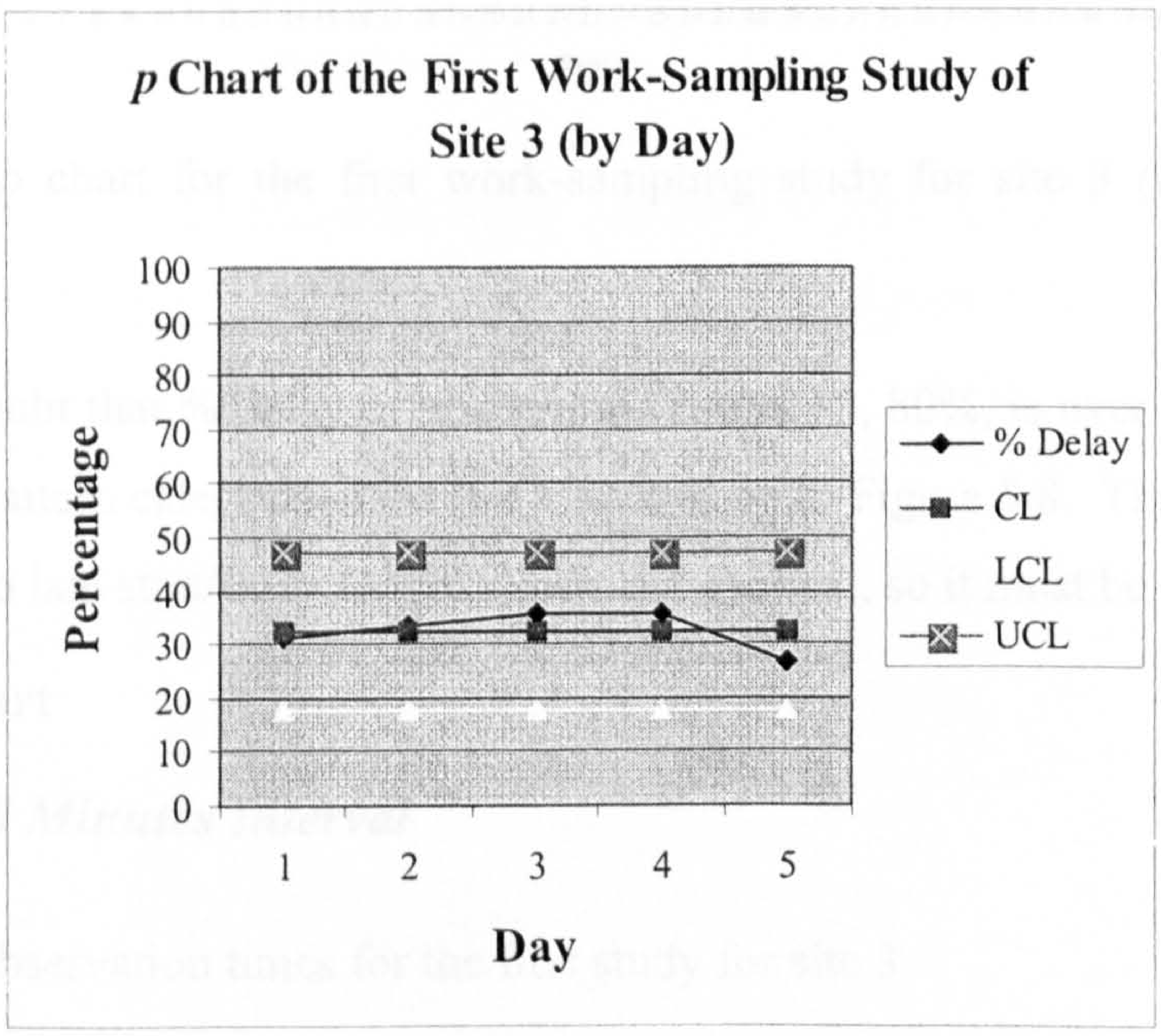


Figure D.17 *p* chart for the first work-sampling study for site 3 (by day)

D.3.1.1.2. Observation Round Basis

Table D.14 Delay percentage for the first study for site 3 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	10	40	20	40	40	20	60	30	20	0	40	30	80	10	40
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	50	10	40	20	40	20	60	30	40	60	20	30	30	0	50
Rounds of observation	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
% Delay	20	30	40	20	60	70	0	20	40	20	30	20	10	50	50

According to Table D.14 and equation 5, UCL = 76.84, CL = 32.44 and LCL = 0.00 Then, we plot % delay of a particular observation round on the p chart, as shown in Figure D.18.

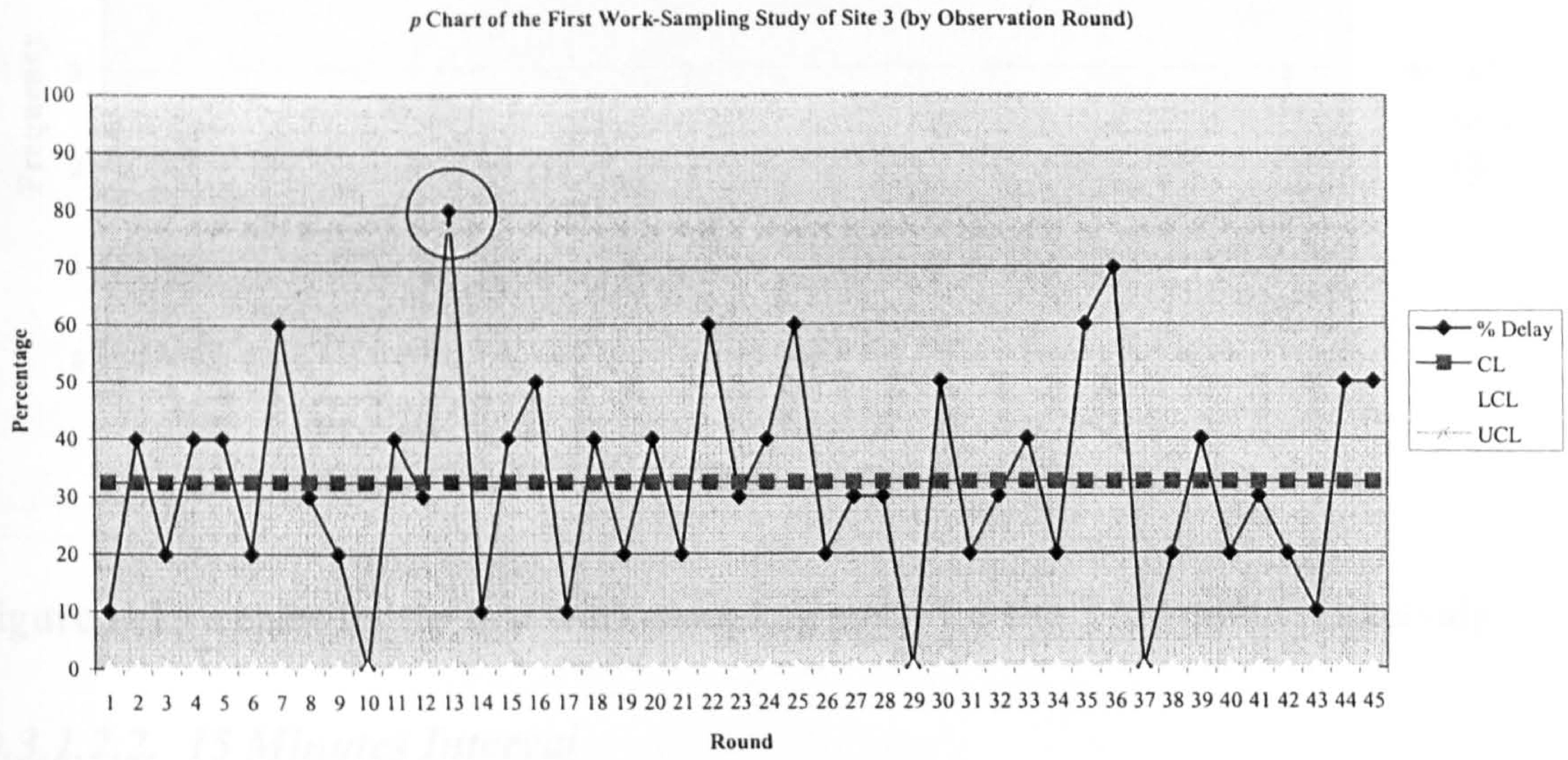


Figure H.18 p chart for the first work-sampling study for site 3 (by observation round)

There is no doubt that % delay of observation round 13, 80%, is over UCL, which is an abnormal pattern categorised in case a, according to Figure 5.8. This unusual high idle was due to late start/early finish, which is a cyclical, so it must be maintained.

D.3.1.2. *c* Chart

D.3.1.2.1. 10 Minutes Interval

Table D.15 Observation times for the first study for site 3

Observation date	Round								
	1	2	3	4	5	6	7	8	9
26/11/01	9.16	9.33	10.46	13.10	13.29	14.00	14.47	15.55	16.34
27/11/01	8.01	8.45	9.03	9.59	10.25	13.38	14.16	15.29	16.39
28/11/01	9.05	9.47	10.29	11.21	11.44	13.20	14.49	15.14	16.10
29/11/01	9.34	10.23	10.47	11.17	11.48	14.30	15.17	16.02	16.31
30/11/01	8.06	8.49	9.40	10.16	11.41	13.06	13.57	14.18	15.00

According to Table D.15 and equation 4, where $\bar{c} = 0.94$, UCL = 3.85, CL = 0.94 and LCL = 0.00, then we have the c chart, as shown on Figure D.19.

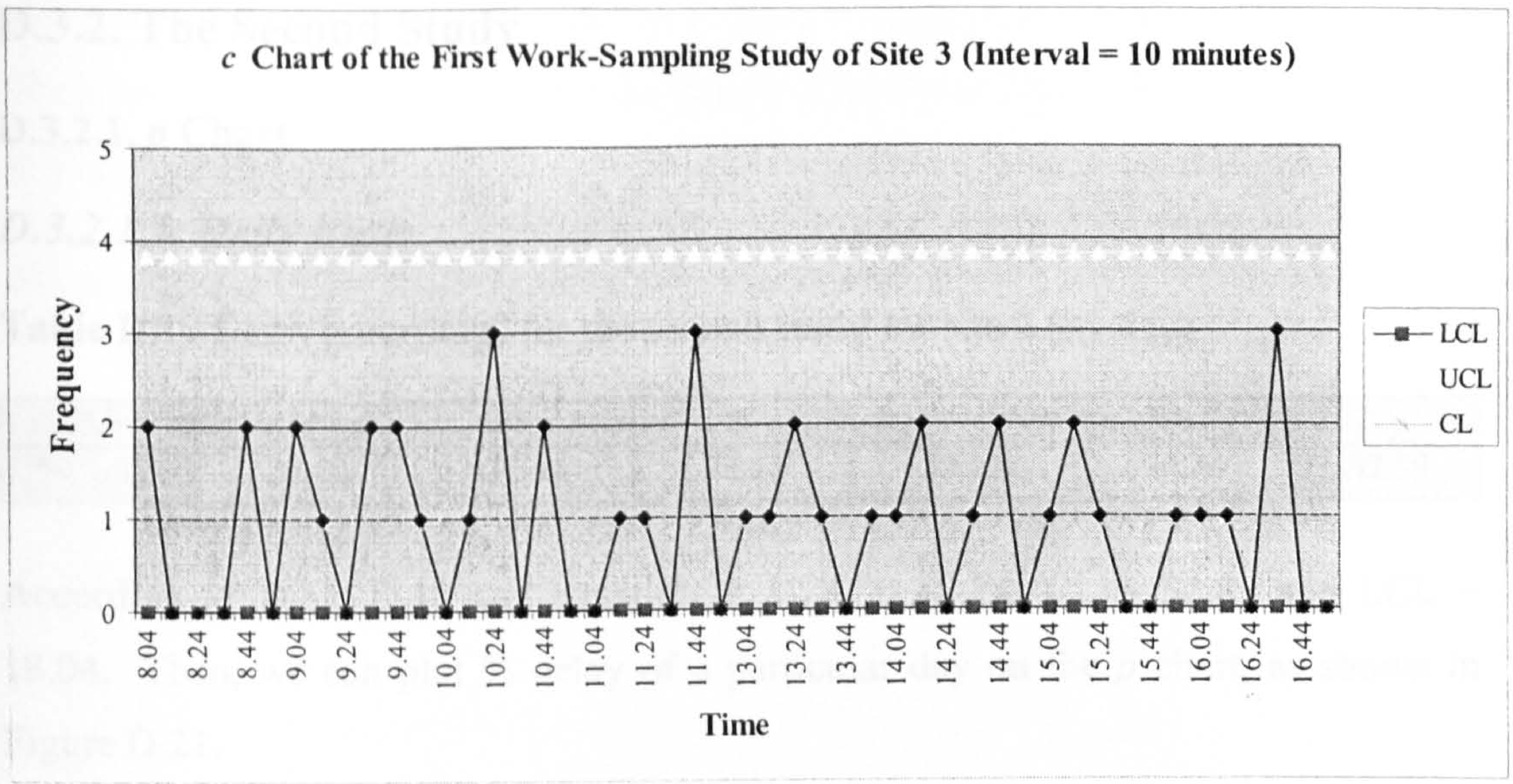


Figure D.19 *c* chart for the first work-sampling study for site 3 (10 minutes interval)

D.3.1.2.2. 15 Minutes Interval

According to Table D.15 and equation 4, where $\bar{c}$ = 1.41, UCL = 4.98, CL = 1.41 and LCL = 0.00, then we have the *c* chart, as shown in Figure D.20.

