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FIELD RESEARCH ON THE NATURE OF ENGINEERING WORK

by

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ABSTRACT

By employing a field research method, the researcher studied engineers' activities in natural, unaltered settings and in a non-restrictive, non-judgmental way. Ten engineers in six organizations were studied closely and comprehensively. The description of the nature of engineering work is developed in three dimensions: the engineer's working roles, the characteristics of engineer's activities, and the engineer's knowledge.

The categorization of the purpose of engineer's activity leads to the development of six working roles. Engineering activities and engineer's roles may be grouped into three categories: those that deal primarily with data---the collector role and the consultant/mentor role; those relating to organizing and facilitating work---the administrator role and the overseer role; and those that involve finding solutions, creating ideas, and making significant judgment---the historian role and the adapter/inventor role. These six roles describe the essential contents of engineers' activities. They form the theory of what engineers do in their daily work.

Through an analysis of how engineers spent their time, detailed descriptions about characteristics of engineers' activities are presented in the thesis, including phone calls, conversations, meetings, desk work, computer work, tours, and travel. The most important two findings are: (1) engineers' activities are characterized by fragmentation, brevity, and interruption; (2) engineers spend a surprisingly large part of time (over 40% in this study) in communicating with others.

Based on the analysis of engineer's working roles, it is reasoned that engineer's knowledge can be categorized into five groups: theoretic tools, stock solutions, symbol-material linkages, operational considerations, and access to distributed knowledge.

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SETTING THE CONTEXT FOR THE STUDY

1.1 Introduction

With the development of the society and technology, the demographic trends in the work force have been changing significantly. Engineering as a profession is expanding very quickly. According to the U. S. Bureau of the Census (1981), "in the past 50 years, the civilian labour force and population have about doubled, but the number of engineers has increased sixfold." In recent years, the increasing growth and complexity of science and technology, and the problems related to growth including environmental concerns and energy shortages have created increasing demands for engineers throughout the world. It can be expected that the number of engineers will increase at an even higher rate in the 21st century.

In the last decade, the role of the engineers in our society has also expanded dramatically. We face major problems in supplying energy, protecting the environment, providing safer and more efficient transportation, and increasing productivity. We must improve communication, speed the processing of information, and facilitate solving problems of increasing complexity. We need to apply technological advances to improve the quality and quantity of food and water, and the effectiveness of medical diagnosis and health care. We have to solve the problems of inner cities while we learn more about outer space. For the solution of these and other pressing problems, society will look to the engineering profession. In today's society, engineering permeates every corner of our life. The Royal Bank of Canada in their monthly letter of Sept./Oct. 1986 stated: "We in the developed countries live in the realm of the engineer. From the moment we turn on the water in the morning until we turn off the lights at night, we are surrounded by engineered structures, systems, products and processes. They help to feed, shelter, cloth, transport, comfort and entertain us, and allow us to communicate invisibly with one another. No matter what we do for a living, much of our work is done with things made by engineers."

However, when we ask the question, "what do engineers do in their daily work?" we will quickly find that it is very difficult to formulate a comprehensive answer. Many engineers who are asked about this question will have a similar feeling to S. C. Florman's (1992):

> "The story is told about Beethoven, who, after having performed one of his piano sonatas, was asked by a member of the audience to describe what the piece "meant." After a moment's thought, Beethoven turned back to his piano and played the sonata again. I think of this anecdote whenever I come upon someone trying to formulate a comprehensive theory about engineering--- what it is, and about engineers --- what they do and how they do it, what they know and how they know it."

Walter G. Vincenti, a professor emeritus of aeronautical engineering at Stanford University and a member of the National Academy of Engineering, wrote in the preface of his book (1990), *What Engineers Know and How They Know It*, "My involvement in the study of engineering knowledge stems in part from a question put to me by my Stanford economics colleague Nathan Rosenberg over lunch in the early 1970s: 'What is it you engineers really do?' What engineers do, however, depends on what they know. ... My attempts to deal with Rosenberg's question led me therefore-without at first realizing just what I was doing-to examine the cognitive dimension of engineering." In this book, he analyzed five important cases from aeronautical history, and provided many important insights about engineer's knowledge. However, since only those important events were recorded in the history, and those five cases involved long time collective effort of whole aeronautical engineering society, his book did not tell much about an individual engineer's activities in daily work. As a result, what engineers do in their workplace is still unclear.

In July 1983, twenty historians of technology met with an equal number of engineers at a three-day conference at the National Academy of Sciences in Washington. The conference was devoted to historical presentations on American engineering and discussion of the relevance of these historical cases to the formation of contemporary policy. The intense discourse the engineers and historians engaged in during those three days concluded that they could not pursue the objectives of the conference before they had a complete understanding of the nature of engineering, and they just could not reach a consensus about what "engineering" is. It soon became clear that, while the engineers indeed knew a great deal about their profession, their views were not informed by a common concept of what engineering is. Hence, those participating in this conference quickly found themselves thrown into a more honest, if also somewhat threatening common enterprise, one that involved asking: What is engineering? At the end of the conference, there was a shared sense of urgency, but little agreement on this question.

Sociologists also showed interest in studying the engineer. Their focuses were primarily on the engineer's social status: professionalism and unionism. The literature is dominated by the research in collective social significance of engineering organizations. However, few did studies by closely examining engineers in the everyday practice of their work. Considerable criticisms (Zussman 1985; Whalley 1986; Crawford 1987) were put on this drawback which obviously limited the significance and meaningfulness of these studies and discussions in this field. Without empirical research, much of the writing often appears to be the outcome of logical analysis.

Obviously, there are a number of difficulties in studying the nature of engineering work. First, to describe engineering work is to describe a process. To study a process, the researcher must observe the whole process directly and closely, and collect the data at every point in the process. Secondly, the range and scope of engineer's work are large, and most engineering work takes place in long cycles. Often, there is seemingly little pattern in the activities. So, unlike the work of an assembly line worker, the engineer's total cycle can not be observed over a few hours. Thirdly, there is considerable variation from engineer to engineer, not only from industry to industry, or company to company, but also from department to department and even within departments of a single company. To understand the nature of engineering work, the researcher must study engineer's activities deeply in real context, under which the activities happen. During the period of field observation, the researcher must work like an engineer to make sure that he understands the meaning of every activity initiated by the engineer. Leonard R. Sayles said in the Foreword of Mintzberg's "The nature of managerial work" (Mintzberg 1973), "Regrettably, the rush to easy qualification — to the questionnaire that can be administered by a graduate student and evaluated by a computer — dissuades most social scientists from painstaking and painful examination of what human beings do as distinct from their perceptions, whimsies, and wishes. (It is always easier to ask than to see.)"

Yet, these difficulties by no means excuse us from the responsibility to describe what engineers do. Indeed, each of them represents a gap in our knowledge. Thus, to take note of these difficulties serves only to whet our appetite for some detail and more evidence.

1.2 The Significance of Research on Engineer's Work

As discussed above, engineering permeates every corner of our life. The development of our society depends largely on the engineers' work. The national overall productivity, the competitiveness of our products in the international markets, and people's living level are all directly related to the productivity of engineering work. Thus, how to enhance engineers' productivity is the matter of vital concern in our society. Over the last decade, new ideas for increasing engineers' productivity have proliferated. Team work, peer assessment, flat structure, and telecommuting are but a partial list. However, in those instances where changes have been tracked and measured, acceptance is limited, results marginal, and success elusive. In retrospect, this is not surprising because thorough understanding of a process is an essential prerequisite to alteration, adaptation, or improvement, and this does not exist. Without the clear picture of what engineers do, we can not know in advance which methods will work, when they work, where they work, and why they work. Because of the lack of a base for judgement, blindness is inevitable in developing, selecting, and applying productivity enhancement methods. This study is trying to provide such a base from which productivity enhancement methods can be assessed.

Peter Meiksins and Chris Smith (1993) mentioned similar blindness in their study. "There is no agreement among the major industrial powers, over such basic questions as, What is an engineer? Where does one draw the line between the professional engineer and the non-professional technician? How and where should engineers be produced? This diversity has spawned a vast "literature of emulation," in which analysts of engineering and industry have attempted to persuade their compatriots that some other country has a superior system for producing and organizing technical workers. Nineteenth-century Americans admired German technical education and the French Ecole Polytechnique (Calvert, 1967), whereas late 19th-century German emulated the practicality of British and American engineering (Gispen, 1989). More recently, critical observers of British engineering have advocated the adoption of elements of German or American practice (Lawrence, 1992), whereas American critics look to Japan for ways to recapture the technological lead (Kinmoth, 1986).

History tells us that technology, organization, and work co-evolve, although cause and effect are difficult to untangle. The changes in technologies are always accompanied by the changes in organizational structure, and the broad shifts in what people do for living. For this reason, "no organizational structure can be optimal unless it is tailored to the technology and the work it seeks to systematize." (Stephen R. Barley, 1996) In an era of widespread economic and technological change, understanding the changing nature of work is important to understand organizing and reorganizing. As Scott (1981) noted, most contemporary organizational theory focuses on an organization's relation with its environment. Stephen R. Barley said (1996), "Although economic pressures, institutional changes, and population dynamics certainly shape organizational strategies and structures, organizations must still make choices about how to organize systems of work effectively to remain viable. Simply acknowledging that work is becoming more and more complex or interdependent does not describe a changing mode of production.

Without answers to questions about what is done, how knowledge is distributed, and how exigencies of work and relations of production are structured, organizational theorists risk telling incomplete and even inaccurate stories about these choices and how and why organizations should change." Through the close observation on engineers' activities, our work can provide the data about what is actually done, how knowledge is used and obtained, and how the engineering work is organized. All these data can be helpful for the development of organization theory.

In today's society, engineers are facing more and more challenges. As J. M. Whiting (1994) notes, some of the factors contributing to these challenges are "lack of clearly-defined social goals, uncertainty, risk, competition, regulations, interaction with society, demand for quality, concern about environmental impact, and the requirement to deal with resources which are either increasingly diffuse or remote from North American markets." The public is placing a new expectation and requirement on engineers. Correspondingly, engineering education has to be reshaped to help engineers meet the new expectation and requirement. "Already there is growing admission within the profession that engineering students emerging from university often do not communicate effectively, are insensitive to social cues, are not open to new ideas, are incapable of critical thinking, can not cope with uncertainty, and can not place technology in its social context." (The PEGG January 1997, p13) There are some criticisms on the present system of engineering education in the university. Norman R. Ball (1997) criticized, "The Canadian recipe for making good engineers is simple: stuff them with the maximum amount of technical information. ...But what use is information all by itself, without context? ...In our lopsided approach to engineering education, we have filled our graduates with answers and failed to teach them how to pose questions. In so doing, we are narrowing the horizons of some of the brightest young people in our country. All too often, we take intelligent, hard-working high school graduates and disable them." He thought Canadian engineering education system can not be fixed with a bit of "fine tuning", because this system is based on an unexamined wrong assumption that (1) there is only one way to design an engineer, and (2) we have nothing to learn from the approach taken in other countries. He also mentioned that Japanese engineering students spend a large part of their time on non-technical subjects. E. S. Fuguson (1992) complained, "...shop courses, as well as courses dealing with design and with the art and practice of engineering, have increasingly been replaced by courses in the theoretical engineering sciences: mechanics, heat transfer, fluid mechanics, and so on. Students are given little introduction to the real world of engineering practice, and develop little understanding or ability in the art of engineering design. The inevitable impact on engineering practice is a growing number of seriously flawed designs and technological failures." Jerry M. Whiting (1994) thought, "we are still doing a very good job of training Resource Engineers in the 'basics'. He or she could not function as an engineer without a solid foundation of math, mechanics, chemistry, and so on. This type of training was appropriately focused, and generally adequate, for a less complex world. However, both the demands to be placed on Resource Engineers in the future, as well as the leadership role they should be expected to play, are not receiving adequate attention in the evolution of degree programs."

While it seems to be pretty certain that engineering education needs changes to meet the new requirement, the question is how to change it. Without answers to questions about what is done, what knowledge and skill are used, and how engineers get the knowledge and skills, we have no base to decide what changes should be made.

With the increasing demands for engineers, it is predicted that there will be a serious shortage of engineers in the 21st century. Some people (O'Reilly 1967; Greenwold 1967; Christenson 1967; Torpey 1966) discussed the possibilities of using technicians to supplement engineers. How to understand the essential difference between engineers' and technicians' work necessarily depends on understanding the true nature of engineering work.

Sociologists are interested in the discussion on the professionalization and de-skilling of engineer's work. In the absence of detailed studies of engineering work, sociologists have often used the collective organization as a surrogate measure of structure change. If employees increasingly join professional associations, then this is used as evidence of professionalization. If employees join unions, then this is used as evidence that their conditions are being de-skilled. Obviously, the reasoning based on such evidence is not logically sound. Our research provides detailed description of engineering work, and identifies the knowledge and skill engineers use. Thus, it can provide sound evidence to remedy this flaw, and help to develop further discussion on this subject.