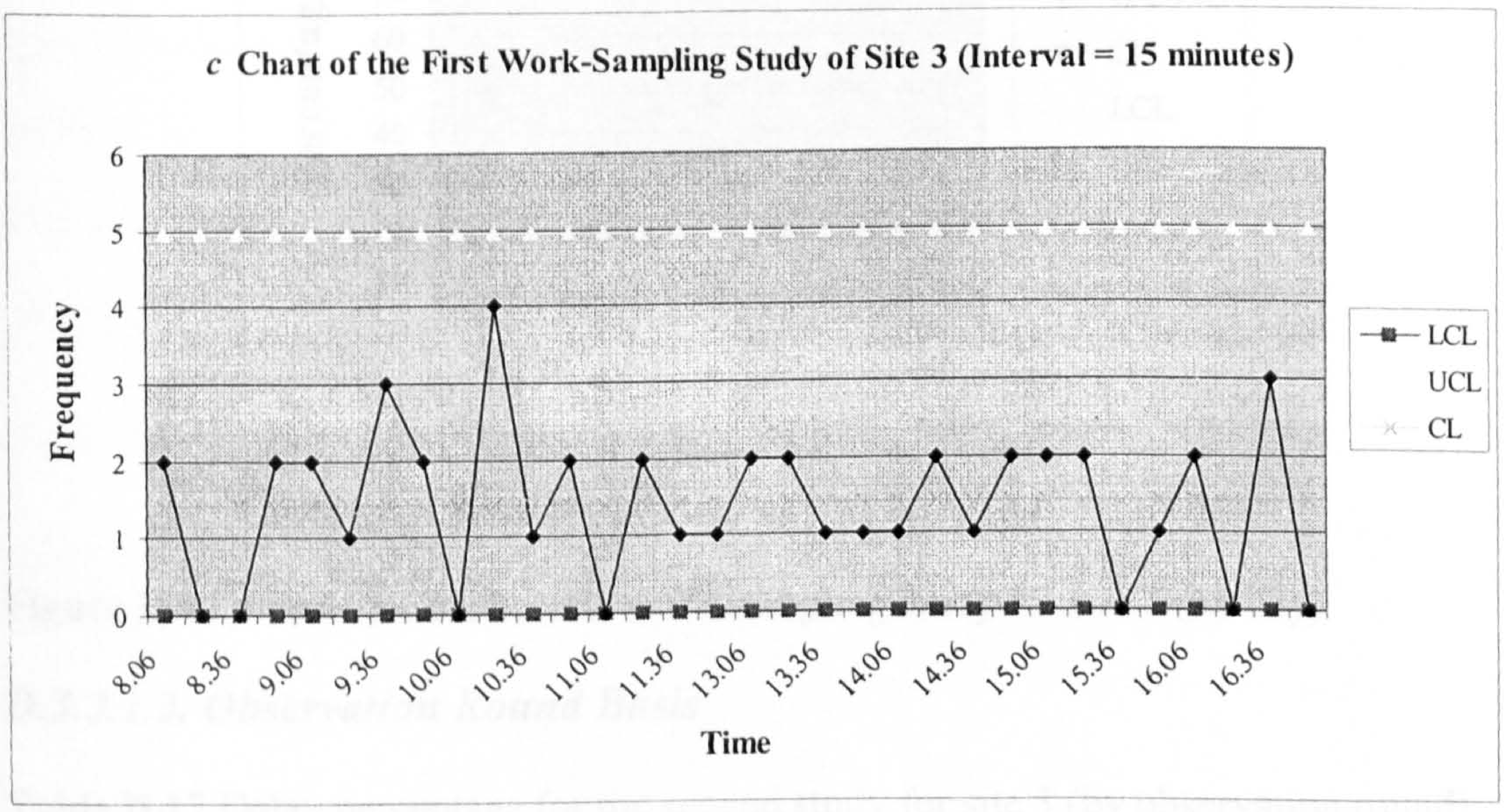


Figure D.20 *c* chart for the first work-sampling study for site 3 (15 minutes interval)

D.3.2. The Second Study

D.3.2.1. *p* Chart

D.3.2.1.1. Daily Basis

Table D.16 Delay percentage for the second study for site 3 (by day)

Day	1	2	3	4	5	$\bar{p}$
% Delay	32.22	36.67	27.78	33.33	34.44	32.89

According to Table D.16 and equation 5, UCL = 47.74, CL = 32.89 and LCL = 18.04. Then, we can plot % delay of a particular day on the *p* chart, as shown in Figure D.21.

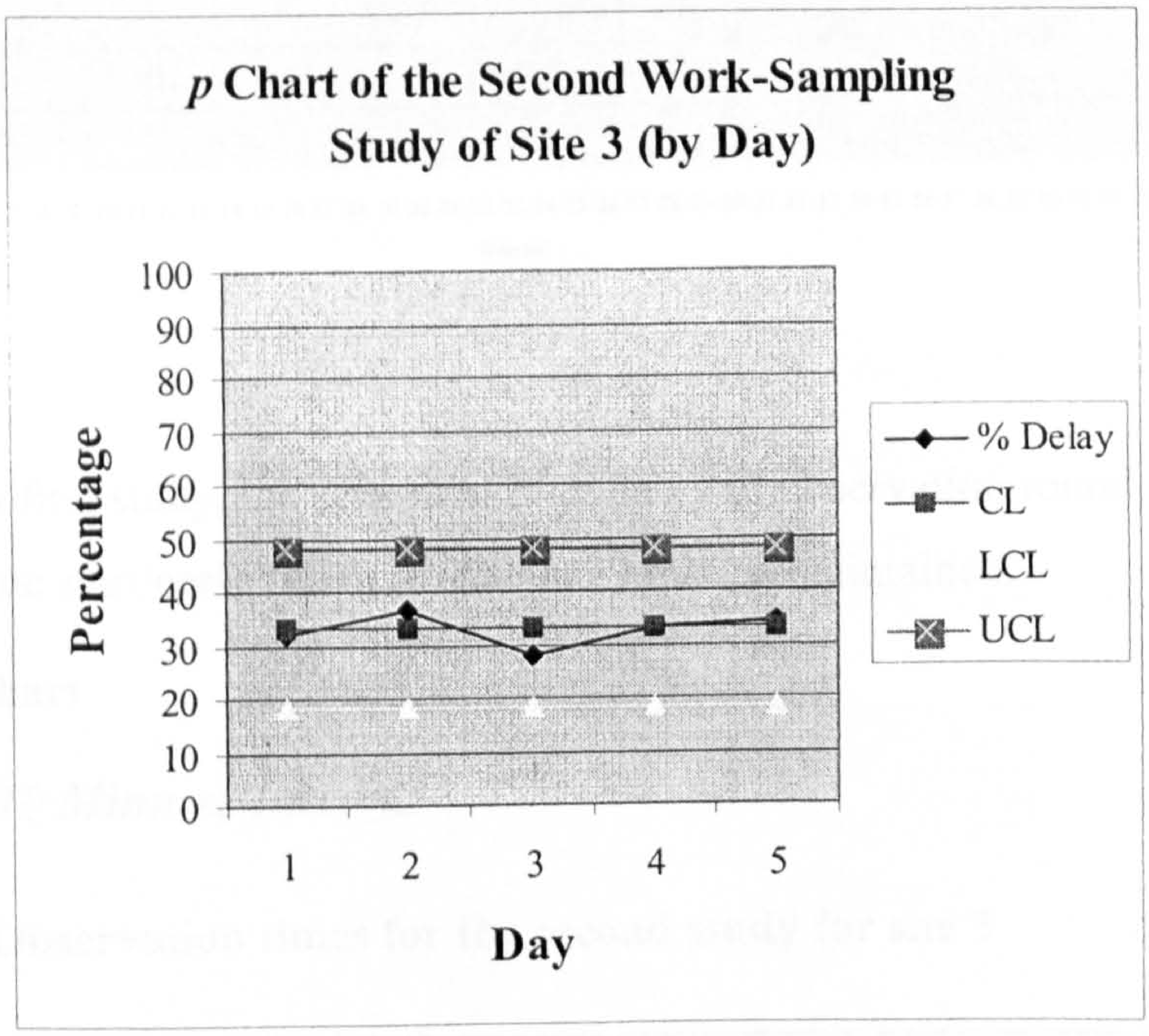


Figure D.21 *p* chart for the second work-sampling study for site 3 (by day)

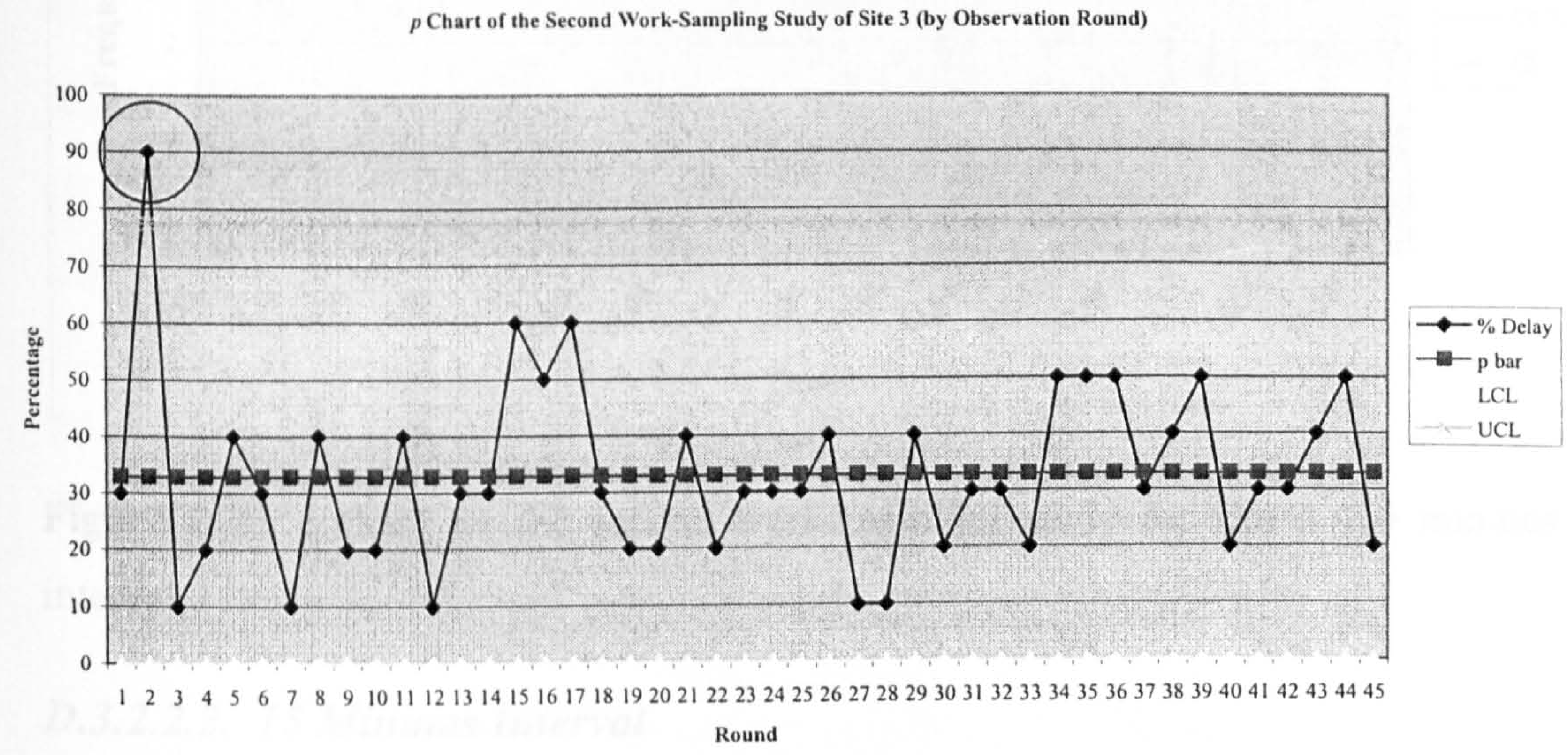
D.3.2.1.2. Observation Round Basis

Table D.17 Delay percentage for the second study for site 3 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	30	90	10	20	40	30	10	20	40	20	40	10	30	30	60
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	50	60	30	20	20	40	20	30	40	30	40	10	10	40	20
Rounds of observation	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
% Delay	30	30	20	50	50	50	30	40	50	20	30	30	40	50	20

According to Table D.17 and equation 5, UCL = 77.41, CL = 32.89 and LCL = 0.00. Then, we plot % delay of a particular round of observation on the *p* chart, as shown in Figure D.22.

Figure D.22 *p* chart for the second work-sampling study for site 3 (by observation round)



Similar to its first study, the abnormal high delay of observation round 2 of this study was due to late start/early finish, so the data must be maintained.

D.3.2.2. *c* Chart

D.3.2.2.1. 10 Minutes Interval

Table D.18 **Observation times for the second study for site 3**

Observation date	Round								
	1	2	3	4	5	6	7	8	9
11/12/01	9.00	9.54	10.19	13.02	14.06	14.48	15.49	16.28	16.54
12/12/01	8.48	9.48	10.53	13.00	13.55	14.59	15.48	16.05	16.49
13/12/01	8.24	9.32	10.29	13.14	13.53	14.56	15.27	15.47	16.58
14/12/01	8.18	8.42	10.34	11.27	13.17	13.36	14.17	15.02	15.56
15/12/01	8.39	9.32	9.49	10.51	11.08	11.43	13.10	14.38	15.27

According to Table D.18 and equation 4, where $\bar{c} = 0.94$, UCL = 3.85, CL = 0.94 and LCL = 0.00, then we have the *c* chart, as shown Figure D.23.

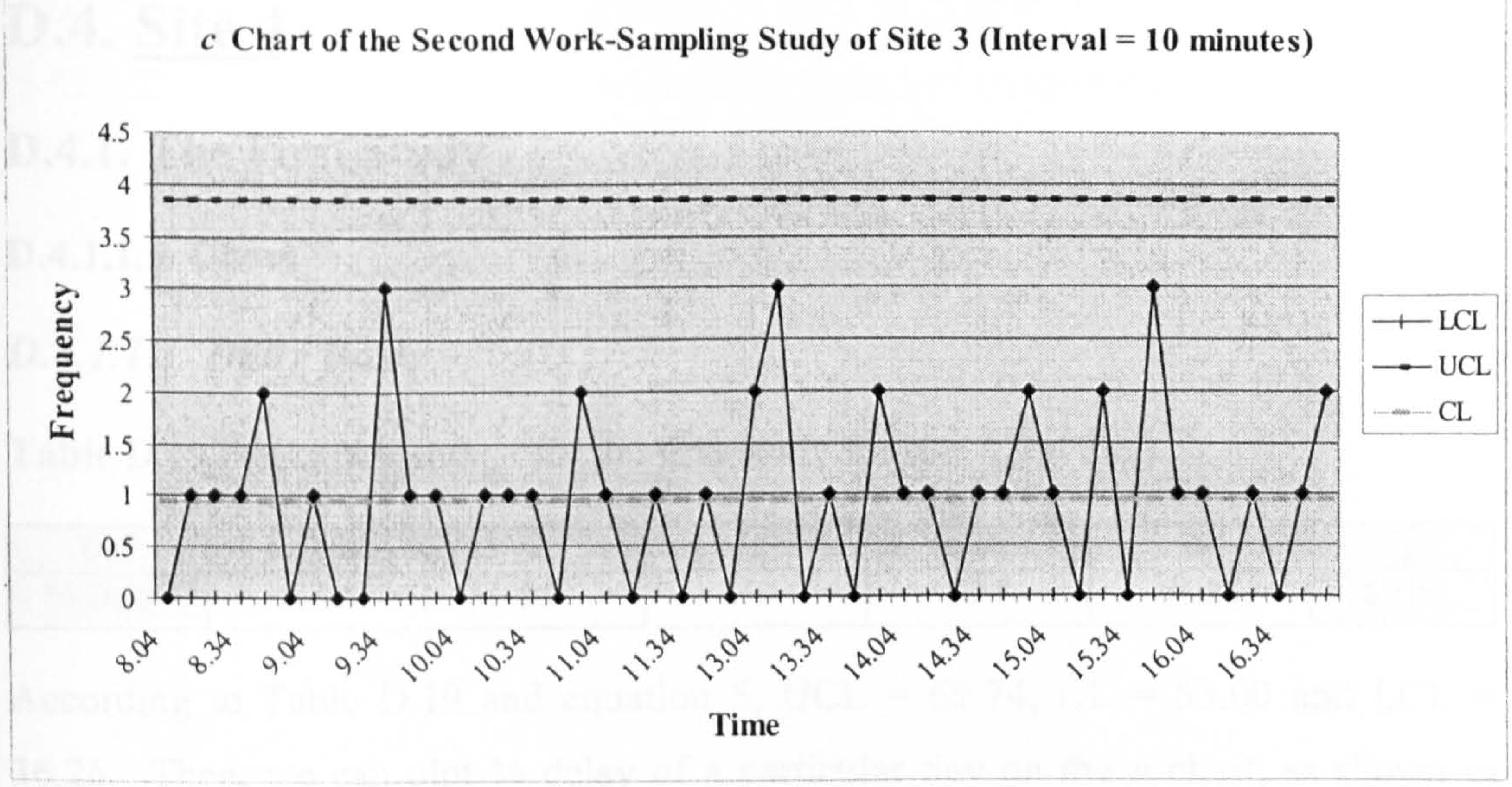


Figure D.23 *c* chart for the second work-sampling study for site 3 (10 minutes interval)

D.3.2.2.2. 15 Minutes Interval

According to Table D.18 and equation 4, where $\bar{c}$ = 1.41, UCL = 4.98, CL = 1.41 and LCL = 0.00, then we have the *c* chart, as shown in Figure D.24.