1.3 Research Questions

The general research question is "what is the nature of engineering work?" However, this general question is proposed to be answered in the following three dimensions:

What are the contents of engineer's work?

What are the characteristics of engineer's activities?

What kinds of knowledge are used in engineer's daily work?

The purpose of this thesis is to begin to answer these three questions and to stimulate others to seek more precise answers to them.

As we can see from above, the research focuses on the details of the process of engineering work. This study will use the pragmatic definition, engineering is what engineers do, as the starting point. If a person's job title is engineer, if their time is billed at engineering rates, if their output is considered engineering service, then what they do during their working day will be considered the practice of engineering, and this is what will be studied in this thesis. Ten engineers in six organizations were studied. They are chosen to be studied according to the following four criteria: (1) they are registered professional engineer; (2) They have engineering degree; (3) Their time is billed at engineering rate; (4) Their organizations provide engineering service.

It needs to be made clear that the word "activity" in this thesis means a series of actions with clear meaning and purpose, such as reading, writing, and drawing. Throughout the thesis, the word "task" means an engineering project, or a part of an engineering project, which is assigned to the engineer. The engineer needs to perform many activities to finish an engineering task.

Chapter 2

LITERATURE REVIEW

Although much material has been published on engineers and engineering, little of it focuses on the study of engineering work. Much of the materials related to "engineering work" are mainly from the fields of sociology, philosophy, history, management, industry engineering, and discussions about the design process. However, most of them were old, published during 1960s and 1970s. Gary, Donovan, and Elliot (1989) explained the reasons in *The Invisible Engineer: How Engineering Ceased to be a Problem in Science and Technology Studies*, "no traditions of research in the American disciplines of sociology, philosophy, or history have systematically inquired into the activity of engineering. A number of attempts to establish sustained studies of engineering have been made, but each ultimately encountered significant conceptual barriers and failed to establish widespread legitimacy. As a result, all three disciplines have externalized engineering from their sets of significant analytic problems."

The purpose of a literature search is to examine what has been studied about engineering and engineers by previous researchers. The lack of the study on engineering work indicates, from another angle, the necessity and the significance of this study. Another purpose is to try to extract the useful findings from those materials. The best starting point is from the definition of engineering work.

2.1 Definitions of Engineering Work

One method of defining engineering work is to use simple sentences to include all kinds of engineering work. For example, the Encyclopaedia Britannia talks about engineering work as: "the optimum conversion of the resources of nature to benefit mankind." Such definitions are so inclusive as to make almost everything engineering. They are similar to Thomas Tredgold's 1828 definition (Hinton of Bankside 1970): "Engineering is the art of directing the great sources of power in nature for the use and convenience of man." Under it, anything and everything can be shoehorned in as engineering work. Besides the input (resources) and the purpose (to benefit mankind) of engineering work, such definitions do not tell enough about what engineering work is.

Many definitions can be categorized as "input-output" type of definitions. The definition by Engineering Council for Professional Development details the knowledge as an input: "Engineering is the profession in which a knowledge of mathematical and natural sciences gained by study, experience and practice is applied with judgement to develop ways to utilize economically and safely the materials and forces of nature for the benefit of mankind." The New Century Dictionary is more interested in the outputs of engineering work: "Engineering: the design and construction of military works, of roads, bridges, canals, etc., of engines or machines, or of any structures or works, requiring special knowledge and application of the principles of mechanics."

The "input-output" type of definitions tell what is needed in engineering work, the purpose of engineering work, and what output engineering work produces. But they tell nothing about the process of engineering work. Questions such as, "how do engineers use these inputs (knowledge, resources, etc.)?", "how do they produce the outputs economically?", remain unanswered. Although we know the inputs and outputs, and therefore can describe what the process should be, we do not have a clear picture of what engineering work actually is in so far as we do not know in detail what engineers do. "Analytical procedures can not be brought to bear on processes that are not well understood" (Mintzberg 1973). So, the "input-output" type of definitions offers little help in understanding the nature of engineering work.

Another set of definitions emphasize the functions of engineering work. When one asks engineers, "what do you do in your work?", the answer will probably be similar to the following definition:

> The practice of professional engineering is any act of planning, designing, composing, evaluating, advising, reporting, directing or supervising, or managing any of the foregoing, that requires the application of engineering principles, and that concerns that safeguarding of life, health, property, economic interests, the public welfare or the environment." (Canadian Council of Professional Engineers) (G.C. Andrew 1992)

The functional type of definition uses many verbs and seems to describe the engineers' activities, but when we check our three dimensions of research questions, we may find that they remain unanswered. To explain the reasons, now we must draw a distinction between the activities and the purpose of the activities. For example, an engineer may make phone calls to get information, look for references, discuss with a supervisor and colleagues, draw, and calculate. The functional purpose of all these activities may be for designing a machine. So, functions such as design, development, management, and evaluation, do not describe the actual activities of engineers at all. At most, each of them represents a group of activities. At least, they are just ways of indicating what we need to observe and describe. But these functions serve to block the search for a deeper understanding of engineering work, because they are so easy, readily available, believable, and stereotyped, and everyone uses them to describe engineering work. The situation is very akin to management texts that use the functional definition and define management as planning, organizing, and controlling. This was the issue Henry Mintzberg studied in his 1968 observational study of managers.

There are a huge number of definitions of engineering work. All of them belong to these three types: inclusive type, input-output type, functional type, or a mix of them. As we can see, from the definitions, we learn very little about, "what is engineering work?"

2.2 Engineering in Sociology

Sociologists are interested in the topics of occupation formation, labour process, and social status. In these discussions of engineering, two broad concepts have dominated the literature: one, that engineers will at last "professionalize"; the other, that engineers will be subjected to a process of "proletarianization."

Professionalization

Bernard Barber (1963) characterized the distinctive social features of professions, such as lawyers and doctors, in terms of:

* a high degree of generalized and systematic knowledge;
* a primary orientation to the community interest rather than to individual self-interest;
* a high degree of self-control of behavior through codes of ethics;
* a system of rewards (monetary and honorary) that is primarily a set of symbols of work achievement and thus ends in themselves, not means to some end of individual self-interest.

A recurring claim in the literature on these "professions" is that professional values and norms differ significantly from those of business enterprises and bureaucratic organizations. Professionals are distinguished not simply by the complex and codified character of their knowledge, but also by their exceptional autonomy and authority in the use of that knowledge. Such autonomy and authority stem in part from the public's trust in professional claims of commitment to client and public welfare and from the public's confidence in occupational self-regulation.

These alleged differences in professional values and norms are said to generate "value conflict" and "role strain" for professionals who work in bureaucratic settings. Some authors such as Kornhauser (1965), and Orth, Bailey & Wolek (1964) identify such conflicts among scientists in industry. However, their studies were limited to scientists and engineers working in research laboratories. There is considerable evidence that this model of conflict between professional and organizational values is not applicable to the majority of industrial engineers. On the basis of a large sample survey, Goldner and Ritti (1967) report that "engineers generally enter industry with non professional goals... are oriented toward entrance into positions of power and participation in the organization rather than simply practicing their specialities... and strongly identify with the organization and its goals."

This is not surprising when one considers the long history of career mobility into management for American engineers. William Wichenden (Noble 1979) found that within fifteen years of graduating from college, about two-thirds of engineering graduates from 1884 to 1924, had become managers. More importantly, such mobility into management represented professional success in the eyes of engineers. A national survey (LeBold 1966) of 4,000 engineering graduates, which was sponsored by American

Society for Engineering Education (ASEE), concluded that engineering school recruits generally came from lower social origins than recruits into medicine, law and the clergy, and that upward social mobility was a primary motivation for selecting an engineering career. Robert Perrucci (1971), one of the survey's authors, announced that a consequence of this mobility experience was that engineers direct their "particular loyalties...to their employers and to organizational careers, rather than to their colleagues." In other words, what was fully formed long before engineers became organizational employees was an employee-orientation. An organizational identity was part of the novice's original conception of an engineering career and was both reinforced and solidified by the social process.

Research on more contemporary engineers supports a view of them as predominantly "local" in orientation rather than "cosmopolitan." Perucci and Gerstl (1969) emphasize the lack of a professional community among engineers and the "relative absence of major conflict between organizational and professional norms concerning autonomy." In short, by the early 1970s, sociologists (Carter 1977; Ritti 1968, 1971; Rothstein 1969; Wilensky 1964) were largely in agreement that analyzing engineers as professionals shed little light on their particular dilemmas and attitudes.

However, with the booming of such "science-based' industries as electronics and aeronautics, many of the writers about post-industrial society (Lane 1966; Etzioni 1968; Galbraith 1968; Bennis and Slater 1968; Touraine 1971) point to the growing importance of "knowledge-based" work. Most notably, Daniel Bell(1973) and Eliot Freidson(1973) have seen new, science-based industry as providing the basis for greater professional power. Not only do engineers have a much greater presence in such companies, but the skills they use there are more theoretical. Such theoretical knowledge not only requires university training, putting it out of the control of employers, but its generality encourages greater inter-company mobility and an orientation to a wider professional audience than does the experiential knowledge used in traditional industries. As Freidson (1973) puts it: “in high-tech industry, the jobs or organizational positions are dependent on management for capital, supportive services, and at least some lines of communication... The tasks of these workers are not. Their tasks are not created by, or dependent on management, nor are the qualifications to perform them so dependent. Finally, evaluation of the performance of the tasks does not rest solely with management.”

Freidson's vision of post-industrial society is one in which the processors of knowledge "hire" capital. The America doctors' relationship with their facilitating hospital becomes a paradigm for the relationship between all kinds of experts and their employers.

This post-industrial thesis has been paralleled at the level of organizational research by predictions of an emergent collegial workplace, as employer are forced to adapt to professional demands. (Bennis, 1973; Burns and Stalker, 1961; Lawrence and Lorsch, 1967; Scott 1966 and 1981).

Proletarianization

If speculation about the professionalization of engineering is modelled only loosely on the historical experience of medicine and law, speculation about proletarianization is modelled more closely on the historical experience of the crafts. In this, the indispensable starting point is Harry Braveman's (1974) *Labor and Monopoly Capital.*

Braveman's book focuses on the historical deskilling of craft and clerical workers. According to Braveman, the proletarianzation of skilled crafts began with the replacement of their autonomy by managerial control. The imposition of such control involved the discontinuation of both the putting-out system and subcontracting, the concentration of craftsmen within the confines of the factory, and the enforcement of regular hours of work. Most important was the development of a fixed division of labour, which, by vesting management with responsibility for co-ordination, divested the craftsmen of knowledge about and responsibility for the overall production process.

The extension of managerial control in the early decades of the twentieth century was realized in part by the widespread adoption of Taylor's program of scientific management. By encouraging analysis and reorganization of the labor process. Taylorism extended managerial control from the simple co-ordination of already existing skills to the very definition of those skills. It encouraged the destruction of traditional apprenticeships, replacing them with shorter periods of training in limited and specialized techniques. Most important, it encouraged the separation of concept from execution.

The attack on craft skills was continued with the introduction of fixed-cycle machinery, which routinized machine tending. Fixed cycle machinery removed responsibility for variations in the speed and quality of production from operators, vesting it instead in those technical departments that design and develop the machinery. By homogenizing skill, it reduced craftsmen to the level of general labor.

Engineers played an important part in the proletarianization of the crafts, both as scientific managers and as designers of the mechanical environment of manual work. At first, these developments increased engineers' autonomy by providing a basis for their authority independent of ownership. Then, Braveman argues that "having become a mass occupation engineering has begun to exhibit, even if faintly, some of the characteristics of other mass employments: rationalization and division of labor, simplification of duties, application of mechanization, a downward drift in relative pay, some unemployment, and some unionization."

Several sociologists (Aronowitz 1971; Carchedi 1977; Kraft 1977; Oppenheimer 1970; Derber 1982, 1983; Meiksins 1982; Larson 1980; Bauer and Cohenh 1980, 1982) have applied deskilling thesis to engineers, and claimed that engineers themselves have become subject to a process of proletarianization similar to that they imposed on the crafts. Derber (1982) claims that "like other workers," professional employees 'have become detail workers, unable to choose their own projects or tasks and forced to work at the rhythms and procedures institutionalized in the job descriptions and standard operating procedures of the organization." Although not yet subjected to the intensive rationalization and control of technical proletarianization," engineers "are deprived of their right to select and formulate their own research objectives," and experience a "loss of control over the organizational uses and application of their technical investigations."

Technization of Work

However, evidence amassed since the early 1980s (Hirschhorn, 1984; Attewell, 1987; Zuboff, 1989; Adler, 1992; Barley, 1996) suggests that work is subjected to a process of "technization". The semi-skilled or unskilled jobs are eliminated, rather than deskilled, coupled with the upskilling or reskilling of jobs that remain. This technization of work appears to proceed along two paths.

The first path is demographic. As firms adopt computer technologies, employment shifts to more highly skilled and often technical occupations. Recent studies (Attewell, 1987; Baran, 1987; Diprete, 1988) of office automation in insurance and banking indicate that computers allow firms to employ fewer clerks, but firms must hire more programmers, systems analysts, and computer technicians. Thus, computer systems seem to shift the skill structure of a firm upward by eliminating low-level jobs and by moderately expanding the number of technical and professional employees.

The second path entails a transformation of existing jobs and relations of production, the reskilling of the workforce. Zuboff (1989) observed that digital control and sensor technologies enabled operators in pulp paper mills to monitor and intervene in production processes by analyzing and manipulating representations displayed on computer screens. By this she concluded that their work has become more abstract, more symbolic, more focused on the intricacies of instrument, and increasingly distanced from its physical and sensory referents. Others who study computer-integrated manufacturing routinely reach similar conclusions (Hirschhorn, 1984; Majchrzak, 1988; Kern and Schumman, 1992). Stephen R. Barley's (1996) study on technicians found that the core of technicians' work lies in creating the linkages between the symbolic and the physical worlds. "Using sophisticated instruments, techniques, and bodies of knowledge, technicians stood with one foot in the material world and the other in a world of representations." A large part of the technicians' knowledge is contextual knowledge which comes from doing. The technicians first reduce physical phenomena to representations and then convey those representations to a professional, who operates on the representations to synthesize a more complex symbolic product. Due to technicians' work, the professionals such as scientists, engineers and doctors do not have to concern themselves with the practical uncertainties of empiricism. Thus, these professionals' work is re-skilled, and the requirement of contextual knowledge on their job is reduced.

These sociological discussions provide some insights about the impact of technology advance on the workplace, and about the skill and knowledge that engineers possess which are helpful to understand how engineers do their jobs.

However, much of the writing often appears to be the outcome of logical analysis rather than empirical research. many criticisms are put on this drawback by sociologists themselves. Peter Whalley wrote (1986): "The professionalization and de-skilling thesis make dramatically opposing claims about the likely impact of new industry on the structure of engineers' work but they are based on very little evidence of the task structure of engineer's work.... Very few investigations have been done of how technical work is actually organized inside the plant. We know little of how engineers or other technical workers see their own positions, or how actual changes in the organization of work might shape such perceptions." Robert Zussman (1985) had the similar statement: "The lack of agreement on these questions stems largely from a pervasive lack of firm empirical grounding, especially of closely observed data on what engineers actually do at work."

For example, Poulantazas (1975) bases his arguments entirely on "theoretical" considerations. Gorz (1976) cites only one conversation with a single "technician", Mallet (1975) reports from interviews with technical workers conducted outside of plants but apparently without the benefit of having spent any time within the plants themselves. Bell (1973) cites census data on the sectional distributions of technical workers but admits himself that "the crucial question is what use is made of scientific personnel within each sector."

"Relying primarily on survey data, often to the exclusion of any workplace observation, most research on engineers has concentrated on the structure of attitudes and opinions rather than on the structure of work itself ... Rarely do we find a discussion of what engineers actually do on the job." (Zussman 1985)

Stephen Crawford (1989) said in his book, "... but except for the work of Zussman and Whalley, none to my knowledge are based on investigations of engineers."

Including Crawford's work, there are three major studies did observation of engineer's work: Zussman's "Mechanics Of The Middle Class", Whalley's "The Social Production Of Technical Work", and Crawford's "Technical Workers In An Advanced Society". These three studies are very similar in the method, content, and conclusion. All of them use the method so called "comparative study", in which interviews and intensive observation of engineers are carried out in two companies, one in an older industry, the other is on advanced industry. By comparing the difference of engineers' work in these two companies, they draw the conclusion about the impact of advanced industry on engineers, and then discuss if engineers' work is de-skilling.

All these three chose the metal products industry as the older industry, and electronics or computer industry as the advanced industry. The main conclusions from these three books are summarized as follows:

(1) Administrative responsibilities pervade most engineering positions outside of the research and development department.

(2) Engineers in both firms are largely autonomous in the day to day performance of their work. Few engineers are under close supervision.

(3) There is little evidence in these observation of systematic differences in the skill level of engineers from older to advanced industry. De-skilling is not a serious problem.

(4) The engineers reported making much greater use of the concrete knowledge they had acquired through experience on the job than of their theoretical training at school.

Though all these studies did address the skill and knowledge used in engineering work, and describe some characteristics, the reference value for this research is limited. Many of our research questions remain unanswered. The first limitation results from that the purpose of sociological research is different from this study. During the observation, they focused on engineers' authority, autonomy, attitudes, and politics towards bureaucracy and unionization, and the career orientation. The data collection relied primarily on the informal interview conducted in the workplace. They did not care about the pace and quantity of engineering work, what media engineers use, what information engineers communicate, and how. Therefore, they can not offer help in these aspects.

The second limitation exists in that their studies assume that the impact of advanced technology on engineering work only happens in the firms in advanced industries such as electronics and computer. In reality, many effects imputed to advanced industry may well permeate every sectors of industry, even every corner of the society. So, it is in doubt that the difference of engineering work between two companies results from the impact of technology advance.

However, although the limitations exist in their studies, their studies are valuable reference materials for this research, because these are the only studies which are based on the observation of engineering work.

2.3 Engineering in Philosophy

The philosophers' interests are only indirectly concerned with engineering. The predominant discussion is about the relation of technological and scientific knowledge. Because technology was generally understood as, referring either to artifacts or to the whole practical, that is, nontheoretical and context-bound, activity involved in their production, philosophers tended to view it either as totally irrelevant to epistemology or, at best, as the product of applying science. However, several contemporary philosophers express their different opinions.

Philosopher of science, Michael Polanyi (1969) contended that scientific and technological are epistemological equivalent because all knowledge is rooted in "tacit knowledge." Best exemplified by the craft skills involved in the use of tools, whether by engineers, artisans, or laymen, tacit knowledge is derived wholly from experience, and hence is both highly contingent and immensely personal in content. Polanyi claimed that it provides the foundation of confidence in all beliefs, including the claims of science, because it constitutes the essential connection between the experience of reality and the commitment to beliefs about reality.

Mario Bunge (1966) drew a sharp line between pure and applied science. Linking engineering to technology and technology to applied science, Bunge identified two types of technological theories, "substantive" and "operative," that differed according to the means and extent to which they applied the theories and methods of pure science. Bunge claimed that the notion of applying scientific knowledge to produce technological theories did not suggest a cognitive subordination because technological theories are practical rather than cognitive in orientation and content. Scientific theorizing, he argued, pursues "purely cognitive" goals and produces "scientific laws," which are evaluated as true or false and "see what the shape of possible events is". Technological theorizing, however, pursues "practical goals" and produces "technological rules, " such as engineering descriptions of how to boil water or produce a controlled nuclear reaction, which are evaluated as "effective or ineffective" and are "normative" in content.

Joseph Agassi (1966) drew his line between applied science and technology. He argued that applied science is nothing more than pure science conducted under "conditions specified by practical considerations." Technology appears to be similar to applied science in that it is a theoretical activity geared toward practical objectives. But Agassi maintained, technology also contains an additional element of pure individual practice-invention-that, like tacit knowledge, is theoretically incomprehensible.

Henryk Skolimowski (1966) thought the distinction between science and technology was initially ambiguous because of the uncertain epistemological status of "technical" problem solving. Although technology differed from science in that its problems are originally not cognitive but technical," the process of technical problem solving appeared to have an important knowledge component and a parallel function. In science, he argued, "we investigate the reality that is given," but in technology "we create a reality according to our designs." Technical problem solving was eventually reduced to one variant of contingent social action when Skolimowski identified the wholly practical criterion of "effectiveness" as the measure of technological success. He explained that effectiveness in technology is "multichanneled and multileveled," and then defined successful technological change as improving "the measure of its effectiveness in at least one aspect." The nature of effectiveness varied across engineering disciplines, meaning, for example, "durability of the construction" in civil engineering and "efficiency" in mechanical engineering. But Skolimowski himself lamented that this approach was "hampered by the fact that nowadays the construction of bridges, highways, automobiles, or even domestic gadgets is inseparably linked with the consideration of beauty and comfort which are basically 'non-technical' categories."

Goldman (1984) thought that technological knowledge is "captive knowledge," or is always organized in pursuit of managerial goals. The primary locus of engineering activity is "decision-dominated" industry, and engineering can be understood as providing one "basis of knowledge" necessary to its success. Engineering practice thus becomes an "intentional" process driven by a range of objectives, only one of which is the pursuit of knowledge.

These philosophers' analytical thinking provides their views about engineering knowledge:

- Experience and craft skills are important knowledge components for engineers;
- Engineers apply pure science in the work;
- Practical considerations including effectiveness, beauty, and comfort are necessary for engineering;
- One product of engineering practice is knowledge.

2.4 Engineering in the Eyes of Historians

Historians seek to illuminate key individual and social groups in past events that contributed to the development of social structures and social transformation. A common mode of historical inquiry is to identify currents, themes, or trends in historical process that may be seen important in either social or theoretical terms. Studies of engineering have implemented this approach by giving considerable attention to the interpretive roles played by engineers themselves.

In historians' eyes, the engineers in nineteenth century were heroes. In Downey, Donovan, and Elliott's (1989) words,

> "Ninteenth century Americans regarded civil engineers as supreme individualists and celebrated them as national heroes. The individuality of engineers was established by the view that the immensely visible and highly valued technological works they produced were physical expressions of their singular craftsmanship. They were considered heroes because their works were symbols of and means to social progress. Just as engineering practice became identified with progressive action, so individual engineers became promethean representatives of the nation itself."

> "In the twentieth century, however, the absorption of engineering into the corporate structure of American business, combined with the increasing reliance of design on scientific principles, dissolved the homology between engineering craftsmen and the advancing nation. Feats of engineering came to be seen as efficient organizational realizations of scientific possibilities rather than of craft genius. Engineers lost their visibility as individuals and became instead corporate men buried within organizations somewhere between labor and management."

Most of contemporary historical studies (Calhoun 1960; Calvert 1967; Merritt 1969; Hughes 1971; Noble 1977) focus on the question concerned the extent to which engineers and engineering community helped to facilitate and consolidate the transformation from independent craftsmen to corporate organization. Although these studies have little reference value for this study on engineers' work, they indirectly reflects two important historical views about engineers and engineering:

(1) In the 19th century, engineering was independent craftsmanship. In the 20th century, engineering becomes organizational dependency.

(2) Originally engineers rely on craft genius. Now engineers rely on scientific principles.

2.5 Engineering in Industrial Engineering and Management

It is well agreed that the management of scientists and engineers is very different from the management of salesmen, clerks, or labour workers. In actual practice, the managers tend to use the classical techniques, which are developed for the employees other than engineers, with the consideration of the specialities of engineers and engineering job. Some related studies in this field are reviewed as in the following.

Engineering jobs are different. Two studies have given some insight into the similarities and differences of engineering jobs. Through checklists of key activities, the researchers detected clusters of activities which were significantly more characteristic of one group than another. One study (Saunders 1954) emerged with the categories of research engineer, application engineer, design engineer, and product engineer. The research engineer's most crucial function is the developing of useful hypotheses and generalizations. For the application engineer, it is most important to evaluate the present performance of materials, design, methods, products, and equipment and be informed of new developments. The design engineer's job emphasizes the making of preliminary sketches and detailed drawings, along with planning the best use of materials and making and checking complex calculations. The job of the production engineer is distinguished by the amount of writing required, including writing of manuals and specifications together with the preparation of technical recommendations and proposals. The product engineer is also charged with developing and maintaining records, and is involved in trouble shooting.

These job categories also have elements in common. The originating of technical ideas is of the greatest importance to the research engineer, for example, but this activity is shared in decreasing amounts by the applications, design and product engineers. Looking at the activities of these engineering job families suggests that the jobs fall along a continuum. The research engineer is on one end and the product engineer on the other. Applications engineering and design engineering are somewhat in the middle of the continuum.

Another study (Dunnette & England 1957) differentiated between engineering jobs according to the heading research, development, production, and sales. This categorization stresses the functional identification of the engineer and therefore the location or the situation in which he works (French 1963).

We can see from above that such studies on engineering work offer no more help than the functional definition of engineering work. Engineering work can not be described in such simple words as design, development, production, and etc. As Burns (1957) notes:

> The use of a simplified diary schedule of this kind means that the amount of information contained in each is extremely limited; it amounts to a description of one's behavior in a language of less than fifty verbs and nouns...