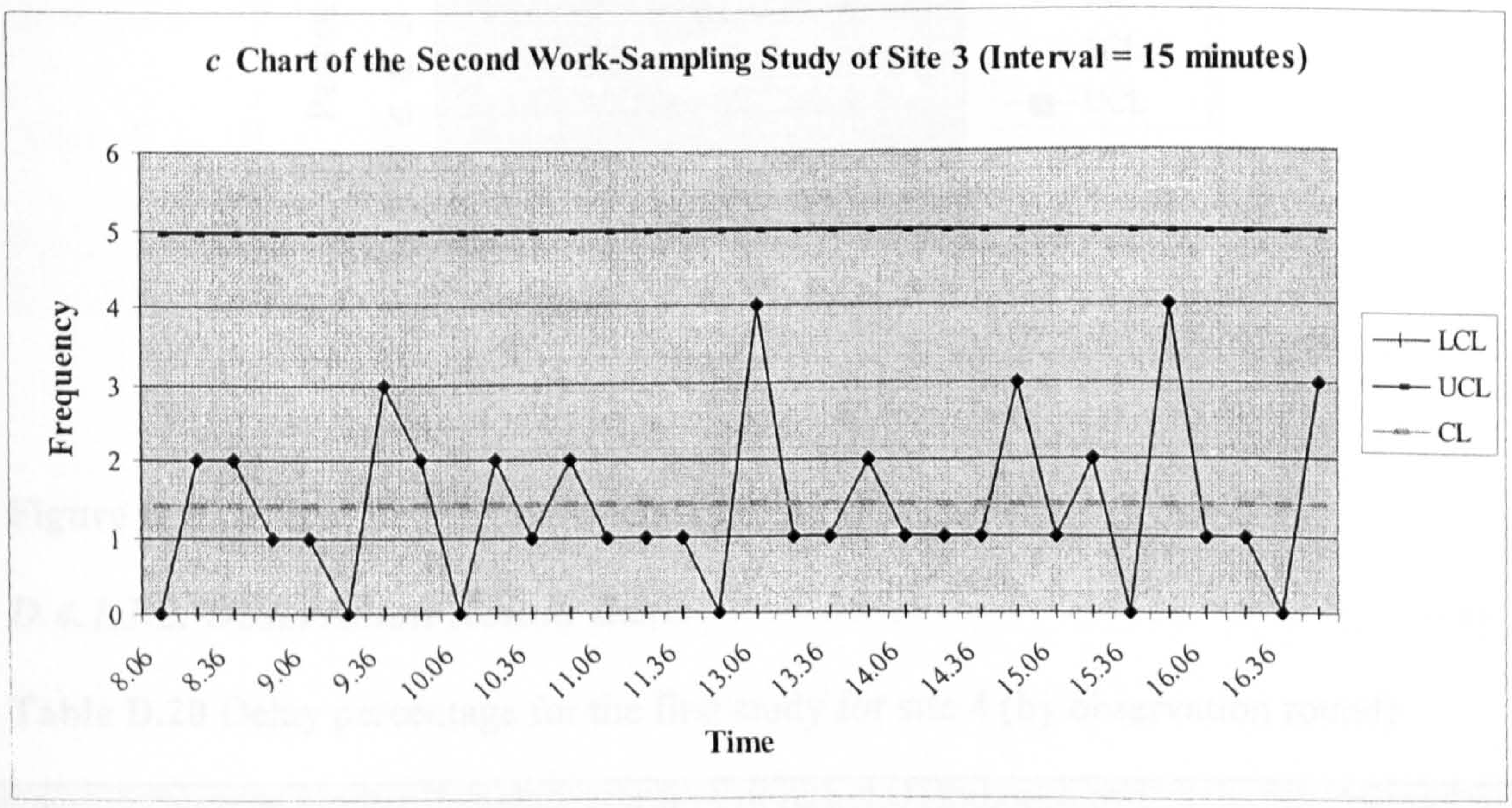


Figure D.24 *c* chart for the second work-sampling study for site 3 (15 minutes interval)

D.4. Site 4

D.4.1. The First Study

D.4.1.1. *p* Chart

D.4.1.1.1. Daily Basis

Table D.19 Delay percentage for the first study for site 4 (by day)

Day	1	2	3	4	5	$\bar{p}$
% Delay	51.25	55	50	52.5	56.25	53.00

According to Table D.19 and equation 5, UCL = 69.74, CL = 53.00 and LCL = 36.26. Then, we can plot % delay of a particular day on the *p* chart, as shown in Figure D.25.

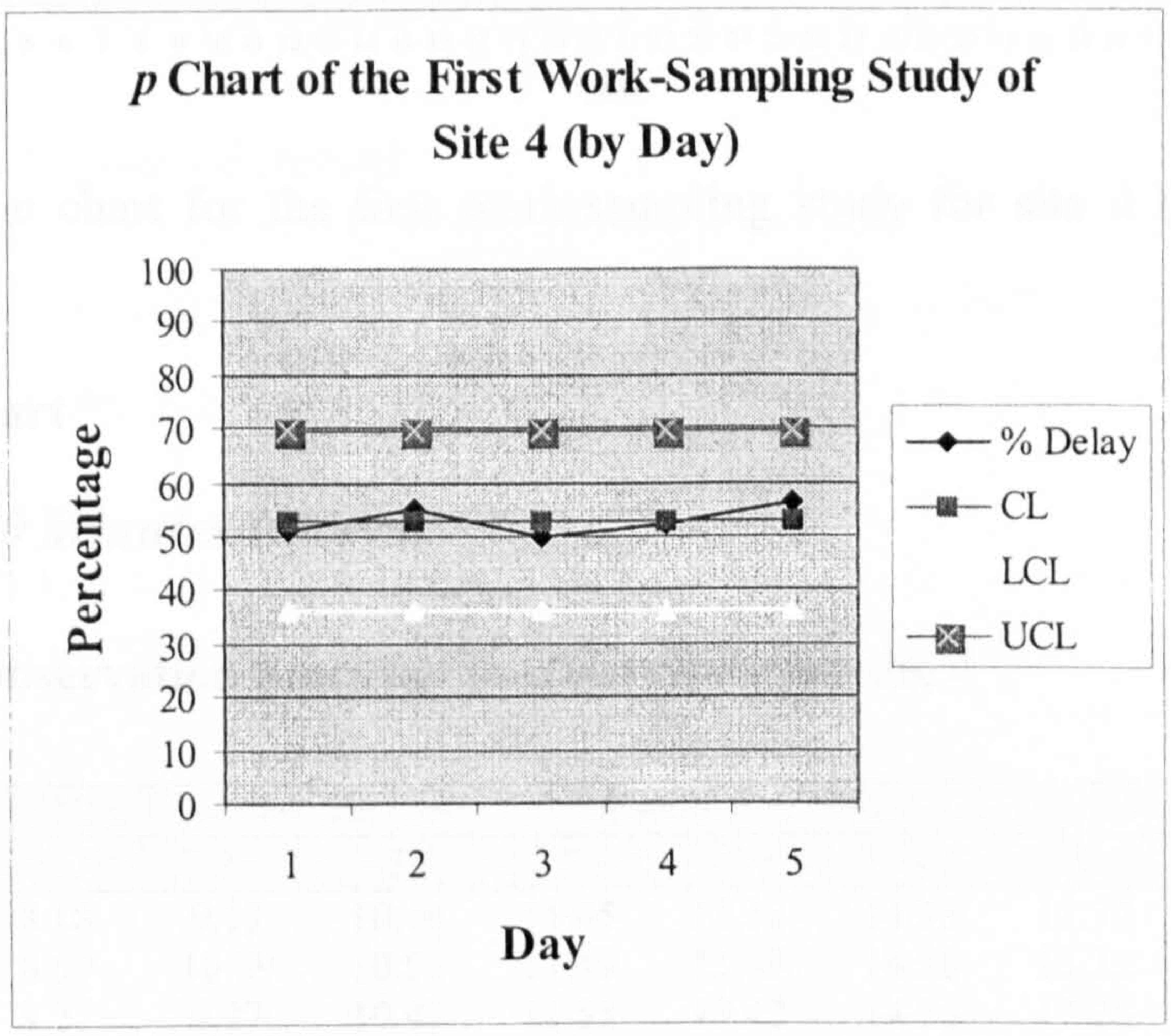


Figure D.25 *p* chart for the first work-sampling study for site 4 (by day)

D.4.1.1.2. Observation Round Basis

Table D.20 Delay percentage for the first study for site 4 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	20	30	80	70	30	50	40	90	40	40	60	80	40	60	50
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	70	30	60	40	80	50	40	40	60	30	50	40	80	50	60
Rounds of observation	31	32	33	34	35	36	37	38	39	40					
% Delay	50	60	30	60	60	80	40	50	50	80					

According to Table D.20 and equation 5, UCL = 100.00, CL = 53.00 and LCL = 5.65. Then, we plot % delay of a particular round of observation on the *p* chart, as shown in Figure D.26.

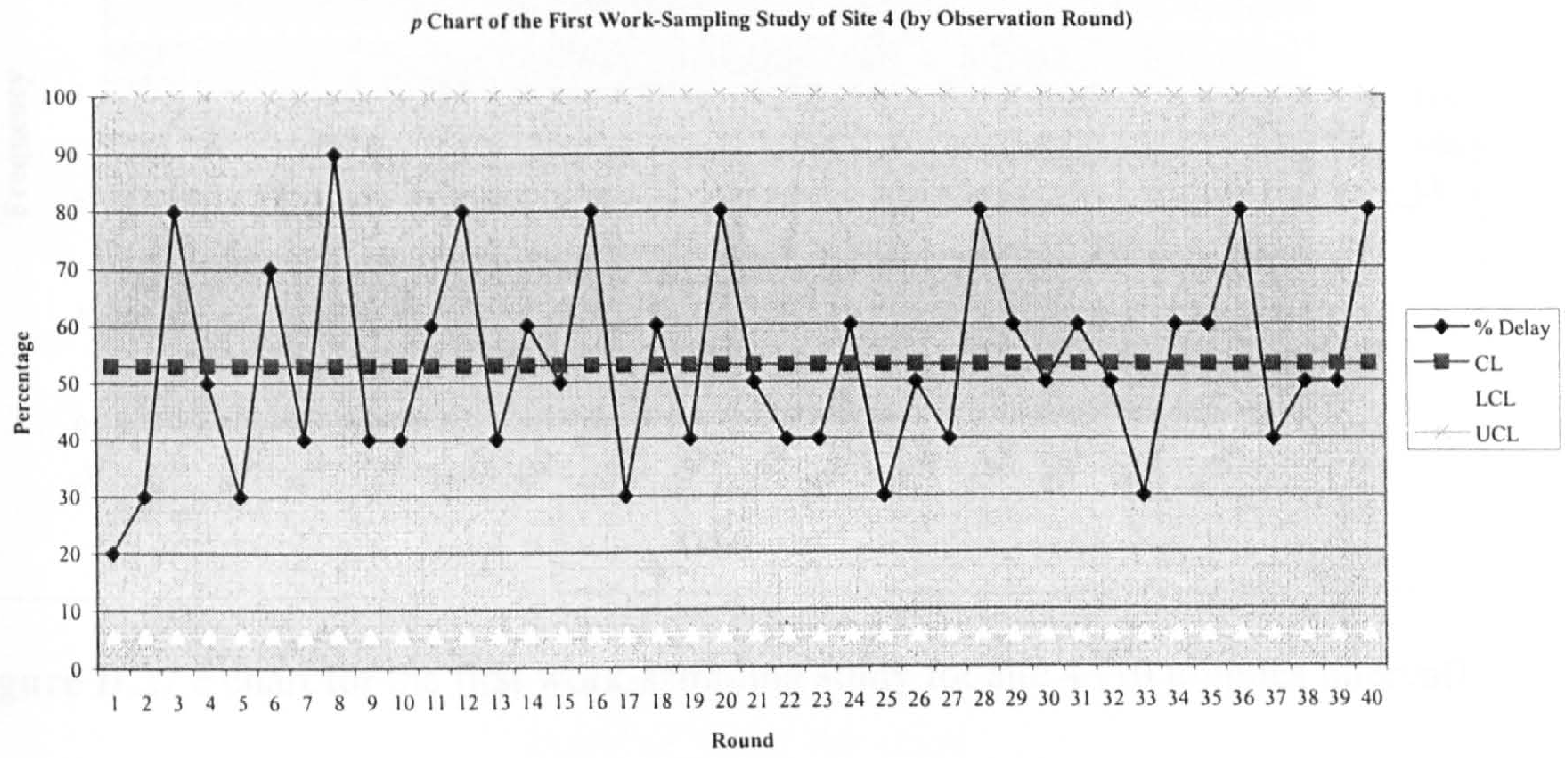


Figure D.26 *p* chart for the first work-sampling study for site 4 (by observation round)

D.4.1.2. *c* Chart

D.4.1.2.1. 10 Minutes Interval

Table H.21 **Observation times for the first study for site 4**

Observation date	Round							
	1	2	3	4	5	6	7	8
21/12/01	8.18	9.17	10.16	11.05	13.31	14.35	15.37	16.16
22/12/01	8.59	10.09	10.55	11.49	13.49	14.36	15.22	16.23
24/12/01	8.27	9.27	10.47	11.55	13.43	14.26	15.26	16.36
25/12/01	8.43	9.58	10.55	11.40	13.42	14.42	15.46	16.49
26/12/01	8.09	9.21	10.23	11.28	13.39	14.33	15.28	16.18

According to Table D.21 and equation 4, where $\bar{c} = 0.83$, UCL = 3.57, CL = 0.83 and LCL = 0.00, then we have the *c* chart, as shown in Figure D.27.