Because checklists are predesigned. The researcher forced the various activities to fall into these categories of functions. As a result, various engineers will have to have the same categories of activities, and the description of engineering work is limited to several words such as design, development, and production.

Another study (Pelz & Andrew 1966) found that scientists and engineers could be divided into those with a "scientific orientation" and those with an "institutional orientation." Those who are scientifically oriented tend to value "using present abilities and knowledge," "the freedom to carry out original ideas," and the "chance to contribute to basic scientific knowledge." The institutionally oriented, on the other hand, value "having important jobs," the "association with high-level persons having important responsibilities," and the "sense of belonging to an organization with prestige in the lay communities." Those who are rated high on scientific values and low on institutional values are usually the best performers in conducting research and development work. Conversely, those with a high institutional orientation and low scientific orientation tend to be the poorest performers.

This study also found that research and development engineers who reported close communication with several peers were higher performers.

Michael Beer (1967) referred to the individual with high scientific values and relatively theoretical work as a research engineer. The engineer doing applied work and sharing business or utilization values with other members of the industrial organization was referred to as an organization engineer. These two type of engineers will have different needs. The research engineer will seek achievements, recognition, responsibility and advancement primarily related to his discipline, while the organization engineer will seek achievements, recognition, responsibility and advancement related primarily to organizational goals. The freedom to carry out original ideas and work in areas of interest will be more important to the research engineer while the organization engineer will probably be more willing to tackle problems and follow up other's ideas if they are important for organizational success. He concluded that the research engineer will need work which meets his needs but he will also need some diversity in assignment and a feeling that work will contribute to organizational goals. Lacking one or the other, he will fail to be motivated. The organization engineer on the other hand, will become motivated by the importance of the problem to the organization and to a much less degree will type of work be an important element in his motivation.

There are many materials in this field which discuss the human behavior in organizations. They discuss the engineer's attitude, value, needs, motivators, and responses to management system. They discuss the leadership, reward system, and motivation. But little was said about engineering work. Though there are a few materials talking about job design, and communication, these studies are not based on the systematic study of engineering work. Our research is trying to develop a base for further studies in this field.

2.6 Engineering as a Design Process

In all of engineering textbooks, the engineer's activities are generalized and abstracted into one word, design. "Design is the essence of engineering" (R. J. Smith 1969). Therefore, reviewing the literature about the design process may be helpful to understand engineer's activities in their daily work.

Traditional models of engineering design, such as those found in the engineering textbook or professional journal, consists of discrete stages. For example, Alger and Hays

(1964) classify design activities into six steps: recognizing, specifying, proposing solutions, evaluating alternatives, deciding on a solution, and implementing. Typical of most contemporary engineering texts, it lays out the process in block diagram form showing it as a progression through discrete stages, such as in Figure 2.1, with allowance made for back-stepping or "iterating" around each phase. The arrowheads point up as well as down. The notion of different stages is common to most authors' renditions. The difference is the number of stages. Then, engineering work is usually characterized in these books as one word, creativity. "(Engineer's) success depends on his ability to come up with a new ideas, a new technique, a new process, or a new material, in other words, on his creativity" (Smith, Butler, and LeBold 1983). Unfortunately, the authors usually turn quickly into the discussion about how to foster creativity, after talking about the importance of creativity in engineering work. There is almost no literature talking in detail about creativity under engineer's working context.

These textbooks about the engineering and design process are very similar in both content and format. It seems that all the concepts about the design process and engineering work are widely accepted. However, there are three people whose work provides some different insights and opinions about the design process.

David Pye (1964) lists six requirements for a design result, as follows:

1. It must correctly embody the essential principle of arrangement.
2. The components of the device must be geometrically related - in extent and position – to each other and to the objects, in whatever particular ways suit these particular objects and this particular result.
3. The components must be strong enough to transmit and resist forces as the intended

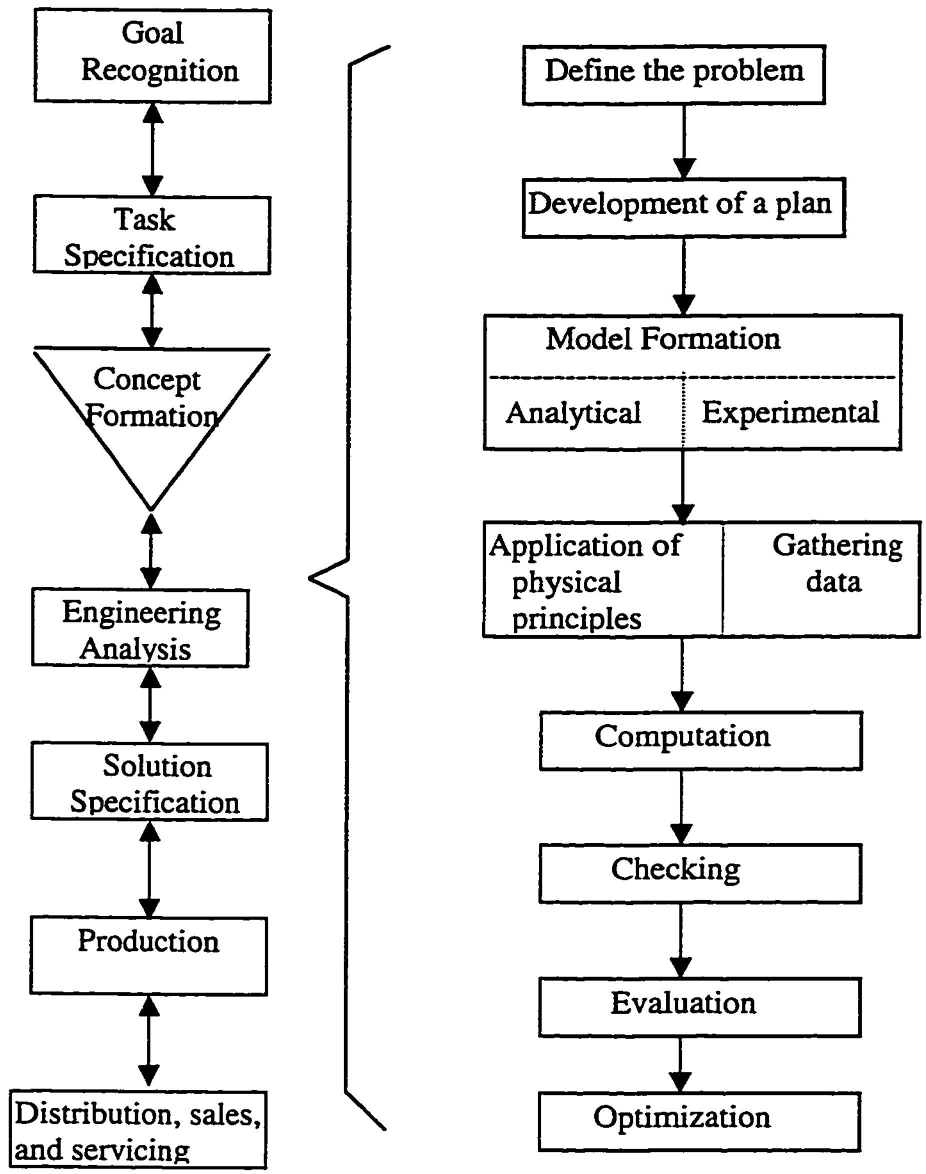


Figure 2.1 Block Diagram of the Design Process

from Dixon (1966)

result requires.

4. Access must be provided (this is a special case of 2 above).

5. The cost of the result must be acceptable.

6. The appearance of the device must be acceptable.

He continues to define that design, in all its fields, is the profession of satisfying these requirements.

Louis L. Bucciarelli (1994), based on his experience and observation on three design projects, concludes that the design process is a social progress. "Executive mandate, scientific law, market needs - all are ingredients of the design process, but more fundamental are the norms and practices of the subculture of the firm where the object serves as icon." There are two worlds within which design practitioners move: an "object-world" and a "process-world." The object-world is "the world of hardware, of performance specifications, of scientific theory and law, of quantitative estimates, of standard hex nut size, of budgets and milestone charts-all the instruments and machinery in mind and in hand that are brought to bear in design. It is the world of the participant engaged with the materials of design." The process-world is "the world of dialogue and negotiation, of social exchange, laughter, gossip, banter-all that which is ever-present in design, but whose significance is generally discounted." He thinks ambiguity and uncertainty are essential to design. "Ambiguity is essential to allow design participants the freedom to manoeuvre independently within their object-worlds save for ties to others to ensure some degree of consensus." "Uncertainty is what gives life to the process, what makes it the challenge that it is. If design proceeds without it, something is wrong, the process is not designing but copying." He criticizes that the essence of this social process is never really captured by the "traditional" models.

Eugene S. Ferguson provides his insights in his book, Engineering and the Mind's Eye. He demonstrates in this book that engineering design is, by nature, rooted principally in non-verbal and experience-based forms of cognition. In other words, it draws on patterns initially perceived by our senses-eyes, ears, nose, fingers, muscles-and then stored in a non-verbal format in our "mind's eye." It is by drawing on this sensory experience that the engineer is able to make creative, innovative, and yet sound and practical judgements in the process of engineering design. Another characteristic of engineering design, according to Ferguson, is that it is open-ended: there is, in general, no single, "correct" solution to a design problem, no "one best way." Thus, engineering can never be made into an exact or deductive science. In fact, says Ferguson, it has closer ties to art than to science.

The discussions about the design process tend to include all engineering activities into one word, design. As result, the word "design" has become like the word "manage," too broad and inclusive to provide the specificity needed to describe an operational activity. It does not tell the true activities that are performed by engineers in their daily work to solve the problems.

As reviewed above, while there are some discussions about the characteristics of engineering work, such as autonomy, creativity, use of abstract knowledge and experience, there is almost no descriptive materials about the content of engineering work. As a result, it is still not clear what engineers do in their daily work. This study tries to answer this question.

Chapter 3

RESEARCH DESIGN AND METHODOLOGY

3.1 The Purpose and Characteristics of the Research Task Define the Methodology.

Various problems require that different methodologies be employed. The purpose and characteristics of a research task define the methodology that should be used.

The purpose of this research is to describe what engineers do in their daily work. The review of the literature undertaken before designing this study revealed a lack of descriptive material on the content of engineer's work. In simple terms, there was little to tell us what engineers actually do. There was no existing theory or model from which we can derive any hypothesis. Therefore, the research must be inductive. The methodology itself must be able to lead us to find out the categories of activities, and then lead us to develop the theory about what engineers do.

There are a number of obstacles both to finding out and to describing what engineers do. First, a significant proportion of engineering work is mental, involving thought processes, which are not directly observable. Second, there is considerable variation from engineer to engineer, not only from industry to industry, or company to company, but also from department to department, and even within departments of a single company. Third, there are layers of complexity in the engineer's work. If, for example, the research question was, "How do engineers use the computer?", then data could be collected to measure the time amount of computer use. This measurement of computer use would not, however, tell whether the subjects were playing games, processing words, running calculation program, searching the internet, or checking email.

It would only indicate the amount, and frequency of use. To go deeper would require us to know the subject and context. But even that might not suffice. The engineer might process words for a project proposal, or for updating the information. As well as content, then we also need to know the context: including current and anticipated projects, the information requirements of these projects, and the relationship among the activities. It is, however, almost impossible to know or find out this information beforehand.

To overcome these three obstacles, the research needs to be designed to explore deeply rather than widely, to focus on the job rather than the person, on basic similarities in engineers' work rather than differences, and on the essential content of the work rather than its peripheral characteristics. In short, the methodology has to be intense.

The methodology must also be comprehensive. Our task is to describe a process. Most engineering work takes place in long cycles. Unlike the work of an assembly line worker, the full range and rhythm of an engineer's work can not be observed over a few hours. The methodology must allow us to capture every activity performed by engineers, allow us to get detailed information on every point of the process.

One important factor that should be noticed in the research design is the preconceived opinions about engineer's work. People tend to describe engineering work by the functions of engineering such as designing, planning, and manufacturing. People tend to exclude some activities, such as writing reports, social contacting, and organizing community events, from engineering work, while they have no problem in considering drawing and calculating as engineering work. These perceived opinions may cause a bias in the research. Starting from a simple definition, "engineering work is what engineers do," we proposed to try and develop an understanding of the nature of engineering work by studying engineers in a non-restrictive, non-judgmental way. There are no predetermined categories; rather the categories arise from the analysis of the data.

In conclusion, the purpose and characteristics of the research task require that the methodology be designed to be an intense and comprehensive inductive research, conducted in a non-restrictive, non-judgmental way.

3.2 Inductive Research Begins With Data Collection.

In many text books, the dominant model of science is represented by a wheel or circle such as the one shown in Figure 3.1 (Carol A. Bailey,1996). The process of scientific discovery supposedly proceeds clockwise around the “wheel of science.” The research begins with a theory. Using deductive reasoning, the researcher derives a

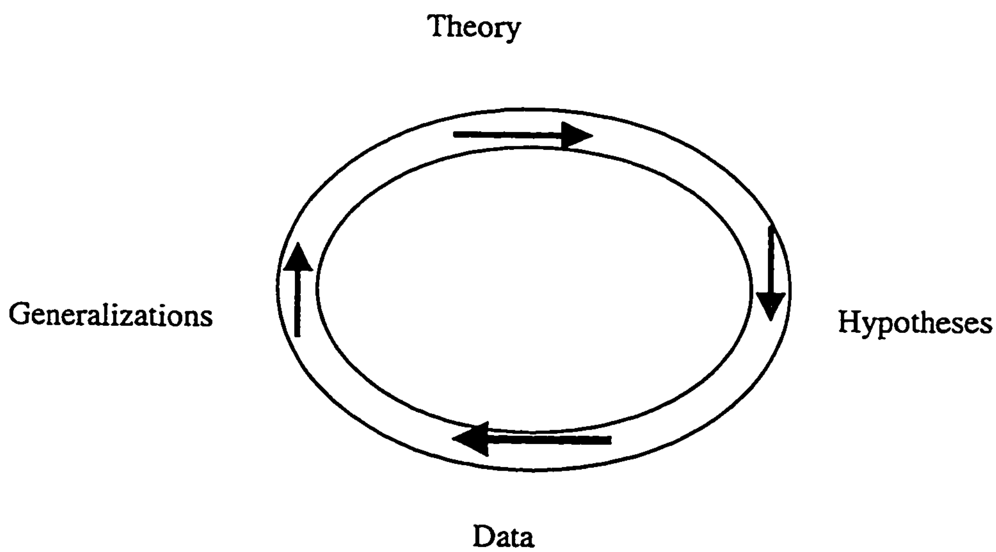


Figure 3.1 The Research Wheel

testable hypothesis from the theory. Then data are collected to test the hypothesis. Based on the results of data analysis, the researcher decides whether there is empirical support for the hypothesis. The right half of the wheel, from theory to data collection, is called deductive research. The purpose of this type of research is usually explanatory or theory testing.

Here is how you might do research if you were following this model of the scientific process and were intrigued by a theory of chess players' behaviour that you read in a journal article. Upon some reflection, you would derive a testable hypothesis about chess players from this theory. Next, you would decide on the appropriate method for testing your hypothesis: collecting survey data, designing an experiment, or engaging in field research. Once you made this decision, selected your sample of chess players, and obtained informed consent, you would collect your data. After analyzing your data, you would decide if you found support for the original theory of chess players' behavior or if the original theory needed to be modified or rejected. Others might repeat your work, testing their hypotheses on different samples of chess players. Eventually you would hope to have a good theoretical understanding of the behavior of chess players through the process of theory testing and modification.

The wheel in this figure can also represent inductive research. During inductive research, the researcher enters the wheel at the point of data collection and travels up the left side of the wheel. The researcher collects data and then extrapolates from the data insights into human behavior. That is, the researcher makes general statements about social life from specific observed behaviors. The general statements, or insights, derived from the data are called generalizations. When a theory is developed inductively, it is called grounded theory because it is developed from the data rather than anticipated in a hypothesis. It has its base in specific observations of social life (Glaser and Strauss 1967). In addition to generating theory, the purpose of inductive research is often exploratory or descriptive.

If you were following the inductive model, you might realize that all those weekends that you spend at chess tournaments might be a valuable source of data. You decide that you want to do some research on this setting because you find chess players a fascinating group and you want to understand them better. You engage in systematic observations and interactions with chess players over a long period. Based upon the field notes from your research, you write and publish the theoretical ideas that you have developed from the data.

Usually, one study on a topic, whether deductive or inductive, is not enough. Social phenomena are too complicated for a full understanding of human behaviors to be gained from one study. Therefore, scientists seek insights into the world through the cumulative effect of their work. The "wheel of science" is travelled many times by researchers who hope that each time the circle is travelled we come closer to understanding our world.

Our current research is an inductive study, because the purpose is to describe what we do not know, to develop a general statement about what engineers do. From the literature, we can not find a theory about engineer's work. Thus, we should enter the "wheel of science" at the point of data collection.

Obtaining sound data (facts) is the most practical and demanding aspect in this research process. As stated above, the purpose and characteristics of the research task require that data must be intense and comprehensive. Since we want to explore deeply, to overcome the layers of complexity in engineering work, to capture every activity performed by engineers, it is natural to select field research as the data collection method.

3.3 Research Traditions

There are two research traditions that use field research methods to collect data: the work study practices of industrial engineering and the ethnographic research practices of anthropologists.

In his famous experiment (F.W. Taylor, 1911), Fredrick Taylor studied a labourer named Schmidt whose job was carrying pig iron for the Bethlehem Steel company. By carefully planning and studying the work, and dictating the movements, Taylor was able to demonstrate that Schmidt could move 47 tons of pig iron per day instead of his normal output of 12.5 tons. Based on his results with Schmidt, not taking a statistical average of all pig iron handlers, he generalized to what might be accomplished by many trained in a similar manner. This and other similar experiments by Taylor and his colleagues were the foundation of the "Scientific Management" approach that revolutionized industry.

In well known Hawthorne experiment (F.J. Roethlisberger & W. J. Dickson, 1964), six women and one observer were put into a test room. The women's activities in their daily job of assembling telephone relays were observed and recorded by the test room observer. The research experimented with rest pauses, shorter working days and weeks, etc. to examine the effects on data. This famous experiment changed forever the way we view industrial productivity and efficiency.

However, the work of engineers is not like the work of iron handlers or the work of telephone relays operators. As stated before, engineer's work takes place in long cycles. The full range and rhythm of an engineer's work can not be observed over a few hours. Also, engineering work is much more active and autonomous, and can not be pre-scheduled. Therefore, it is impossible for researchers to control any factors to do experiments. Because of the layers of complexity in engineering work, the research often needs to know the context in which the activities are performed, in order to know the meaning and purpose of those activities.

Anthropologists gather quantitative and qualitative data by listening, observing, counting, conversing, and asking. They analyze this mix of data to look for themes, connections, and patterns. They supplement the analysis with an extensive background study of context, relationships, and theories. They seek understanding of people and processes. The product of anthropologic inquiry is a careful description of a cultural group in its own terms. The methodology by which cultural meaning is studied called the "ethnographic approach." Because of the requirement of understanding the whole context and cultural meaning, the ethnographic approach often takes a long time.

Comparing with the ethnographic approach to a different culture, this study of engineering work needs much less effort on understanding of context and cultural meaning, although we often need to know the background of activities. We have a focus on engineering work before we enter the field.

These two research streams converged in the work of Henry Mintzberg(1973), when he set out, in his 1969 Ph.D research, to address the question, "what do managers do?" Mintzberg used structured observation to study five chief executives, each for one week. The label structured observation was used by Mintzberg to refer to a method that couples the flexibility of open-ended observation with the discipline of seeking certain types of structured data. The researcher observed the manager as he performed his work. Each observed event (a verbal contact, or a piece of incoming or outgoing mail) was categorized by the researcher in a number of ways (for example, duration, participants, purpose) as in the diary method, but one important difference. The categories were developed during the observation and after it took place.

There has been significant progress and refinement in field research since 1969. Much of the development has centred on reliability, replaceability, and the influence of the observer. The field of anthropology has made major breakthrough in the understanding of the observer effect and the fact that although different observers will affect the research in different ways, and will observe different aspects, methodological rigor can ensure complementary, valid conclusions (N.R. Denzin & Y.S.Lincoln, 1994).

In our research, basically we employed the field research method similar to Mintzberg's. Ten engineers in 6 different organizations were observed when they performed their daily work, each for one week. However, we put more emphasis on understanding the context in which the activities were performed. We also recorded in detail our own feeling in the field. This helps to understand the meaning and purpose of activities more accurately, and facilitate coding data at a later time.

3.4 The Advantage of Field Research Over Survey In This Study

First, let us review these two methodologies:

Survey

The survey is the most widely used method. It refers to the gathering of data from a sample or a specific population, usually by questionnaire, interview, or telephone survey. Both interviews and questionnaire can be extremely rigid or very open, and the style of question within both can range from closed-ended to open-ended, simple "yes" and "no" responses, frequency and intensity, semantic differential rating scale, and ranking to that of the objective information style used to collect demographic data about respondents. The most distinctive thing about an interview is that the respondents are orally presented with questions, whereas in the questionnaire, the respondents are presented with a written question to which they directly respond. The interviewer can explain a question that the respondent does not understand. The advantage of mailing a questionnaire is that it can save time. The interview methods can be classified as focused interview, nondirective interview, clinical interview, and telephone interview.

The high degree of usage of survey is attributed in part to the great flexibility, the nature of where the data are located (in the experiences and memories of people), the ease of collection, and professional training (researchers know more about using these approaches).

Survey method is based on "asking". As the old dictum states, "if you want to find something out, ask!" Yet we all know that to many questions there are no answers, that answers to question may be wrong, and that a question may be incorrectly asked so that it can not elicit the desired information. All these possible problems, which frequently confuse everyday forms of communication, also confront surveys. It requires that the researcher have extensive previous knowledge of the problem to be studied. Also, the data the researcher wants to collect must be located in people's minds.

Field Research

Field research is the systematic study of ordinary events and activities in the settings in which they occur. A primary goal of field research is to understand what these activities and events mean to those who engage in them. To gain this understanding, field researcher collects data by interacting with and observing people during the course of their daily lives, usually in some self-contained setting such as a workplace, a street corner, or a place of worship.

Field research is highly flexible, done by the lone individual or by a team in conjunction with the members in the field. It rarely requires hypothesis testing, standardized questions, or manipulation and control of variables. Field research is well suited for, but not restricted to, descriptive or exploratory research. It is often used for generating theory and hypotheses that can be tested later using other research methods.

In contrast to a survey approach, the field research attempts to thoroughly access a cluster of factors by focusing on a small number of cases. The field research assesses the world or unit as it exists, in a natural, unaltered setting.

Bias might be manifest in the very cases that are selected for study, as well as the open-ended nature of the field research, which may allow the investigator to influence the nature of the case under study. Since field work tends to be so individualized, and non-routinized, it is often difficult for a second field researcher to replicate the earlier work.

The following section reviews some of the terms that appear in the field research literature, according to Carol A. Bailey (1996):

Case Study usually refers to research done on a single case. Because field research tends to be intensive and time-consuming, the researcher often narrows research down to a single field setting. However, field research need not be confined to single cases, but may compare different social settings. For this reason, field research is a more generic form of research than case studies.

Field Study refers to any study that is done in a natural setting. For example, a field experiment is also included in the field study.

Field Work is sometimes used interchangeably with field research, but it more accurately refers to that part of field research that is done in the field.

Ethnography or *Ethnographic Study* has been developed by cultural anthropologists. These terms are often appropriately used interchangeably with field research. Usually, the field research of trying to describe a whole people is referred to as ethnography or ethnographic study.

Observational Studies collect data by using sight, hearing, taste, touch, and smell. Observations are a major part of field research. However, field research frequently includes other forms of data collection, primary involvement in daily activities and informal interviews with members.

Participant or *Nonparticipant Observation* indicate the degree to which the research actively participates in everyday events in the field setting. The participant observer takes part in daily events while observing. The nonparticipant observer observes but does not take part in routine activities and events in the setting.

In excluding survey methodology, we must draw a basic distinction between the content and the characteristics of the job. When Mintzberg studied managerial work, he explained this distinction (1973):

> "A researcher studying the job of the manager may wish to know such things as where managers work, with whom they do so, how long they work, what media they use (telephone, for example). Answers to questions like these give the characteristics of managerial work. Or, the researcher may wish to know what managers do in their work---that is, what activities they carry out and why. Answers to these questions describe the content of managerial work. Categorizations of work content and purpose lead to statement of functions or roles. The first type of analysis would tell us, for example, that a manager

> worked long hours in a given week, whereas the second would show that he did so because he was deeply involved in labour negotiation."

Diary study or survey can be helpful in finding the characteristics of the job. But considering our understanding of engineering work is so limited that all people tend to describe the engineering work according to the functions such as research, development, design, production, construction, operation, sales, management, and etc., diary and survey studies are not suitable to find the content of engineering work. The situation is very similar to that in the study of managerial work. When Rosemary Stewart came to conduct her extensive diary study in the middle 1960s, she explicitly avoided recording job content. She explained (1968):

> There is no problem if one is asking unambiguous questions such as " Where is he working?", "Is he alone or with someone else?", and "Who is he with?"... Such investigations tell one something about how the manager spends his working day, but little about the content of his work, which is the most interesting part of what he does. Those who have sought to describe it have usually thought in terms of the classic management functions, such as planning and organizing, or of activities like giving information or making decisions. The objection to these descriptions is that such activities can not be defined so unambiguously that different managers recording the same tasks will necessarily classify them in the same way. This is even true for such apparently less ambiguous classifications of work as production or sales. It may be a mixture of the two, or production looked at from one point of view and sales looked at from another.