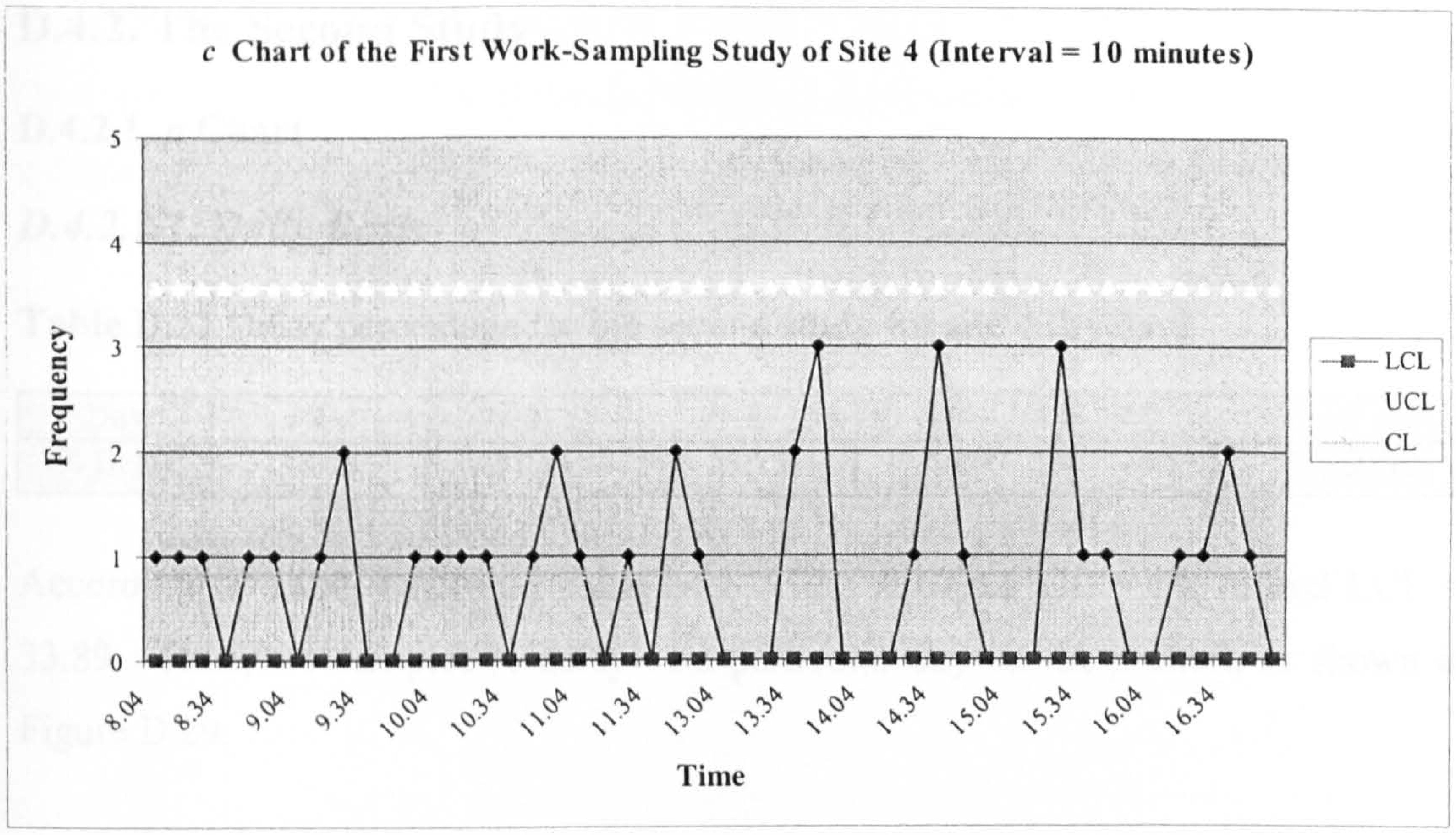


Figure D.27 *c* chart for the first work-sampling study for site 4 (10 minutes interval)

D.4.1.2.2. 15 Minutes Interval

According to Table D.21 and equation 4, where $\bar{c}$ = 1.25, UCL = 4.60, CL = 1.25 and LCL = 0.00, then we have the *c* chart, as shown in Figure D.28.

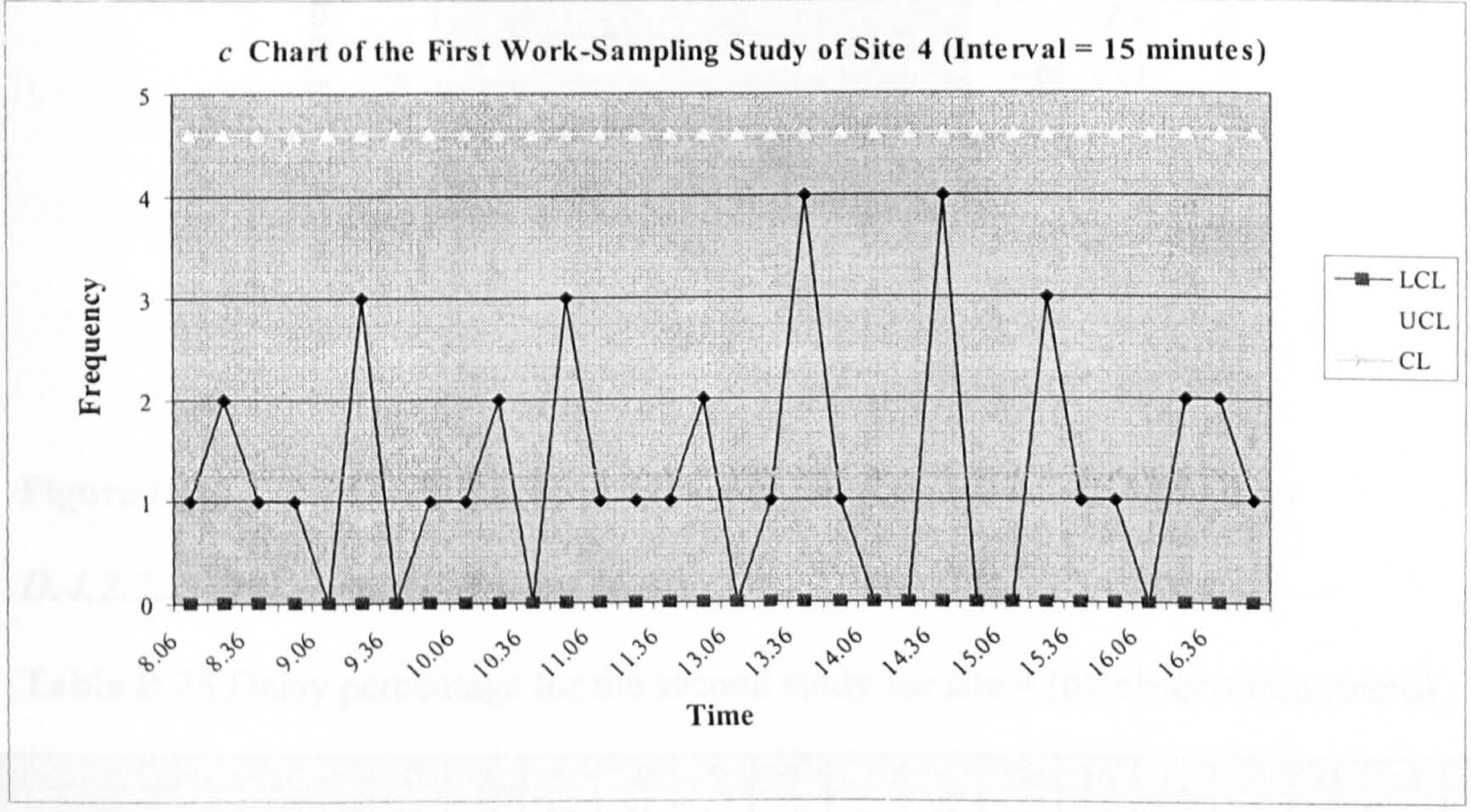


Figure D.28 *c* chart for the first work-sampling study for site 4 (15 minutes interval)

D.4.2. The Second Study

D.4.2.1. *p* Chart

D.4.2.2.1. Daily Basis

Table D.22 Delay percentage for the second study for site 4 (by day)

Day	1	2	3	4	5	$\bar{p}$
% Delay	48.75	51.25	51.25	50.00	52.50	50.75

According to Table D.22 and equation 5, UCL = 67.52, CL = 50.75 and LCL = 33.89. Then, we can plot % delay of a particular day on the *p* chart, as shown in Figure D.29.

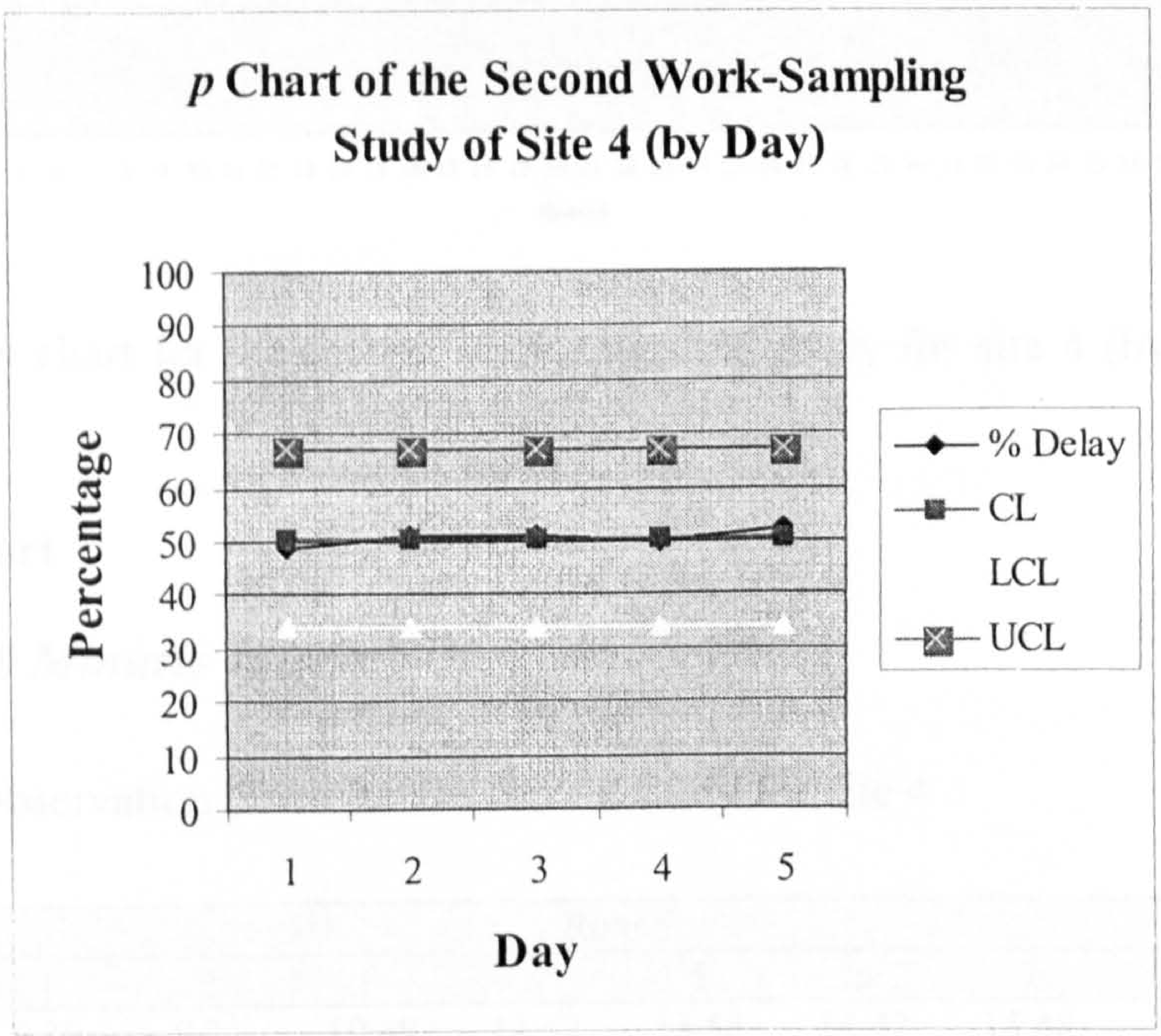


Figure D.29 *p* chart for the second work-sampling study for site 4 (by day)

D.4.2.2.2. Observation Round Basis

Table D.23 Delay percentage for the second study for site 4 (by observation round)

Rounds of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Delay	30	40	50	60	40	60	50	60	60	40	60	70	40	30	50
Rounds of observation	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
% Delay	60	40	50	60	60	40	40	60	60	30	50	40	80	40	50
Rounds of observation	31	32	33	34	35	36	37	38	39	40					
% Delay	50	60	50	40	60	30	80	70	40	50					

According to Table D.23 and equation 5, UCL = 98.18, CL = 50.75 and LCL = 3.32. Then, we plot % delay of a particular round of observation on the *p* chart, as shown in Figure D.30.