Mintzberg (1973) analysed that: "the difficulty appears to be with the diary method itself. It requires that managers who do the recording be armed with precoded pads so that they can code each activity quickly. Thus, to design the form the researcher must have some idea what managers do. For a factor such as "place of work," one need merely list: own office, office of associate, plant, outside company, and so forth. But what words could be used to describe the content of managerial activities? As a matter of fact, nowhere in the literature is content categorized, except in the vague words of POSDCORB." (planning, organizing, staffing, directing, coordinating, reporting, budgeting)

In the words of Hodgson, Levinson, and Zaleznik (1965): "to construct questionnaires, we had to know the salient dimensions of the situation we were studying. It took about a year of field work to find them out, and by that time we were already observing so much data that a questionnaire would have been of no incremental value..."

Another reason that survey is unable to collect the data of work content is that the data is not located in the people's experience and memories. The work content data exist in the field when engineers perform those activities. Who can recall how many calls were made, how long each call took, how many times the reference material was used, after daily work is finished? The survey method is based on "asking." How can people give the information that does not exist in their minds?

Therefore, the survey can not collect work content data because neither is the researcher able to ask correct questions, nor are the respondents able to answer the questions. As to the diary method, same as the survey, the researcher does not have the necessary knowledge to design suitable activity categories. And it demands too much co-operation and effort from engineers.

It is very natural to choose the field research as our methodology. As the age-old adage goes: if you want to know the number of teeth in a horse's mouth, you go to the horse and count its teeth. So too with behavior, to understand engineer's work, one must go to engineers' workplace, observe, and talk to them.

As many scientists noticed, the field is often used for generalizing theory and hypotheses that can be tested later using other research methods. Therese L. Baker (1988) said, "the field research is mainly desirable for the study of problems that are not yet well formulated---a method appropriate for underdeveloped research problems." Stephen Cole (1976) had the following comment, "ethnography (a kind of field research) is a theory-building method. Its aim in the study of the particular is to draw out the general theme."

Adams and Schvaneveldt (1985) indicated, "the focus of field study is usually broad in the type and quantities of variables that can be studied, and the approach tends to be in-depth and comprehensive. Since field research includes only one or a very few cases, it can afford to deal with all pertinent information or aspects of the situation."

According to J.P. Dean, R.L. Eichhorn, and L.R. Dean (1969), the field research has a number of advantages over the survey:

(1) The field researcher is not so bound by prejudgement. He can reformulate the problem as he goes along.

(2) Because of his closer contact with the field situation, the researcher is better able to avoid misleading or meaningless questions.

(3) The impressions of a field worker are often more reliable for classifying respondents than a rigid index drawing upon one or two questions in a questionnaire.

(4) The field worker can constantly modify his categories, making them more suitable for the analysis of the problem he is studying. The survey researcher is often stuck with the categories or variables he originally used in conceiving the problem.

(5) Difficult-to-quantify variables are probably less distorted by direct observation than by survey method.

(6) The field researcher can generally get at depth material more satisfactorily than the

survey researcher.

As we can see, all of these characteristics and advantages of field research method match our research needs very well. Therefore, field research is employed as the main methodology, complemented by the historical research. The historical data are used to enrich, cross-validate, and support the results from field research.

In our research, the main initial data will be collected as field notes through the field research. The categories can be developed during and after observation. We can try to describe the "purpose" of each of the events observed (as well as other features, such as place, participants, duration) in the words that seem appropriate at the time of observation. The formal categorization will be carried out at a later time, when all data are available and when there is time to do it carefully. This approach retains the basic advantage of the diary method---systematic recording of field data, but also maintains the flexibility to develop content categories inductively.

The key underlying all will be direct observation of what is---not questions as to what should be. So, at the outset there will be no attempt to categorize neither the subjects (like the usual classes of junior, intermediate, senior engineers), nor the type of work (such as designing, supervising, managing, etc.). To do so would tend to force the data into potentially inappropriate groupings as discussed before. All activities will be relevant. It is anticipated that groupings and categories will arise naturally from the data.

3.5 Etic Analysis

The field observers routinely distinguish between emic and etic analysis. Emic analysis portray a social scene or way of life from the perspective of participants. The telling is usually organized around concepts drawn from the native's world view. In contrast, etic analysis draws more heavily on the observer's perspective, aims for a portrayal that is theoretically fruitful. It is argued that one can not pursue emic and etic objectives simultaneously, since they require different approaches to data. Obviously, this research should employ etic analysis, because the research is to produce an image of a generalized role.

However, two mutually exclusive analysis approaches do not mean that data collection methods should be exclusive. Even for etic analysis, it is very helpful to be able to understand the activities from the native's view. In this study, if the researchers are able to understand the engineering problems like engineers, they will easily understand the purpose and meaning of each activity engineers perform. Also, they will be able to collect many "anecdotal data," which can support and facilitate etic analysis.

For some kinds of research, such as Mintzberg's study on the nature of managerial work, the difference between etic data and emic data is hard to tell. It is not difficult for the researcher to get an insider's understanding of managers' activities, because these activities do not involve the use of specific knowledge. Therefore, in his study, Mintzberg was able to collect many "anecdotal" data, which helped significantly for his etic analysis of managerial work.

Unfortunately, this is not the case for this research. It is nearly impossible for a researcher to understand each engineer's job. This would require the researcher to have the same engineering background as the participant engineer. If we plan to study 5 different engineers, we need 5 researchers with 5 different engineering backgrounds. We do not have such kind of resources.

In Stephen R. Barley's study (1996) on 9 technicians' occupation, he organized a team of eight researchers in order to pursue emic and etic objectives simultaneously, by separating responsibility for the two. The team as a whole took responsibility for comparative, etic analysis, thereby freeing observers to pursue an insider's understanding of an occupation. Each researcher chose to study a well-known technician's occupation on the basis of their personal interest. As the result, the research yielded two kinds of products: emic ethnographies of individual occupations and etic analysis grounded in the comparison of emic data collected across multiple occupations.

Engineers' work is much more complicated than technicians'. Even if the researcher has the same background, for an example, mechanical engineering, as the participant engineer, it is still possible that the researcher can not understand the problem the engineer is facing, because there are so many specializations within mechanical engineering, and so many different kinds of problems in each specialization. All of them involve the use of specific knowledge, skill and theories.

Further more, it is often difficult to get approval from the organizations to follow their engineers for one week. Without direct benefit, they are usually reluctant to allow you to bother their engineers. For the engineer himself, to be followed and watched for one week may be very uncomfortable. So, actually we are not in a position to be able to choose what kind of engineers to be studied, and thus we are not able to know what kind of researcher should be sent to the field before receiving the organization's permission.

Therefore, although it is helpful to work emically to pursue an insider's understanding, it is not feasible for this research. Since this study is not supposed to produce emic descriptions for individual engineers' occupations, emic data are not necessary, although they are helpful for etic analysis. In the fieldwork, I tried to record all activities, mail, verbal contacts throughout every minute of the workday, and in the meantime, did my best to pursue an insider's understanding, to collect "anecdotal" data. During the observation, the effort was put into clarifying the purpose and meaning of each activity by close observation and asking questions, and recording them in detail. The purpose of doing so is to eliminate any possible misunderstanding for coding data at a later time.

For example, I observed a utility engineer made a phone call out, and then drew on the paper. I recorded the activity: he phoned out, the time and length of this call, what he said. Then when I had a chance, I asked: whom he just called, for what. He told me he just called a land developer to get some data. Then I asked another couple of questions: what kind of data, why do you need to know these data. He told me that those were dimension data, and were necessary for him to decide where and how to layout the pipeline. I recorded all of these in detail. By doing so, I not only knew that the meaning and purpose of that activity: call out, but also the relationship between two activities: call out and drawing on the paper. I might not technically understand the problems he was facing, but I did know that the purpose of his call was to get some data, and these data was for the next activity: drawing. To understand the activity of drawing, I would ask some other questions to clarify its meaning and purpose.

In this way, most of the data we collected from the field are etic data. To complement etic data, I look for "anecdotal" data from the library. There are many stories about great engineers, and great engineering projects, which contain descriptions about engineering problems, and how engineers solved the problems. Although they are often devoid of generalization, and have little description of engineers' activities, these "anecdotal" data are helpful to support and prove the theory, which is developed from the study of engineers' activities.

3.6 Validity and Reliability

According to Kidder (1981), four tests have been summarized in numerous social science textbooks for judging the quality of research design:

Construct Validity: establishing correct operational measures for the concepts being studied.

Internal Validity: establishing a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationship. This is for explanatory or causal studies only, not for descriptive or exploratory studies.

External Validity: establishing the domain to which a study's findings can be generalized.

Reliability: demonstrating that the operations of a study, such as the data collection, can be repeated, with the same results.

Since this study is designed to be an inductive research and the purpose is exploratory, internal validity is inapplicable to this study.

As to construct validity, the concepts being studied here are the content and characteristics of engineering work. Since field research is the systematic study of ordinary events and activities in the settings in which they occur, it is considered the only true way to study human behavior and society unimpeded by the artificial techniques that characterize other methods. As Therese L. Baker (1988) commented, "field research appear to be the basis for the most valid types of social research studies. Because they actually take place in the field and because they try to capture the true meaning of the social context, and understand its nature, a field study attempts to address the most crucial criteria for establishing the validity of a study." Further more, historical study is employed to cross-validate the research.

External validity deals with the problem of knowing whether a study's findings are generalizable beyond the immediate cases. The external validity problem has been a major barrier in doing field research. Critics typically state that single cases offer a poor basis for generalizing. "How can you generalize from a single case?" is a frequently heard question. To answer this question, "the research wheel" provides a good starting point. As showed in Figure 3.1, progress in sciences is a gradual, cumulative process. At the beginning, a discovery comes from a specific case. Then, people test, modify, develop, and complete it. In this way, we know more and more about this world. Whether the theory is OK for the population or not needs to be tested. One can not judge a theory's generalizability by judging its base. The theory comes from a small sample size or even a single sample may be demonstrated to be OK for generalizing to the whole population. As Yin (1984) notices, "when a scientific discovery comes, we never argue, 'how can you generalize you discovery from a single experiment?' In fact, scientific facts are rarely based on single experiments. They are usually based on a multiple set of experiments, which have replicated the same phenomenon under different conditions." The same approach is used in this research. A group of four people studied ten engineers to understand engineer's work, and to discover the common nature of their work. Then, we did some testing by historical data.

However, one study on such a topic is far from enough. We should not expect that a full understanding of engineering work and that a proved, generalizable-to-population theory can be gained from one study. The purpose of this research is to begin to seek the understanding of engineering work, and to stimulate others to seek more precise understanding. Thus, the "wheel of science" can start to circulate, and will travel many times until a full understanding, and a generalizable-to-population theory are gained.

While survey research relies on statistical generalization, field research relies on analytical generalization to generate theoretic propositions, grounded theory. "In analytical generalization, the investigator is striving to generalize particular set of results to some broader theory, analogous to the way a scientist generalizes the theory from experiment results." (Yin 1984) Thus, the study on one engineer for one week in this research does not represent a "sample." It represents a case. This is a multiple cases study. "The logic underlying the use of multiple-case studies is replication, which is analogous to that used in multiple experiments" (Hersen & Barlow 1976). If similar results are obtained from all cases, replication is said to have taken place. In this study, after each observation is finished, the field notes were studied thoroughly and decoded repeatedly with the hope that some essential things could be found. The researcher develops grounded theory by in-depth powerful data, by insight and tuition, by experience and skills, not by statistical analysis. After the common essential contents are found, which are considered to be able to describe the nature of engineering work, historical data are referred to test the similarities.

For statistical generalization, the base must be the probabilistic sample, which is a sample with each element or groups of elements having an equal probability of being included. Only when a probability sample is selected, one can use the appropriate statistical procedures in analyzing the sample, describing it, and making necessary inferences about the population from which it was drawn. If the samples are not probabilistic, no matter how big the sample size is, it is clear that one would not be justified in describing the whole population or making generalizations about the whole based on those non-randomly selected samples.

If a sampling logic had to be applied to all types of research, many important theories, such as Taylor's Scientific Management, could not have been empirically developed. According to Ralph J. Smith(1983), engineering work can be classified as 9 functions, 12 branches with about 130 specilizations. So many functions, specializations, plus various ranks and a great deal of overlapping create too many different engineering jobs to be counted. With such kind of variations, it is impossible for the researcher to study all kinds of engineers' work to find out the nature. It is also impossible to select a "representative' case or set of cases. That is why this study is designed to explore deeply instead of widely.

The goal of reliability is to minimize the errors and biases in a study. In field research, the researcher has to guard himself against altering the situation being studied, as this can lead to observing and recording events that are distorted by being in that setting. This reactive effect in this study should be small. What we observe and record are engineer's working activities, which must be performed to finish their task, no matter whether the researcher exists or not. The reliability of the research is further demonstrated by sending four observers to do observations. This triangulation helps to guarantee the reliability of this study. Another concern about reliability is if one-week periods are representative of each engineer's work. There is reason to believe that an observational week is a typical one. The researcher entered the field only after the engineer predicted that the week would be usual. After the observation, the researcher confirmed it again with the engineers.

3.7 Conduct of Field Research

The procedure of field research was fairly simple. For one week at a time, the observer attached to a individual engineer, following the engineer through the day (like a shadow) as unobtrusively as possible, watching, listening, writing the field notes, and asking questions when the time is proper.

To be able to capture and record all of the engineer's activities throughout every minute of the workday, the researcher must choose a good position for observation. It was found in the pilot study that the best position was just in front of the engineer's desk. This position allows the observer to watch the engineer's activities clearly, and it is convenient to ask questions. Close observation reduces the questions, so it is also good for engineers. Although the observer can see the engineer's activities in a remoter position, the content and purpose of those activities are difficult to be recorded. The purpose of activity is the key data for this study. The categorization of the purpose describes the essential content of the engineer's activity, and it is what leads to the development of the theory on roles.

During the observation, the observer tried to reduce the engineers' discomfort as much as possible. When the engineer was busy, the observer pretended to be busy, too, so that the feeling of being watched and being waited on for the next activity would be minimized. The observer might be busy in recording the data, analyzing previous field notes, or reading a book. If questions appeared in the engineer's busy time, the observer could make notes, and ask questions at a later time. When the engineer was not so busy, the observer might ask questions about the data, or just chat. The purpose of the chat was to get the relationship closer, and to foster a relaxed atmosphere. Depending on different organizations, some engineers might have more time to chat with the researcher than others.

At the beginning of the first day's observation, the observer would ask the engineer to co-operate on one matter, reporting the purpose of leaving the office. It was found that it was not necessary to follow every time when the engineer left the office. It might be just for a cup of coffee, or to chat with colleagues, or to just go to the wash room. By asking the engineer to tell the purpose of leaving, the observer could decide if it is necessary to follow.

Usually, the observer was not allowed to attend meetings, because it needed other attendees' approval. To circumvent this problem, the engineer was asked to provide the information about (1) time and length of the meeting (2) who attended the meeting (3) the purpose of the meeting.

The field research was conducted by a research group consisting a professor, two Master students, and the author of this thesis. The members of research group met weekly to exchange and discuss the experience, insight, and feeling. In later time, the author of this thesis took all people's field notes to do data analysis. The backgrounds of observers are as follows:

Observer A: Professor of Engineering Management Program

Background: Civil Engineering.

Observer B: Ph. D. Student in Engineering Management Program

Background: Mechanical Engineering.

Observer C: M. Sc. Student in Engineering Management.

Background: International Trade.

Observer D: M. Eng. in Engineering Management

Background: Petroleum Engineering.

Ten engineers in six organizations were studied. The following table shows the background of the engineers:

Table 3.1 Engineers Who Were Observed

Engineer	Field	Rank	Firm Type	Firm Size
A	Civil	Intermediate	Environment Eng.	Medium
B	Utility	Intermediate	Gas utility	Large
C	Telephone	Intermediate	Telecommunication	Large
D	Construction	Senior	Construction Eng.	small
E	System	Intermediate	Computer Eng.	Large
F	System	Intermediate	Computer Eng.	Large
G	Mechanical	Intermediate	Municipal Eng.	Large
H	Geological	Senior	Environmental Eng.	Medium
I	Geological	Junior	Environmental Eng.	Medium
J	Structural	Senior	Construction Eng.	Small

Since there is considerable variation in the type of engineering work, it is impossible to seek a comprehensive mix of work types to study. So, the choice of engineering type was based on convenience. However, we tried to formulate a good mix of engineering experiences and organization sizes. Common to all these ten engineers are four basic factors. (1) They are all registered professional engineers. (2) They all have engineering degree. (3) Their time is billed at engineering rate. (4) Their organizations provide engineering service.

3.8 Ethical Considerations

Ethics, confidentiality, and ownership of research data are current issues in all aspects of research involving human participants. Since this research involves the collection of sensitive and possibly embarrassing information, there is risk for both the participant and the participant's organization. At the outset of this research to address this matter, the following confidentiality agreement was drafted. Prior to our initial studies, it was explained and signed by the observer, the observed, and a senior representative of the organization.

Agreement

The study we are conducting is directed toward understanding the nature of engineering work. It is not concerned with the activities, work methods, work practices and productivity of any particular engineer, except in so far as that individual is part of the database. Consequently, all field notes will be taken in such a way as to conceal the identity of the participant and the participant's organization. Specifically, the terms and conditions under which the information is gathered are as follows.

- Participants are fully informed of the objectives and methods of the study. Their suggestions regarding design and evaluation are welcome at all times.
- Data drawn from direct interviews will be coded to ensure the confidentiality of the informants unless otherwise agreed by both the informant and the researcher(s).
- Transcribed interview data from informant interviews will be proofread by the respective informant to ensure that the record accurately reflects the informant's thoughts. Further elaboration will be welcomed.
- Field notes will be made available only to the research team.
- Every effort will be made to inform participants of policies and publications that result directly from this research.
- Participants have the right to withdraw from the research project at any time.
- No information collected at an organization will be disseminated or published without the specific consent of that organization.
- No information that identifies: company, contracts, clients, or any individual shall be used without the written consent of the identified or affected party.

Consent of each participant for participation and derivative use of the data by the researchers is confirmed by the signature on this document.

3.9 Development of the Theory

Figure 3.2 shows the development of the theory in this thesis. First, the data of observation were coded in terms of chronology record. Then categories of components of the work were developed according to the purposes of activities. These coded data formed one basis for the three bodies of theory: (1) characteristics of engineer's work, (2) the engineer's working role, and (3) what engineers know and how they know it. The development of the theory on work characteristics was simple enough. The quantitative data suggested their own conclusions, and these were combined with those reached by other researchers to develop the characteristics.

The theory on the engineer's working roles involved a more complex analysis. It is derived from the statements of purpose. The activities are categorized according to their purpose. The purpose describes the essential content of engineer's activities, and it is what leads to the development of the theory on roles. For each distinct type of activity one question was asked repeatedly---why did the engineer do this? A collection and categorization of the answers---some obvious, others not---led to the statement of roles. Results of other studies and anecdotal data were then used to enrich and test the theory.

At best, the role is a fuzzy concept. A statement of roles represent one attempt, among many that are possible, to slice up a job. There can be no correct or incorrect categorization of roles, just tighter and looser, more or less useful ones. The pragmatist will judge the usefulness of a theory by attempting to use it, the scientist, by the validity of the approach used to arrive at it.

The characteristics and roles are then used as a basis for analyzing what engineers know and how they know it. Other people's results and anecdotal data obtained from the historical research and author's own experience are used to support the analysis.

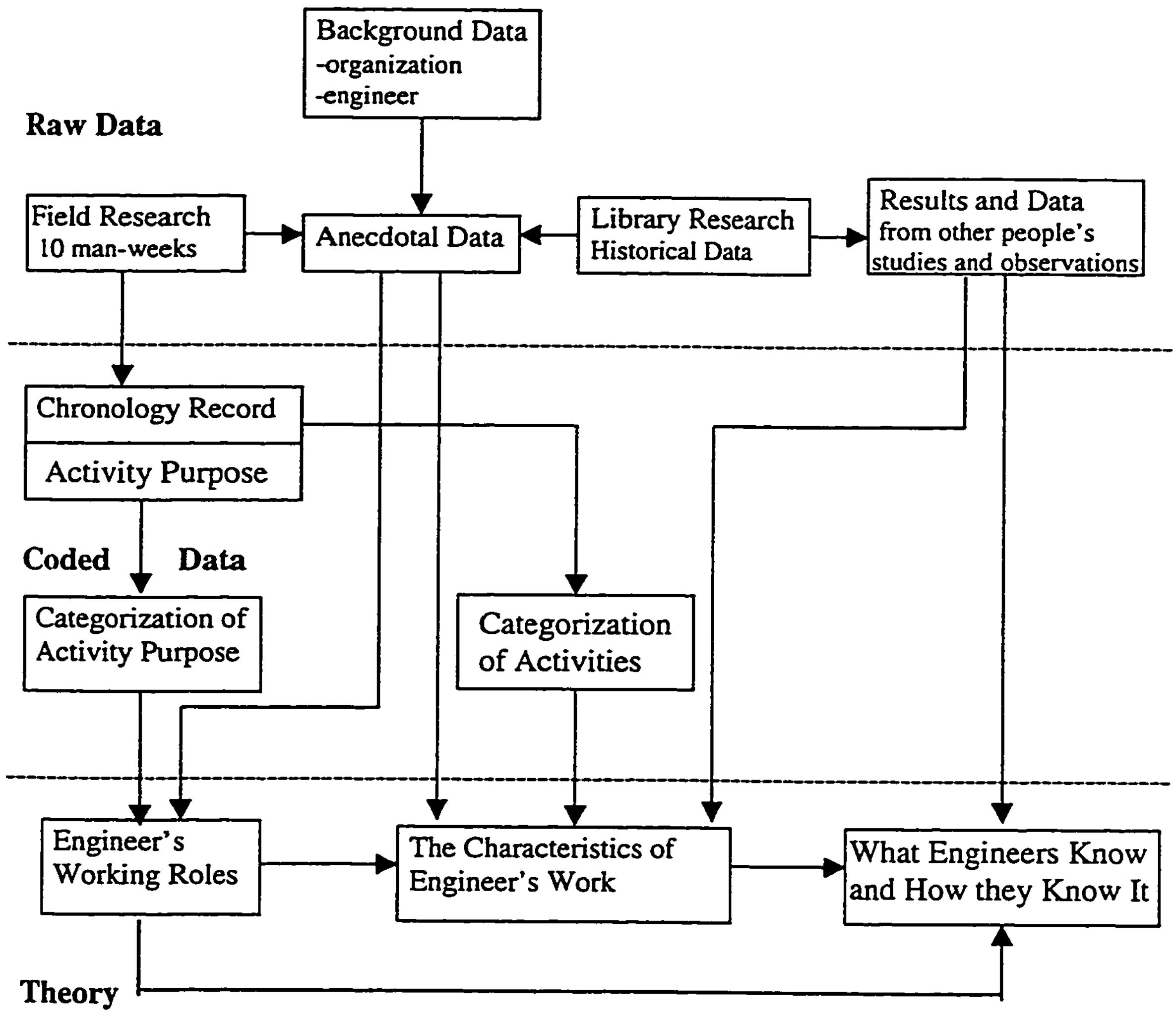


Figure 3.2 Outline of the Analysis

Chapter 4

DATA ANALYSIS I: SOME CHARACTERISTICS OF ENGINEER'S WORK

In this chapter, some characteristics of engineer's work are identified from analyzing how engineers spent their time. The activities need to be categorized to do this time analysis. After analyzing several periods of observation, it was found that the following seven categories can cover all of the observed activities for these engineers:

Desk Work conducted while the engineers were around their desks and working (reading, drawing, sorting the documents, etc.).

Computer Work done on a computer, such as writing reports, updating information, using special software, etc.

Phone A conversation on the telephone, usually from the engineer's desk. It was observed that the telephone was also often used for inter-room conversation within some companies.

Meeting A pre-scheduled face-to-face meeting or discussion.

Conversation Informal face-to-face verbal contact, such as discussion, chat, one word or several words exchange, unscheduled meeting.

Travel Work conducted out of company office. It also includes the time spent on the road.

Tour The engineer often needed to go out of his room to send a fax, pick up the printout, find the documents, get coffee, etc. All these kinds of activities are included in this category. It also includes unknown quick out-and-in activities.

At first, the time allocation among these seven categories is analyzed. Then, the analysis goes deeper to answer the questions of what and how, based on the observation on the contents of engineer's work.

4.1 Analysis of Activity Duration

One phenomenon that impressed the observers was that engineers seldom performed one activity for more than 10 minutes without breaks and interruptions. Unlike the jobs of manufacturing workers, which are highly rationalized, repetitive, uninterrupted, and subject to the steady and unvarying rhythm of the moving conveyor, the engineer's activities are characterized by fragmentation, brevity, and many interruptions.

It needs to be made clear that an activity is considered completed only when the activity place and/or engineer's attention are changed. For example, an engineer writes a report on the computer for a while. If he/she then turns to read email, the activity of writing a report is considered ended or interrupted. In our field notes, writing report and reading email are recorded as two activities, because the engineer's attention is changed from the report to the email.