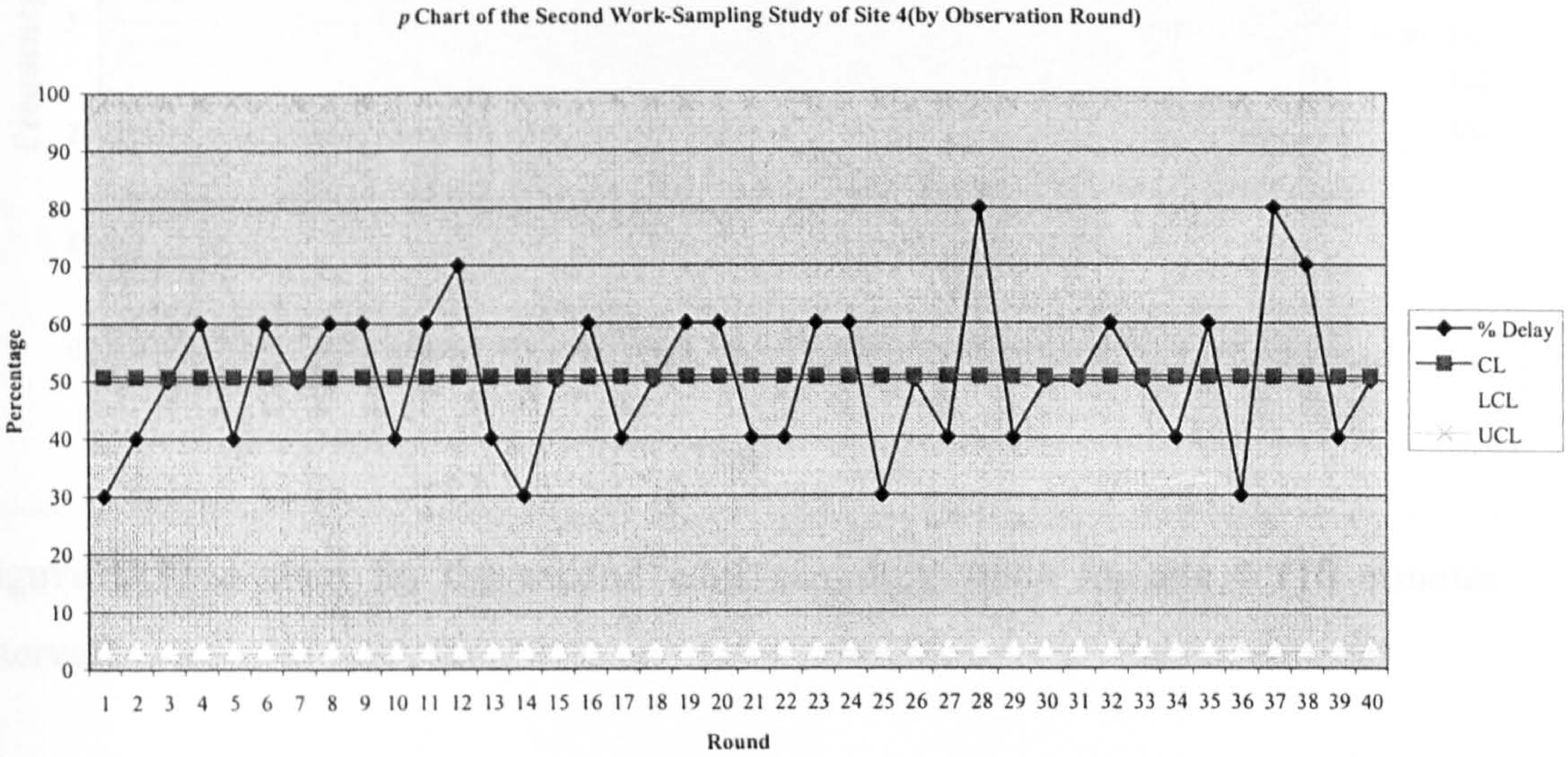


Figure D.30 *p* chart for the second work-sampling study for site 4 (by observation round)

D.4.2.2. *c* Chart

D.4.2.2.1. 10 Minutes Interval

Table D.24 Observation times for the second study for site 4

Observation date	Round							
	1	2	3	4	5	6	7	8
15/1/01	8.30	9.23	10.49	11.52	13.58	14.42	15.48	16.35
16/1/01	8.26	9.27	10.22	11.33	13.31	14.55	15.55	16.40
17/1/01	8.41	9.35	10.21	11.13	13.26	14.39	15.24	16.43
18/1/01	8.33	9.34	10.30	11.35	13.30	14.48	15.55	16.48
19/1/01	8.01	9.14	10.26	11.13	13.07	14.04	15.12	15.57

According to Table D.24 and equation 4, where $\bar{c} = 0.83$, UCL = 3.57, CL = 0.83 and LCL = 0.00, then we have the *c* chart, as shown in Figure D.31.

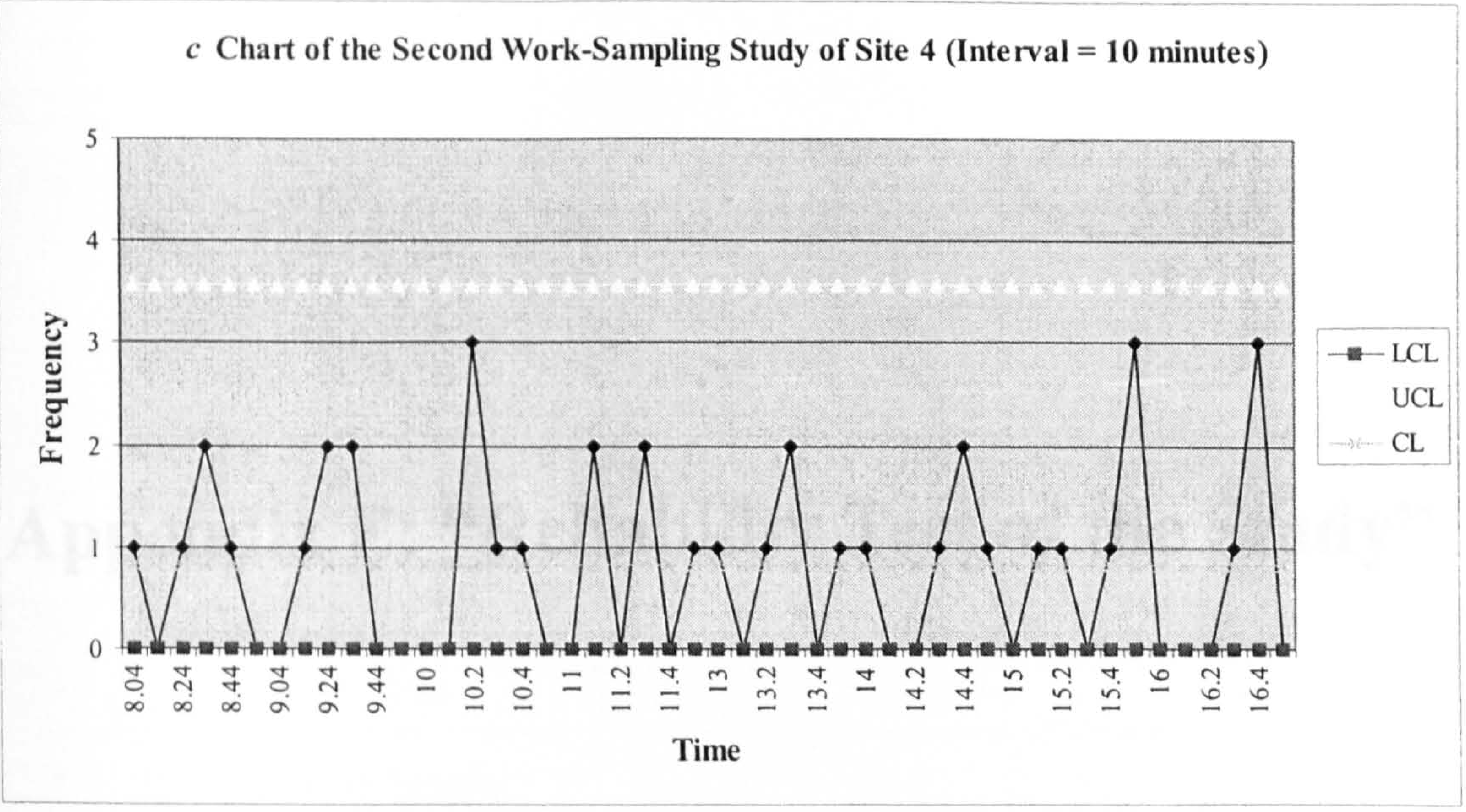


Figure D.31 *c* chart for the second work-sampling study for site 4 (10 minutes interval)

D.4.2.2.2. 15 Minutes Interval

According to Table D.24 and equation 4, where $\bar{c}$ = 1.25, UCL = 4.60, CL = 1.25 and LCL = 0.00, then we have the *c* chart, as shown in Figure D.32.

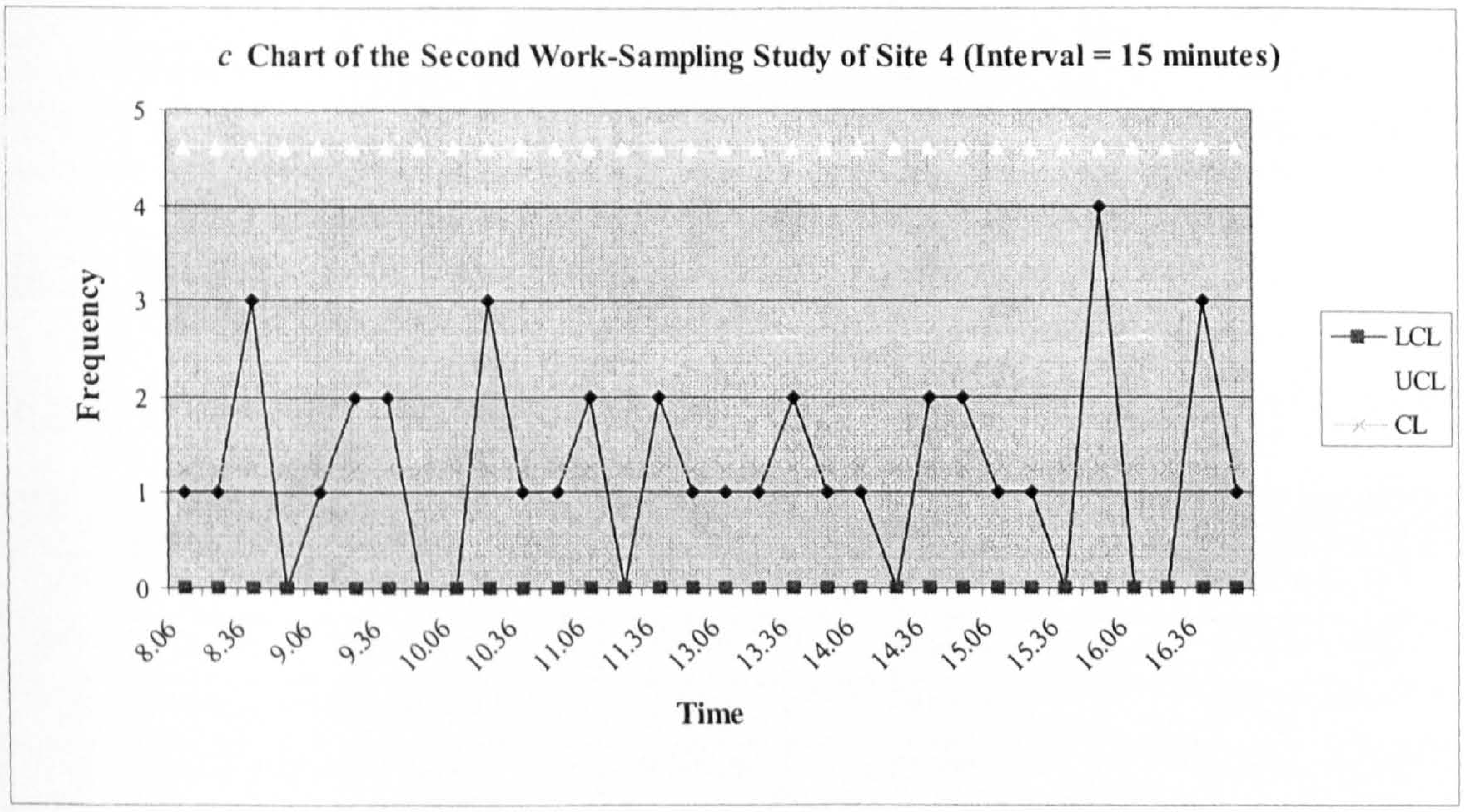


Figure D.32 *c* chart for the second work-sampling study for site 4 (15 minutes interval)

Appendix E: “Reliability Test of the Study”

E.1. Site 1

E.1.1. The First Study

Code	Category	Average	Limit of Error	Interval
100	Effective Work	46.22%	±4.70%	41.52%-50.92%
211	Waiting for materials	2.67%	±1.52%	1.15%-4.19%
213	Waiting for equipment	2.44%	±1.45%	0.99%-3.89%
214	Waiting for instruction	11.11%	±2.96%	8.15%-14.07%
216	Waiting for other trades	10.89%	±2.94%	7.95%-13.83%
217	Waiting for other crews	13.78%	±3.25%	10.53%-17.03%
220	Personal Allowances	7.11%	±2.42%	4.69%-9.53%
230	Late start/Early finish	5.78%	±2.20%	3.58%-7.98%

E.1.2. The Second Study

Code	Category	Average	Limit of Error	Interval
100	Effective Work	51.78%	±4.76%	47.02%-56.54%
211	Waiting for materials	0.22%	±0.45%	0.00%-0.67%
212	Waiting for tools	0.22%	±0.45%	0.00%-0.67%
213	Waiting for equipment	3.11%	±1.66%	1.45%-4.77%
214	Waiting for instruction	2.00%	±1.33%	0.67%-3.33%
216	Waiting for other trades	17.78%	±3.66%	14.12%-21.44%
217	Waiting for other crews	10.89%	±2.97%	7.92%-13.86%
220	Personal Allowances	7.12%	±2.45%	4.67%-9.57%
230	Late start/Early finish	6.44%	±2.34%	4.10%-8.78%

E.2. Site 2

E.2.1. The First Study

Code	Category	Average	Limit of Error	Interval
100	Effective Work	56.82%	±4.72%	52.10%-61.54%
213	Waiting for equipment	2.05%	±1.35%	0.70%-3.40%
216	Waiting for other trades	1.59%	±1.19%	0.40%-2.78%
217	Waiting for other crews	27.05%	±4.24%	22.81%-31.29%
220	Personal Allowances	12.00%	±3.10%	8.90%-15.10%
230	Late start/Early finish	1.59%	±1.19%	0.40%-2.78%
240	No Contact	0.45%	±0.64%	0.00%-1.09%

E.2.2. The Second Study

Code	Category	Average	Limit of Error	Interval
100	Effective Work	59.75%	±4.90%	56.82%-62.68%
211	Waiting for materials	0.25%	±0.45%	0.00%-0.70%
213	Waiting for equipment	0.25%	±0.45%	0.00%-0.70%
216	Waiting for other trades	6.50%	±2.47%	4.03%-8.97%
217	Waiting for other crews	22.50%	±4.18%	18.32%-26.68%
220	Personal Allowances	8.75%	±2.83%	5.92%-11.58%
230	Late start/Early finish	2.00%	±1.40%	0.60%-3.40%

E.3. Site 3

E.3.1. The First Study

Code	Category	Average	Limit of Error	Interval
100	Effective Work	67.56%	±4.41%	63.15%-71.97%
212	Waiting for tools	3.11%	±1.64%	1.57%-4.75%
213	Waiting for equipment	4.00%	±1.85%	2.15%-5.85%
216	Waiting for other trades	4.67%	±1.99%	2.68%-6.66%
217	Waiting for other crews	7.11%	±2.42%	4.69%-9.53%
220	Personal Allowances	9.56%	±2.77%	6.79%-12.33%
230	Late start/Early finish	4.00%	±1.85%	2.15%-5.85%

E.3.2. The Second Study

Code	Category	Average	Limit of Error	Interval
100	Effective Work	67.11%	±4.43%	62.68%-71.54%
212	Waiting for tools	3.11%	±1.64%	1.47%-4.75%
214	Waiting for instruction	2.00%	±1.32%	0.68%-3.32%
215	Waiting for inspection	0.67%	±0.78%	0.00%-1.45%
216	Waiting for other trades	8.89%	±2.68%	6.21%-11.57%
217	Waiting for other crews	4.67%	±1.99%	2.68%-6.66%
220	Personal Allowances	9.33%	±2.74%	6.59%-12.07%
230	Late start/Early finish	4.22%	±1.90%	2.32%-6.12%

E.4. Site 4

E.4.1. The First Study

Code	Category	Average	Limit of Error	Interval
100	Effective Work	47.00%	±4.99%	42.01%-51.99%
211	Waiting for materials	2.00%	±1.40%	0.60%-3.40%
213	Waiting for equipment	0.25%	±0.50%	0.00%-0.75%
214	Waiting for instruction	0.75%	±0.86%	0.00%-1.61%
216	Waiting for other trades	1.00%	±0.99%	0.01%-1.99%
217	Waiting for other crews	20.75%	±4.06%	16.69%-24.81%
220	Personal Allowances	15.75%	±3.64%	12.11%-19.39%
230	Late start/Early finish	12.50%	±3.31%	9.19%-15.81%

E.4.2. The Second Study

Code	Category	Average	Limit of Error	Interval
100	Effective Work	49.25%	±5.00%	44.25%-54.25%
211	Waiting for materials	1.00%	±0.99%	0.01%-1.99%
213	Waiting for equipment	0.75%	±0.86%	0.00%-1.61%
214	Waiting for instruction	1.50%	±1.22%	0.28%-2.77%
217	Waiting for other crews	22.25%	±4.16%	18.09%-26.41%
220	Personal Allowances	15.25%	±3.60%	11.65%-18.85%
230	Late start/Early finish	10.00%	±3.00%	7.00%-13.00%

Appendix F: "Prediction of the Work-Sampling Results"

F.1 Site 1

F.1.1. Developing Probability Transition Matrix

Table F.1 Net changes in number observed and movement of craftsmen's activity from one category to another of the three categories

Sample	The first study			The second study			Net gains/losses		
no.	ET	MD	PA	ET	MD	PA	ET	MD	PA
1	33	6	6	35	5	5	2	-1	-1
2	23	22	0	32	12	1	9	-10	1
3	35	9	1	35	7	3	0	-2	2
4	17	26	2	25	18	2	8	-8	0
5	21	19	5	27	12	6	6	-7	1
6	13	30	2	2	43	0	-11	13	-2
7	16	23	6	18	25	2	2	2	-4
8	11	30	4	19	24	2	8	-6	-2
9	17	25	3	21	18	6	4	-7	3
10	22	20	3	19	21	5	-3	1	2
Subtotal	208	210	32	233	185	32	25	-25	0
Total		450			450			0	

According to Table F.1, the calculation of movement of craftsmen's activity from one category to another can be identified, as shown in Table F.2.

Table F.2 Calculation of the movement of craftsmen's activity from one category to another

Order	Sample no.	Total number
ET retained	1-10	33 + 23 + 35 + 17 + 21 + 2 + 16 + 11 + 17 + 19 = 194
ET gained from MD (MD lost to ET)	1, 2, 4, 5, 8 and 9	1 + 9 + 8 + 6 + 6 + 4 = 34
ET gained from PA (PA lost to ET)	1, 7 and 8	1 + 2 + 2 = 5
MD retained	1-10	5 + 12 + 7 + 18 + 12 + 30 + 23 + 24 + 18 + 20 = 169
MD gained from ET (ET lost to MD)	6 and 10	11 + 1 = 12
MD gained from PA (PA lost to MD)	3 and 7	2 + 2 = 4
PA retained	1-10	5 + 0 + 1 + 2 + 5 + 0 + 2 + 2 + 3 + 3 = 23
PA gained from ET (ET lost to PA)	7	2
PA gained from MD (MD lost to PA)	2, 3, 5 and 9	1 + 2 + 1 + 3 = 7

Referring to the above, the movement of craftsmen's activity from one category to another can be now shown in Table F.3.

Table F.3 Numbers retained, gained and lost at the second study

		To category		
	From category	ET	MD	PA
208	ET	194	12	2
210	MD	34	169	7
32	PA	5	4	23
		233	185	32

Having obtained numbers retained, gained and lost for each category, the resulting probability transition matrix is described in Table F.4.

Table F.4 Transition matrix for the three categories

	To category		
From category	ET	MD	PA
ET	0.9327	0.0577	0.0096
MD	0.1619	0.8048	0.0333
PA	0.1563	0.1250	0.7188

F.1.2. Initial Conditions

According to the results of the second study of site 1, the working time is divided 51.78% (233/450) to effective work, 41.11% (185/450) to management delays and 7.11% (32/450) to personal allowances (see Figure 8.3). The initial conditions are thus described by the row vector.

$$[0.5178 \quad 0.4111 \quad 0.0711]$$

F.1.3. Predicting Future States and Steady State

Prediction of future states and steady state of site 1 are summarised in Table F.5.

Table F.5 Reaching steady state

Period (t)	Transition Matrix (P^t)	System state p(t)
0		$\begin{bmatrix}0.518 & 0.411 & 0.071\end{bmatrix}$
1	$\begin{bmatrix}0.933 & 0.058 & 0.010\\0.162 & 0.805 & 0.033\\0.156 & 0.125 & 0.719\end{bmatrix}$	$\begin{bmatrix}0.561 & 0.370 & 0.070\end{bmatrix}$
2	$\begin{bmatrix}0.881 & 0.101 & 0.018\\0.287 & 0.661 & 0.052\\0.278 & 0.339 & 0.068\end{bmatrix}$	$\begin{bmatrix}0.594 & 0.339 & 0.068\end{bmatrix}$
4	$\begin{bmatrix}0.810 & 0.160 & 0.030\\0.456 & 0.477 & 0.067\\0.448 & 0.264 & 0.288\end{bmatrix}$	$\begin{bmatrix}0.639 & 0.298 & 0.064\end{bmatrix}$
8	$\begin{bmatrix}0.742 & 0.214 & 0.044\\0.617 & 0.318 & 0.065\\0.612 & 0.274 & 0.114\end{bmatrix}$	$\begin{bmatrix}0.682 & 0.261 & 0.058\end{bmatrix}$
16	$\begin{bmatrix}0.710 & 0.239 & 0.052\\0.694 & 0.251 & 0.055\\0.693 & 0.249 & 0.058\end{bmatrix}$	$\begin{bmatrix}0.702 & 0.244 & 0.053\end{bmatrix}$
29	$\begin{bmatrix}0.705 & 0.242 & 0.053\\0.704 & 0.243 & 0.053\\0.704 & 0.243 & 0.053\end{bmatrix}$	$\begin{bmatrix}0.705 & 0.242 & 0.053\end{bmatrix}$
30	$\begin{bmatrix}0.705 & 0.242 & 0.053\\0.705 & 0.242 & 0.053\\0.705 & 0.242 & 0.053\end{bmatrix}$	$\begin{bmatrix}0.705 & 0.242 & 0.053\end{bmatrix}$
31	$\begin{bmatrix}0.705 & 0.242 & 0.053\\0.705 & 0.242 & 0.053\\0.705 & 0.242 & 0.053\end{bmatrix}$	$\begin{bmatrix}0.705 & 0.242 & 0.053\end{bmatrix}$

F.2 Site 2

F.2.1. Developing Probability Transition Matrix

The number of observations for the first and the second study for site 2 are different, 440 and 400, respectively. As a result, four rounds of observation (equal to 40 samples) for the first study are randomly eliminated in order to decrease the observation numbers to 400, equal to the second study, so the Markov process can be applied.

Table F.6 Net changes in number observed and movement of craftsmen's activity from one category to another of the three categories

Sample no.	The first study			The second study			Net gains/losses		
	ET	MD	PA	ET	MD	PA	ET	MD	PA
1	21	13	6	30	2	8	9	-11	2
2	18	15	7	21	13	6	3	-2	-1
3	29	8	3	17	21	2	-12	13	-1
4	20	16	4	18	20	2	-2	4	-2
5	31	7	2	30	5	5	-1	-2	3
6	25	12	3	26	13	1	1	1	-2
7	29	10	1	31	9	0	2	-1	-1
8	21	15	4	24	12	4	3	-3	0
9	17	18	5	16	22	2	-1	4	-3
10	20	15	5	26	9	5	6	-6	0
Subtotal	231	129	40	239	126	35	8	-3	-5
Total		400			400			0	

According to Table F.6, the calculation of movement of craftsmen's activity from one category to another can be identified, as shown in Table F.7.

Table F.7 Calculation of the movement of craftsmen's activity from one category to another

Order	Sample no.	Total number
ET retained	1-10	21 + 18 + 17 + 18 + 30 + 25 + 29 + 21 + 16 + 20 = 215
ET gained from MD (MD lost to ET)	1, 2, 7, 8 and 10	9 + 2 + 1 + 3 + 6 = 21
ET gained from PA (PA lost to ET)	2, 6 and 7	1 + 1 + 1 = 3
MD retained	1-10	2 + 13 + 8 + 16 + 5 + 12 + 9 + 12 + 18 + 9 = 104
MD gained from ET (ET lost to MD)	3, 4 and 9	12 + 2 + 1 = 15
MD gained from PA (PA lost to MD)	3, 4, 6 and 9	1 + 2 + 1 + 3 = 7
PA retained	1-10	6 + 6 + 2 + 2 + 2 + 1 + 0 + 4 + 2 + 5 = 30
PA gained from ET (ET lost to PA)	6	1
PA gained from MD (MD lost to PA)	1 and 5	2 + 2 = 4

Referring to the above, the movement of craftsmen's activity from one category to another can be now shown in Table F.8.

Table F.8 Numbers retained, gained and lost at the second study

		To category		
	From category	ET	MD	PA
231	ET	215	15	1
129	MD	21	104	4
40	PA	3	7	30
		239	126	35

Having obtained numbers retained, gained and lost for each category, the resulting probability transition matrix is described in Table F.9.

Table F.9 Transition matrix for the three categories

	To category		
From category	ET	MD	PA
ET	0.9307	0.0649	0.0043
MD	0.1628	0.8062	0.0310
PA	0.0750	0.1750	0.7500

F.2.2. Initial Conditions

According to the results of the second study of site 2, the working time is divided 59.75% (239/400) to effective work, 31.50% (126/400) to management delays and 8.75% (35/400) to personal allowances (see Figure 8.9). The initial conditions are thus described by the row vector.

$$[0.5975 \quad 0.3150 \quad 0.0875]$$

F.2.3. Predicting Future States and Steady State

Prediction of future states and steady state of site 2 are summarised in Table F.5.

Table F.10 Reaching steady state

Period (t)	Transition Matrix (P^t)	System state p(t)
0		$\begin{bmatrix}0.598 & 0.315 & 0.088\end{bmatrix}$
1	$\begin{bmatrix}0.931 & 0.065 & 0.018\\ 0.163 & 0.806 & 0.031\\ 0.075 & 0.175 & 0.750\end{bmatrix}$	$\begin{bmatrix}0.614 & 0.308 & 0.078\end{bmatrix}$
2	$\begin{bmatrix}0.877 & 0.114 & 0.009\\ 0.285 & 0.666 & 0.049\\ 0.155 & 0.277 & 0.568\end{bmatrix}$	$\begin{bmatrix}0.627 & 0.302 & 0.071\end{bmatrix}$
4	$\begin{bmatrix}0.803 & 0.178 & 0.019\\ 0.447 & 0.489 & 0.063\\ 0.302 & 0.360 & 0.338\end{bmatrix}$	$\begin{bmatrix}0.647 & 0.292 & 0.061\end{bmatrix}$
8	$\begin{bmatrix}0.731 & 0.237 & 0.033\\ 0.598 & 0.342 & 0.061\\ 0.506 & 0.351 & 0.143\end{bmatrix}$	$\begin{bmatrix}0.669 & 0.280 & 0.051\end{bmatrix}$
16	$\begin{bmatrix}0.692 & 0.265 & 0.043\\ 0.671 & 0.280 & 0.049\\ 0.652 & 0.290 & 0.058\end{bmatrix}$	$\begin{bmatrix}0.682 & 0.272 & 0.046\end{bmatrix}$
36	$\begin{bmatrix}0.684 & 0.270 & 0.045\\ 0.684 & 0.270 & 0.045\\ 0.684 & 0.271 & 0.045\end{bmatrix}$	$\begin{bmatrix}0.684 & 0.270 & 0.045\end{bmatrix}$
37	$\begin{bmatrix}0.684 & 0.270 & 0.045\\ 0.684 & 0.270 & 0.045\\ 0.684 & 0.270 & 0.045\end{bmatrix}$	$\begin{bmatrix}0.684 & 0.270 & 0.045\end{bmatrix}$
38	$\begin{bmatrix}0.684 & 0.270 & 0.045\\ 0.684 & 0.270 & 0.045\\ 0.684 & 0.270 & 0.045\end{bmatrix}$	$\begin{bmatrix}0.684 & 0.270 & 0.045\end{bmatrix}$

The Markov process predicts that, during the next 37 months, if work-sampling is applied monthly, site 2 will achieve its steady state and its effective time will be 68.4%, while management delays and personal allowances will account for 27% and 4.5%, respectively. Fortunately, within the next 8 months, a significant improvement should be obvious, as at that period, the effective time of site 2 is predicted to be around 66.9%, which is close to the 68.4% which will be achieved in its steady state.

F.3 Site 3

F.3.1. Developing Probability Transition Matrix

Table F.11 Net changes in number observed and movement of craftsmen's activity from one category to another of the three categories

Sample no.	The first study			The second study			Net gains/losses		
	ET	MD	PA	ET	MD	PA	ET	MD	PA
1	25	14	6	30	11	4	5	-3	-2
2	33	9	3	28	15	2	-5	6	-1
3	33	7	5	28	10	7	-5	3	2
4	31	9	5	28	14	3	-3	5	-2
5	30	10	5	35	3	7	5	-7	2
6	28	12	5	29	11	5	1	-1	0
7	32	11	2	29	10	6	-3	-1	4
8	35	6	4	32	11	2	-3	5	-2
9	29	10	6	33	11	1	4	1	-5
10	28	15	2	30	10	5	2	-5	3
Subtotal	304	103	43	302	106	42	-2	3	-1
Total		450			450			0	

According to Table F.11, the calculation of movement of craftsmen's activity from one category to another can be identified, as shown in Table F.12.

Table F.12 Calculation of the movement of craftsmen's activity from one category to another

Order	Sample no.	Total number
ET retained	1-10	25 + 28 + 28 + 28 + 30 + 28 + 29 + 32 + 29 + 28 = 285
ET gained from MD (MD lost to ET)	1, 5, 6 and 10	3 + 5 + 1 + 2 = 11
ET gained from PA (PA lost to ET)	1 and 9	2 + 4 = 6
MD retained	1-10	11 + 9 + 7 + 9 + 3 + 11 + 10 + 6 + 10 + 10 = 86
MD gained from ET (ET lost to MD)	2, 3, 4 and 8	5 + 3 + 3 + 3 = 14
MD gained from PA (PA lost to MD)	2, 4, 8 and 9	1 + 2 + 2 + 1 = 6
PA retained	1-10	4 + 2 + 5 + 3 + 5 + 5 + 2 + 2 + 1 + 2 = 31
PA gained from ET (ET lost to PA)	3 and 8	2 + 3 = 5
PA gained from MD (MD lost to PA)	5, 7 and 10	2 + 1 + 3 = 6

Referring to the above, the movement of craftsmen's activity from one category to another can be now shown in Table F.13.

Table F.13 Numbers retained, gained and lost at the second study

	From category	To category ET	MD	PA
304	ET	285	14	5
103	MD	11	86	6
43	PA	6	6	31
		302	106	42

Having obtained numbers retained, gained and lost for each category, the resulting probability transition matrix is described in Table F.14.

Table F.14 Transition matrix for the three categories

From category	To category ET	MD	PA
ET	0.9375	0.0461	0.0164
MD	0.1068	0.8350	0.0583
PA	0.1395	0.1395	0.7209

F.3.2. Initial Conditions

According to the results of the second study of site 3, the working time is divided 67.11% (302/450) to effective work, 23.56% (106/450) to management delays and 9.33% (42/450) to personal allowances (see Figure 8.17). The initial conditions are thus described by the row vector.

$$[0.6711 \quad 0.2356 \quad 0.0933]$$

F.3.3. Predicting Future States and Steady State

Prediction of future states and steady state of site 3 are summarised in Table F.15.

Table F.15 Reaching steady state

Period (t)	Transition Matrix (P^t)	System state p(t)
0		$\begin{bmatrix} 0.671 & 0.236 & 0.093 \end{bmatrix}$
1	$\begin{bmatrix} 0.938 & 0.046 & 0.016 \\ 0.107 & 0.835 & 0.058 \\ 0.140 & 0.140 & 0.721 \end{bmatrix}$	$\begin{bmatrix} 0.667 & 0.241 & 0.092 \end{bmatrix}$
2	$\begin{bmatrix} 0.886 & 0.084 & 0.030 \\ 0.197 & 0.710 & 0.092 \\ 0.246 & 0.224 & 0.530 \end{bmatrix}$	$\begin{bmatrix} 0.664 & 0.244 & 0.091 \end{bmatrix}$
4	$\begin{bmatrix} 0.809 & 0.141 & 0.050 \\ 0.338 & 0.542 & 0.121 \\ 0.393 & 0.298 & 0.309 \end{bmatrix}$	$\begin{bmatrix} 0.659 & 0.250 & 0.091 \end{bmatrix}$
8	$\begin{bmatrix} 0.722 & 0.205 & 0.073 \\ 0.504 & 0.377 & 0.119 \\ 0.540 & 0.309 & 0.151 \end{bmatrix}$	$\begin{bmatrix} 0.654 & 0.255 & 0.091 \end{bmatrix}$
16	$\begin{bmatrix} 0.664 & 0.248 & 0.088 \\ 0.618 & 0.282 & 0.100 \\ 0.627 & 0.274 & 0.099 \end{bmatrix}$	$\begin{bmatrix} 0.650 & 0.258 & 0.092 \end{bmatrix}$
42	$\begin{bmatrix} 0.649 & 0.259 & 0.092 \\ 0.648 & 0.259 & 0.092 \\ 0.649 & 0.259 & 0.092 \end{bmatrix}$	$\begin{bmatrix} 0.649 & 0.259 & 0.092 \end{bmatrix}$
43	$\begin{bmatrix} 0.649 & 0.259 & 0.092 \\ 0.649 & 0.259 & 0.092 \\ 0.649 & 0.259 & 0.092 \end{bmatrix}$	$\begin{bmatrix} 0.649 & 0.259 & 0.092 \end{bmatrix}$
44	$\begin{bmatrix} 0.649 & 0.259 & 0.092 \\ 0.649 & 0.259 & 0.092 \\ 0.649 & 0.259 & 0.092 \end{bmatrix}$	$\begin{bmatrix} 0.649 & 0.259 & 0.092 \end{bmatrix}$

The Markov process predicts that, during the next 43 months, site 3 will achieve its steady state and its effective time will be 64.9%, while management delays and personal allowances will account for 25.9% and 9.2%, respectively.

F.4 Site 4

F.4.1. Developing Probability Transition Matrix

Table F.16 Net changes in number observed and movement of craftsmen's activity from one category to another of the three categories

Sample	The first study			The second study			Net gains/losses		
no.	ET	MD	PA	ET	MD	PA	ET	MD	PA
1	13	25	2	15	23	2	2	-2	0
2	25	9	6	22	9	9	-3	0	3
3	19	16	5	20	16	4	1	0	-1
4	28	6	6	19	16	5	-9	10	-1
5	18	13	9	20	10	10	2	-3	1
6	15	23	2	17	17	6	2	-6	4
7	16	16	8	20	15	5	4	-1	-3
8	17	14	9	12	17	11	-5	3	2
9	16	12	12	20	13	7	4	1	-5
10	21	15	4	32	6	2	11	-9	-2
Subtotal	188	149	63	197	142	61	9	-7	-2
Total		400			400			0	

According to Table F.16, the calculation of movement of craftsmen's activity from one category to another can be identified, as shown in Table F.17.

Table F.17 Calculation of the movement of craftsmen's activity from one category to another

Order	Sample no.	Total number
ET retained	1-10	13 + 22 + 19 + 19 + 18 + 15 + 16 + 12 + 16 + 21 = 171
ET gained from MD (MD lost to ET)	1, 5, 6, 7 and 10	2 + 2 + 2 + 1 + 9 = 16
ET gained from PA (PA lost to ET)	3, 7, 9 and 10	1 + 3 + 4 + 2 = 10
MD retained	1-10	23 + 9 + 16 + 6 + 10 + 17 + 15 + 14 + 12 + 6 = 128
MD gained from ET (ET lost to MD)	4 and 8	9 + 3 = 12
MD gained from PA (PA lost to MD)	4 and 9	1 + 1 = 2
PA retained	1-10	2 + 6 + 4 + 5 + 9 + 2 + 5 + 9 + 7 + 2 = 51
PA gained from ET (ET lost to PA)	2 and 8	3 + 2 = 5
PA gained from MD (MD lost to PA)	5 and 6	1 + 4 = 5

Referring to the above, the movement of craftsmen's activity from one category to another can be now shown in Table F.18.

Table F.18 Numbers retained, gained and lost at the second study

		To category		
	From category	ET	MD	PA
188	ET	171	12	5
149	MD	16	128	5
63	PA	10	2	51
		197	142	61

Having obtained numbers retained, gained and lost for each category, the resulting probability transition matrix is described in Table F.19.

Table F.19 Transition matrix for the three categories

	To category		
From category	ET	MD	PA
ET	0.9096	0.0638	0.0266
MD	0.1074	0.8591	0.0336
PA	0.1587	0.0317	0.8095

F.4.2. Initial Conditions

According to the results of the second study of site 4, the working time is divided 49.25% (197/400) to effective work, 35.50% (142/400) to management delays and 15.25% (61/400) to personal allowances (see Figure 8.23). The initial conditions are thus described by the row vector.

$$[0.4925 \quad 0.3550 \quad 0.1525]$$

F.4.3. Predicting Future States and Steady State

Prediction of future states and steady state of site 1 are summarised in Table F.20.

Table F.20 Reaching steady state

Period (t)	Transition Matrix (P^t)	System state p(t)
0		$\begin{bmatrix} 0.493 & 0.355 & 0.153 \end{bmatrix}$
1	$\begin{bmatrix} 0.910 & 0.064 & 0.027 \\ 0.107 & 0.859 & 0.034 \\ 0.159 & 0.032 & 0.810 \end{bmatrix}$	$\begin{bmatrix} 0.510 & 0.341 & 0.148 \end{bmatrix}$
2	$\begin{bmatrix} 0.838 & 0.114 & 0.048 \\ 0.195 & 0.746 & 0.059 \\ 0.276 & 0.063 & 0.661 \end{bmatrix}$	$\begin{bmatrix} 0.524 & 0.330 & 0.145 \end{bmatrix}$
4	$\begin{bmatrix} 0.738 & 0.183 & 0.078 \\ 0.326 & 0.582 & 0.092 \\ 0.426 & 0.120 & 0.453 \end{bmatrix}$	$\begin{bmatrix} 0.544 & 0.315 & 0.140 \end{bmatrix}$
8	$\begin{bmatrix} 0.638 & 0.251 & 0.110 \\ 0.469 & 0.410 & 0.121 \\ 0.547 & 0.203 & 0.250 \end{bmatrix}$	$\begin{bmatrix} 0.564 & 0.300 & 0.135 \end{bmatrix}$
16	$\begin{bmatrix} 0.586 & 0.286 & 0.128 \\ 0.558 & 0.310 & 0.132 \\ 0.581 & 0.271 & 0.147 \end{bmatrix}$	$\begin{bmatrix} 0.575 & 0.292 & 0.132 \end{bmatrix}$
33	$\begin{bmatrix} 0.577 & 0.291 & 0.132 \\ 0.577 & 0.291 & 0.132 \\ 0.577 & 0.290 & 0.132 \end{bmatrix}$	$\begin{bmatrix} 0.577 & 0.291 & 0.132 \end{bmatrix}$
34	$\begin{bmatrix} 0.577 & 0.291 & 0.132 \\ 0.577 & 0.291 & 0.132 \\ 0.577 & 0.291 & 0.132 \end{bmatrix}$	$\begin{bmatrix} 0.577 & 0.291 & 0.132 \end{bmatrix}$
35	$\begin{bmatrix} 0.577 & 0.291 & 0.132 \\ 0.577 & 0.291 & 0.132 \\ 0.577 & 0.291 & 0.132 \end{bmatrix}$	$\begin{bmatrix} 0.577 & 0.291 & 0.132 \end{bmatrix}$

The Markov process predicts that, during the next 34 months, site 4 will achieve its steady state and its effective time will be 57.7%, while management delays and personal allowances will account for 29.1% and 13.2%, respectively. Fortunately, within the next 8 months, a significant improvement should be obvious, as at that period, the effective time of site 2 is predicted to be around 56.4%, which is close to the 57.7% which will be achieved in its steady state.

Appendix G: "Example of Data Recorded (Second Study for Site 1)"

OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2111
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/07/2001 Time: 8.56 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1		1		1	1								
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1										Fitter
217 Waiting for other crews				1					1	1						
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
11
12
13
14
15

OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2112
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/07/2001 Time: 9.17 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1			1	1	1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1										Fitter
217 Waiting for other crews										1						
220 Personal Allowances																
221 Taking a break					1											
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
11
12
13
14
15

OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2113

Observer: Arun Makulsawatudom No. of craftsmen observed: 10

Date: 11/07/2001 Time: 10.22 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1				1		1									
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter(5), Welder (6)
217 Waiting for other crews		1	1	1					1							
220 Personal Allowances																
221 Taking a break										1						
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
11
12
13
14
15

OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2114
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/07/2001 Time: 11.16 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1							1	1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection							1									Penetration test
216 Waiting for other trades						1		1								Fitter(5), Welder(8)
217 Waiting for other crews			1	1												
220 Personal Allowances																
221 Taking a break																
222 Personal needs					1											
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
11
12
13
14
15

OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2115
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/07/2001 Time: 13.15 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1		1	1	1					1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment		1														M/C breakdown
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1	1							Fitter, Welder, QA
217 Waiting for other crews							1									
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
11
12
13
14
15

OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2116
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/07/2001
Time: 13.58 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1													
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment							1									Crane
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								
217 Waiting for other crews					1	1			1	1						
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2117
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/07/2001 Time: 14.22 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work		1	1	1	1		1	1								
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1										Fitter
217 Waiting for other crews									1	1						
220 Personal Allowances																
221 Taking a break	1															
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2118
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/07/2001 Time: 15.25 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1		1	1			1								
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews									1							
220 Personal Allowances																
221 Taking a break			1							1						
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2119
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/07/2001 Time: 15.52 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work		1	1	1	1			1		1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break									1							
222 Personal needs	1															
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2121
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/08/2001
Time: 8.34 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1				1	1	1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment					1											Grinder (wire)
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2122
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/08/2001 Time: 9.29 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1		1	1				1		1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials		1														L beam
212 Waiting for tools																
213 Waiting for equipment					1											Grinder (wire)
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break									1							
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2123
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/08/2001 Time: 10.48 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work		1	1	1				1	1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break	1									1						
222 Personal needs					1											
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2124
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/08/2001
Time: 11.46 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work		1							1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades																
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays	1		1	1	1	1	1	1		1						Late start/early finish
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2125
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/08/2001
Time: 13.13 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1	1			1	1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Welder
217 Waiting for other crews										1						
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2126
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/08/2001 Time: 13.41 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1		1		1			1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews				1					1							
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2127
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/08/2001 Time: 14.35 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1		1			1		1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break									1							
222 Personal needs				1												
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2128
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/08/2001 Time: 15.52 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1			1		1			1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews				1												
220 Personal Allowances																
221 Taking a break			1						1							
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2129
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/08/2001 Time: 16.27 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1			1			1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews					1				1							
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2131
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/09/2001 Time: 8.27 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1	1		1		1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews										1						
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2132
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/09/2001 Time: 8.50 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1			1									
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews					1					1	1					
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2133
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/09/2001 Time: 10.02 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1		1				1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews				1						1						
220 Personal Allowances																
221 Taking a break								1								
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2134
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/09/2001 Time: 11.23 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1		1		1		1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews				1						1						
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2135
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/09/2001 Time: 11.51 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work		1														
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1										
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays	1		1	1	1		1	1	1	1						Late start/early finish
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2136
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/09/2001
Time: 14.44 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1		1					1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews				1					1							
220 Personal Allowances																
221 Taking a break							1									
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2137
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/09/2001 Time: 15.07 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1	1			1								
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews									1							
220 Personal Allowances																
221 Taking a break										1						
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2138
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/09/2001 Time: 16.01 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work		1	1	1	1		1		1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment	1															Cutting m/c breakdown
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews										1						
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2139
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/09/2001 Time: 16.25 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1			1			1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction					1											
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews									1							
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2141
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/10/2001 Time: 8.18 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1		1	1			1	1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools								1								Personal protection
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades							1									
217 Waiting for other crews				1												
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2142
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/10/2001 Time: 9.29 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1		1		1		1									
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment		1														Motor removed
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews									1	1						
220 Personal Allowances																
221 Taking a break				1												
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2143
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/10/2001
Time: 10.37 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1		1	1	1			1	1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment		1														Motor removed
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews										1						
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2144
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/10/2001 Time: 11.19 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1	1											
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction							1									
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break									1	1						
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2145
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/10/2001
Time: 11.45 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work		1														
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction							1									
215 Waiting for inspection																
216 Waiting for other trades						1										Fitter
217 Waiting for other crews									1							
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays	1		1	1	1			1		1						
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2146
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/10/2001 Time: 13.19 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1					1	1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment										1						
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Welder
217 Waiting for other crews				1	1											
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2147
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/10/2001 Time: 13.48 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1		1	1			1		1	1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews					1											
220 Personal Allowances																
221 Taking a break		1														
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2148
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/10/2001 Time: 14.40 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1	1			1		1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment									1							
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2149
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/10/2001 Time: 15.14 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work			1	1					1	1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction		1														
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break	1				1			1								
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2151
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/11/2001 Time: 8.13 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1		1	1	1	1	1			1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment									1							
214 Waiting for instruction		1														
215 Waiting for inspection																
216 Waiting for other trades								1								Welder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2152
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/11/2001
Time: 8.54 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1		1	1	1		1		1	1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment		1														Motor removed
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2153
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/11/2001 Time: 9.22 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1	1	1	1				1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment										1						
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs							1									
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2154
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/11/2001 Time: 9.44 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1					1		1	1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection																
216 Waiting for other trades						1		1								Fitter, Welder
217 Waiting for other crews				1												
220 Personal Allowances																
221 Taking a break					1											
222 Personal needs			1													
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2155
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/11/2001 Time: 10.07 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1		1	1	1		1	1	1	1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction		1														
215 Waiting for inspection																
216 Waiting for other trades						1										Fitter
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 2156
Observer: Arun Makulsawatudom
No. of craftsmen observed: 10
Date: 11/11/2001 Time: 10.40 hrs.
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1		1		1			1								
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment										1						
214 Waiting for instruction		1														
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Grinder
217 Waiting for other crews				1												
220 Personal Allowances																
221 Taking a break									1							
222 Personal needs																
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2157
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/11/2001 Time: 13.00 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work					1			1	1							
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction																
215 Waiting for inspection							1									Welding
216 Waiting for other trades						1										Fitter
217 Waiting for other crews																
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays	1	1	1	1						1						Late start/early finish
240 No Contact																

Craftsmen key

1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 2158
Observer: Arun Makulsawatudom No. of craftsmen observed: 10
Date: 11/11/2001 Time: 15.15 hrs. Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work			1	1				1								
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment									1							
214 Waiting for instruction		1														
215 Waiting for inspection																
216 Waiting for other trades						1	1									Fitter, Welder
217 Waiting for other crews										1						
220 Personal Allowances																
221 Taking a break					1											
222 Personal needs	1															
230 Miscellaneous Delays																
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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OBSERVATION RECORDING SHEET

Project: Factory Italian-Thai Industrial Complex
Observer: Arun Makulsawatudom
Date: 11/11/2001 Time: 16.30 hrs.
Reference: 2159
No. of craftsmen observed: 10
Total observation No.: 10

Category	Craftsman															Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	1	1							1	1						
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials																
212 Waiting for tools																
213 Waiting for equipment																
214 Waiting for instruction							1									
215 Waiting for inspection																
216 Waiting for other trades						1		1								
217 Waiting for other crews				1												
220 Personal Allowances																
221 Taking a break																
222 Personal needs																
230 Miscellaneous Delays			1		1											Late start/early finish
240 No Contact																

Craftsmen key
1 Mr. C Tinnawin (mark/cut)
2 Mr. N Sutnait (fitter)
3 Mr. M Chiengda (fitter)
4 Mr. T Wangsook (fitter)
5 Mr. P Waigaysri (fitter)
6 Miss S Sarnchompoo (welder)
7 Mr. S Pongpeude (welder)
8 Mrs. S Yapun (finisher)
9 Mr. C Toomme (rigger)
10 Mr. B Daothong (rigger)
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DAILY SUMMARY SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 211
Observer: Arun Makulsawatudom
No. of rounds observed: 9
Date: 11/07/2001 Day: 1
Total observation No.: 90

Category	Observation round 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
100 Effective Work	6	7	3	4	5	3	6	5	6							45
200 Ineffective Work																0
210 Management Delays																
211 Waiting for materials	0	0	0	0	0	0	0	0	0							0
212 Waiting for tools	0	0	0	0	0	0	0	0	0							0
213 Waiting for equipment	0	0	0	0	1	1	0	0	0							2
214 Waiting for instruction	0	0	0	0	0	0	0	0	0							0
215 Waiting for inspection	0	0	0	1	0	0	0	0	0							1
216 Waiting for other trades	1	1	2	2	3	2	1	2	2							16
217 Waiting for other crews	3	1	4	2	1	4	2	1	0							18
220 Personal Allowances																
221 Taking a break	0	1	1	0	0	0	1	2	1							6
222 Personal needs	0	0	0	1	0	0	0	0	1							2
230 Miscellaneous Delays	0	0	0	0	0	0	0	0	0							0
240 No Contact	0	0	0	0	0	0	0	0	0							0
Total	10	10	10	10	10	10	10	10	10							90

Observation times key

1 8.56 hrs.
2 9.17 hrs.
3 10.22 hrs.
4 11.16 hrs.
5 13.15 hrs.
6 13.58 hrs.
7 14.22 hrs.
8 15.25 hrs.
9 15.52 hrs.
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Comments: 1. 2nd phase's welders worked only the first two hours, after that they had to
2. Finishers had very small amount of works. wait for work from the fitters.
3. 1st phase's welders spent most of the time wait for work from the fitters.

DAILY SUMMARY SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 212
Observer: Arun Makulsawatudom No. of rounds observed: 9
Date: 11/08/2001 Day: 2 Total observation No.: 90

Category	Observation round															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	7	5	5	2	7	6	6	5	6							49
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials	0	1	0	0	0	0	0	0	0							1
212 Waiting for tools	0	0	0	0	0	0	0	0	0							0
213 Waiting for equipment	1	1	0	0	0	0	0	0	0							2
214 Waiting for instruction	0	0	0	0	0	0	0	0	0							0
215 Waiting for inspection	0	0	0	0	0	0	0	0	0							0
216 Waiting for other trades	2	2	2	0	2	2	2	2	2							16
217 Waiting for other crews	0	0	0	0	1	2	0	1	2							6
220 Personal Allowances																
221 Taking a break	0	1	2	0	0	0	1	2	0							6
222 Personal needs	0	0	1	0	0	0	1	0	0							2
230 Miscellaneous Delays	0	0	0	8	0	0	0	0	0							8
240 No Contact	0	0	0	0	0	0	0	0	0							0
Total	10	10	10	10	10	10	10	10	10							90

Observation times key

1 8.34 hrs.
2 9.29 hrs.
3 10.48 hrs.
4 11.46 hrs.
5 13.13 hrs.
6 13.41 hrs.
7 14.35 hrs.
8 15.52 hrs.
9 16.27 hrs.
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Comments: 1. 2nd phase's welders and finishers took turns for correcting job, but most of the time still idle.
2. 1st phase's welders spent most of the time wait for work from the fitters.

DAILY SUMMARY SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 213
Observer: Arun Makulsawatudom No. of rounds observed: 9
Date: 11/09/2001 Day: 3 Total observation No.: 90

Category	Observation round															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	7	5	5	6	1	5	6	6	6							47
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials	0	0	0	0	0	0	0	0	0							0
212 Waiting for tools	0	0	0	0	0	0	0	0	0							0
213 Waiting for equipment	0	0	0	0	0	0	0	1	0							1
214 Waiting for instruction	0	0	0	0	0	0	0	0	1							1
215 Waiting for inspection	0	0	0	0	0	0	0	0	0							0
216 Waiting for other trades	2	2	2	2	1	2	2	2	2							17
217 Waiting for other crews	1	3	2	2	0	2	1	1	1							13
220 Personal Allowances																
221 Taking a break	0	0	1	0	0	1	1	0	0							3
222 Personal needs	0	0	0	0	0	0	0	0	0							0
230 Miscellaneous Delays	0	0	0	0	8	0	0	0	0							8
240 No Contact	0	0	0	0	0	0	0	0	0							0
Total	10	10	10	10	10	10	10	10	10							90

Observation times key

1	8.27 hrs.	6	14.44 hrs.	11	
2	8.50 hrs.	7	15.07 hrs.	12	
3	10.02 hrs.	8	16.01 hrs.	13	
4	11.23 hrs.	9	16.25 hrs.	14	
5	11.51 hrs.	10		15	

Comments: 1. 2nd phase's welders and finishers took turns for correcting job, but most of the time still idle.
2. 1st phase's welders spent most of the time wait for work from the fitters.

DAILY SUMMARY SHEET

Project: Factory Italian-Thai Industrial Complex
Reference: 214
Observer: Arun Makulsawatudom
No. of rounds observed: 9
Date: 11/10/2001 Day: 4
Total observation No.: 90

Category	Observation round															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	7	4	6	5	1	5	6	7	4							45
200 Ineffective Work																0
210 Management Delays																0
211 Waiting for materials	0	0	0	0	0	0	0	0	0							0
212 Waiting for tools	1	0	0	0	0	0	0	0	0							1
213 Waiting for equipment	0	1	1	0	0	1	0	1	0							4
214 Waiting for instruction	0	0	0	1	1	0	0	0	1							3
215 Waiting for inspection	0	0	0	0	0	0	0	0	0							0
216 Waiting for other trades	1	2	2	2	1	2	2	2	2							16
217 Waiting for other crews	1	2	1	0	1	2	1	0	0							8
220 Personal Allowances																0
221 Taking a break	0	1	0	2	0	0	1	0	3							7
222 Personal needs	0	0	0	0	0	0	0	0	0							0
230 Miscellaneous Delays	0	0	0	0	6	0	0	0	0							6
240 No Contact	0	0	0	0	0	0	0	0	0							0
Total	10	10	10	10	10	10	10	10	10							90

Observation times key

1 8.18 hrs.
2 9.29 hrs.
3 10.37 hrs.
4 11.19 hrs.
5 11.45 hrs.
6 13.19 hrs.
7 13.48 hrs.
8 14.40 hrs.
9 15.14 hrs.
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11
12
13
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Comments: 1. 2nd phase's welders and finishers most of the time were idle.
2. 1st phase's welder spent most of the time wait for work from the fitters.
3. The cutting m/c's motor was removed, so job can not be done.
However, packing steel rod was assigned, but at the end was idle.

DAILY SUMMARY SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 215
Observer: Arun Makulsawatudom No. of rounds observed: 9
Date: 11/11/2001 Day: 5 Total observation No.: 90

Category	Observation round															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
100 Effective Work	7	7	6	5	8	4	3	3	4							47
200 Ineffective Work																
210 Management Delays																
211 Waiting for materials	0	0	0	0	0	0	0	0	0							0
212 Waiting for tools	0	0	0	0	0	0	0	0	0							0
213 Waiting for equipment	1	1	1	0	0	1	0	1	0							5
214 Waiting for instruction	1	0	0	0	1	1	0	1	1							5
215 Waiting for inspection	0	0	0	0	0	0	1	0	0							1
216 Waiting for other trades	1	2	2	2	1	2	1	2	2							15
217 Waiting for other crews	0	0	0	1	0	1	0	1	1							4
220 Personal Allowances																
221 Taking a break	0	0	0	1	0	1	0	1	0							3
222 Personal needs	0	0	1	1	0	0	0	1	0							3
230 Miscellaneous Delays	0	0	0	0	0	0	5	0	2							7
240 No Contact	0	0	0	0	0	0	0	0	0							0
Total	10	10	10	10	10	10	10	10	10							90

Observation times key

1 8.13 hrs.
2 8.54 hrs.
3 9.22 hrs.
4 9.44 hrs.
5 10.07 hrs.
6 10.40 hrs.
7 13.00 hrs.
8 15.15 hrs.
9 16.30 hrs.
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Comments: 1. The removed motor has not been reinstalled, so mark/cut were idle most of the day.
2. 2nd phase's welders and finishers most of the time were idle.
3. 1st phase's welder spent most of the time wait for work from the fitters.

STUDY SUMMARY SHEET

Project Factory Italian-Thai Industrial Complex Reference: 21
No. of rounds observed: 45 Study period: 5 days
Total observation No.: 450 Start date: 07/11/2001 Finsish date: 11/11/2001

Category	Observation day										Total
	1	2	3	4	5	6	7	8	9	10	
100 Effective Work	45	49	47	45	47						233
200 Ineffective Work											
210 Management Delays											
211 Waiting for materials	0	1	0	0	0						1
212 Waiting for tools	0	0	0	1	0						1
213 Waiting for equipment	2	2	1	4	5						14
214 Waiting for instruction	0	0	1	3	5						9
215 Waiting for inspection	1	0	0	0	1						2
216 Waiting for other trades	16	16	17	16	15						80
217 Waiting for other crews	18	6	13	8	4						49
220 Personal Allowances											
221 Taking a break	6	6	3	7	3						25
222 Personal needs	2	2	0	0	3						7
230 Miscellaneous Delays	0	8	8	6	7						29
240 No Contact	0	0	0	0	0						0
Total	90	90	90	90	90						450

Observation date key:

1 07/11/2001
2 08/11/2001
3 09/11/2001
4 10/11/2001
5 11/11/2001
6
7
8
9
10

Comments:

STUDY ANALYSIS SHEET

Project: Factory Italian-Thai Industrial Complex Reference: 21
No. of rounds observed: 45 Study period: 5 days
Total observation No. : 450 Start date: 07/11/2001 Finish date: 11/11/2001

Category	Total	Percentage (%)
100 Effective Work	233	51.78
200 Ineffective Work	217	48.22
210 Management Delays	156	34.67
211 Waiting for materials	1	0.22
212 Waiting for tools	1	0.22
213 Waiting for equipment	14	3.11
214 Waiting for instruction	9	2.00
215 Waiting for inspection	2	0.44
216 Waiting for other trades	80	17.78
217 Waiting for other crews	49	10.89
220 Personal Allowances	32	7.11
221 Taking a break	25	5.56
222 Personal needs	7	1.56
230 Miscellaneous Delays	29	6.44
240 No Contact	0	0.00
Total	450	100.00