During this study, about 46 observable activities are recorded on average each day, and the average duration of an activity is 9.45 minutes. Figure 4.1 presents the result of histogram analysis on all recorded activities. It provides an indication about how fragmented and brief the engineer's work can be.

With reference to Figure 4.2, it can be seen that 41 percent of activities lasted less than 3 minutes. Most of the activities (76 percent) were completed in less than 10 minutes. Only 6 percent of activities needed more than 30 minutes. Most of those very long activities (more than 60 minutes) were travelling and scheduled meetings (in which actually many issues were involved, and dealt with).

Compared with the results from Mintzberg's study (1973) on managerial work, it is surprising to find that engineer's work is even more fragmented and brief than manager's work. The following table shows the comparison:

Table 4.1 Duration of Activities

	Desk	Phone	Meeting	Conversation	Tour
Manager	15 min.	6 min.	68 min.	12min.	11min.
Engineer	9.4 min.	5 min.	55 min.	8 min.	5.8 min.

To get a clearer understanding about how engineers worked fragmentarily and briefly, the following paragraph is quoted from the field notes:

> At 10:00 am, he is working on the computer to edit a material list for a project. At 10:04, he prints out the list and goes out to pick up the printout. Back to office in 1 minute, and puts the material list in a folder, then goes to the computer again to look for the information on a gate valve. At 10:08, he places a phone call to the Purchase Department to ask why a kind of valve is not in the database. The call ends at 10:10. Pause for a while, go to another engineer's room to see if he has the valve information. Back quickly with nothing. He finds that he can not proceed any more without the information about this valve. So, he decides to work on another project, in which a pipeline has to be laid either through a park or a school, and he has to discuss the issue with related parties. At 10:12, he goes to his boss's office with a folder to discuss next Tuesday's meeting with related parties. Back at 10:25, and starts to draw on a map to present his options of laying a pipeline. At 10:27, a phone call in from the developer to ask for the drawings, and in the mean time, talk about the status of the project. The call ends at 10:31. Then, he continues his drawing. At 10:34, a draftsman sends in a roll of drawings, and they have a short conversation referring to the drawing. At 10:36, the draftsman leaves, he continues his drawings. At 10:43, he puts the map in a folder, sorts the materials and documents, and cleans the desk. His boss comes in at 10:45, talking about the "tight" project, in which the space is very

limited for laying the pipeline. His boss suggests that the pipeline be laid in the middle of the road, and remove some valves. At 10:51, his boss calls another engineer in to ask if he has the experience of laying the pipeline in the middle of the road. These three then discuss this topic for about 14 minutes.

As we can see from this paragraph, the fragmentation and brevity result mainly from the activity itself, partly from the forced interruptions, and partly from the engineer's need. The activities, such as confirming a data, asking for cost information, informing someone regarding a change in the drawing, are probably not long. Engineering work involves many decisions during various processes of figuring out the solution. In the process of drawing, writing proposals, doing calculations, engineers frequently found that they lacked some data, information, and/or experience. So, they often had to stop their work to seek necessary data, information, and experience. When they make big decisions, they often discuss ideas with their colleagues and bosses to get confirmation. Also, in many cases, engineers have to work with many parties to get the job done, such as technicians, draftsmen, subcontractors, clients, etc. The interruptions coming from these people were often the responses to their previous requests, or for some help to complete their work. All of these contributed to the fragmentation and brevity in engineer's activities.

Figure 4.3 shows the time allocation among quick, short, medium, long, and very long activities. With reference to Figure 4.2, it can be seen that quick activities accounted for 41 percent of activity number, but only consume 8 percent of time. This indicates that how efficient these quick activities are. They actually facilitate the engineer's productivity.

Figure 4.1a Duration of Activities

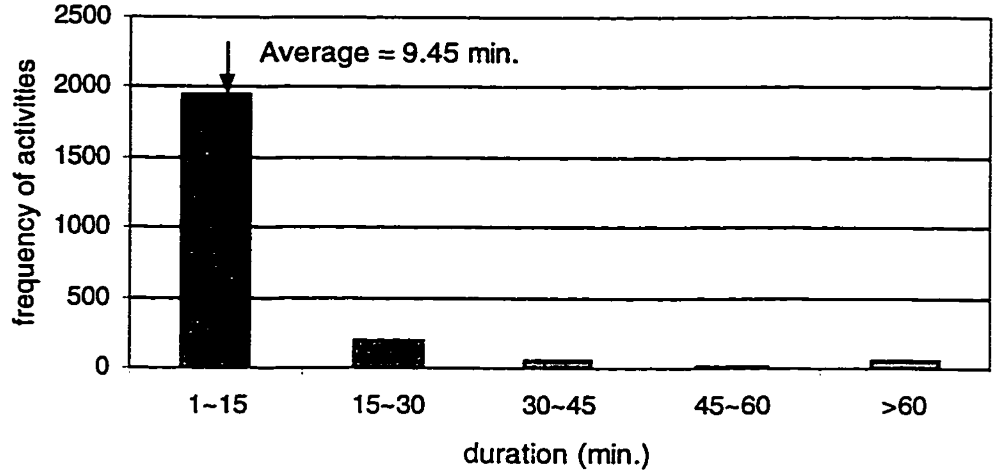


Figure 4.1b Duration of Activities

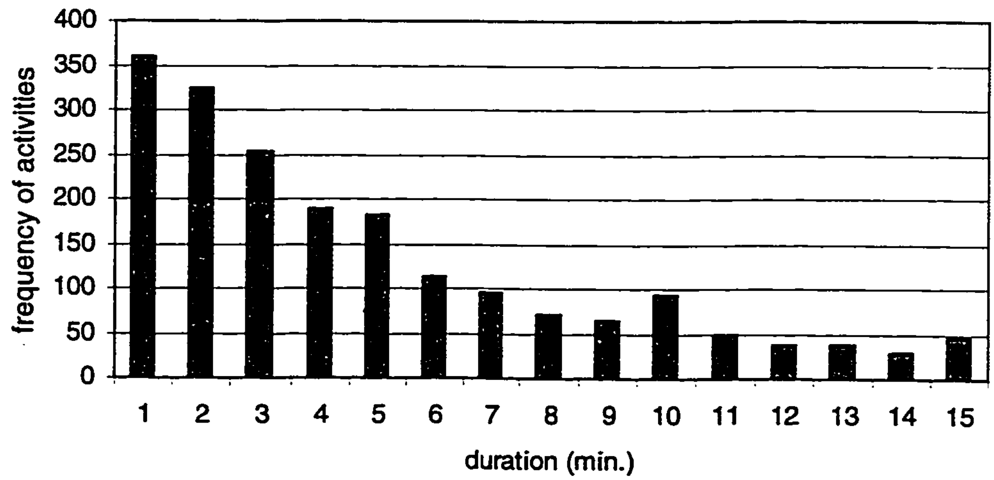


Figure 4.2 Distribution of Activity Frequency

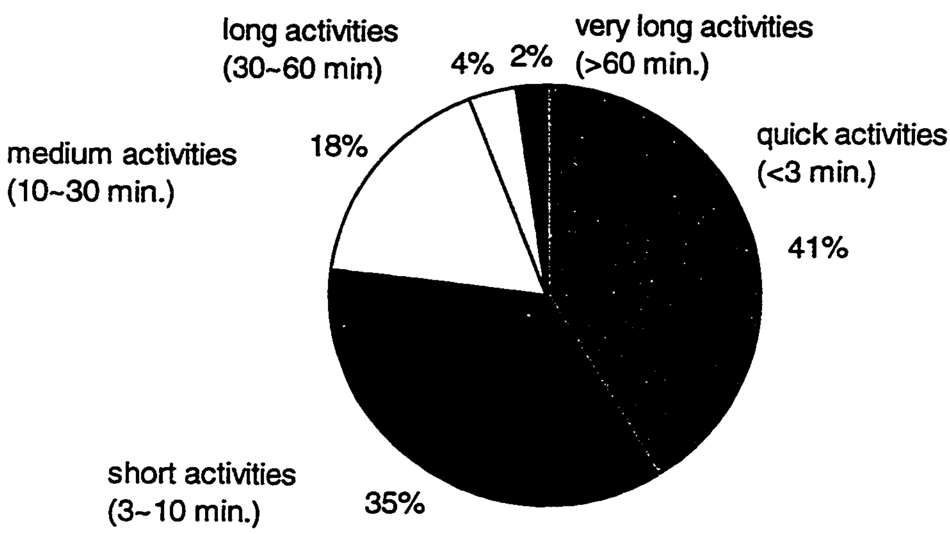
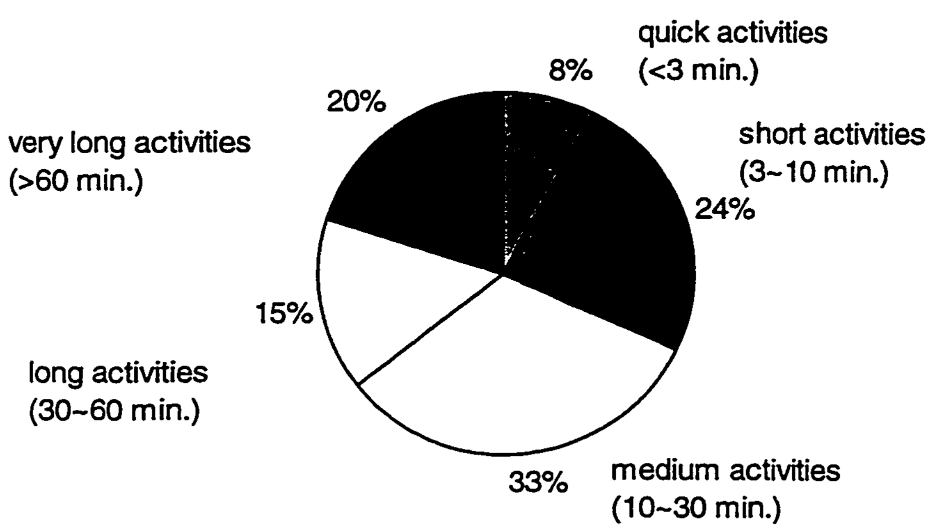


Figure 4.3 Distribution of Activity Time



4.2 Analysis of Time Allocation

Figure 4.4 shows how the engineers' time was allocated among seven categories of activities: computer, conversation, desk, phone, meeting, tour, and travel. The most surprising thing is how much time was spent in communicating with others. In our observation, conversations account for 22 percent of total time, meetings account for 12 percent, and phone for 10 percent. The total of these three is 44 percent. If the conversations and meetings in the travel are included, the number will be even larger. The activities, such as phone calls to confirm a parameter with the clients, discussions with peers on project status, explaining his new work to technicians and draftsman, reviewing the program with the boss, are an important part of their daily work, and a means to get the job done.

It is very consistent in the data that every engineer spent large part of time in talking. Table 4.2 shows this consistency. They spent at least 30 percent, at most 79 percent in talking. Engineer H, who is a senior civil engineer and also the owner and manager of the company, spent 79 percent of his time in talking. This number compares

Table 4.2 Percent Of Time Spent In Talking

Engineer	A	B	C	D	E	F	G	H	I	J
Convers.	12%	36%	12%	12%	26%	34%	32%	25%	19%	16%
Phone	10%	17%	9%	15%	7%	3%	11%	16%	8%	5%
Meeting	14%	1%	19%	6%	8%	11%	14%	38%	4%	9%
Total	36%	54%	40%	33%	41%	48%	57%	79%	31%	30%

with Burn's study (1954), where the executives spent 80 percent of their work time talking; or with Stogdill & Shartle (1955), whose 470 naval officers spent 60 percent of their time in contact with persons; or with Joe Kelly's study (1964), in which section managers spent approximately two-thirds of their time in talking with people. It seems to be understandable that engineers spent less time than managers in talking, but 44 percent is still surprisingly large.

Figure 4.4 also indicates that the informal face-to-face conversation is the type of communication consuming the most of time. It was noted in the observation that the activities of processing mail and fax only consumed 2 percent of desk work time, which is only 0.4 percent of total time. Compared with conversations (22%), meetings (12%), and phones (10%), the mail and fax were used much less frequently. In our observation, the mail was usually used to send the package of formal documents, which often needed a long time to prepare and produce. The fax was often used to send drawings or tables of data for discussion. In one unusual case, one senior engineer (Engineer D) seemed to have a strong preference to fax. Most fax contacts in the record were from the observation on him.

In Figure 4.4, the computer work accounts for about same percentage of time as desk work. However, it is misleading because there are two system engineers and one telephone engineer observed in the study. Their computer work was very similar to the desk work of other engineers. If the data from these three engineers are excluded, the results of time allocation will be similar to Figure 4.5. As we can see, the computer work only accounts for 9% of total time, the least among the seven categories.

Figure 4.4 Time Allocation of Activities

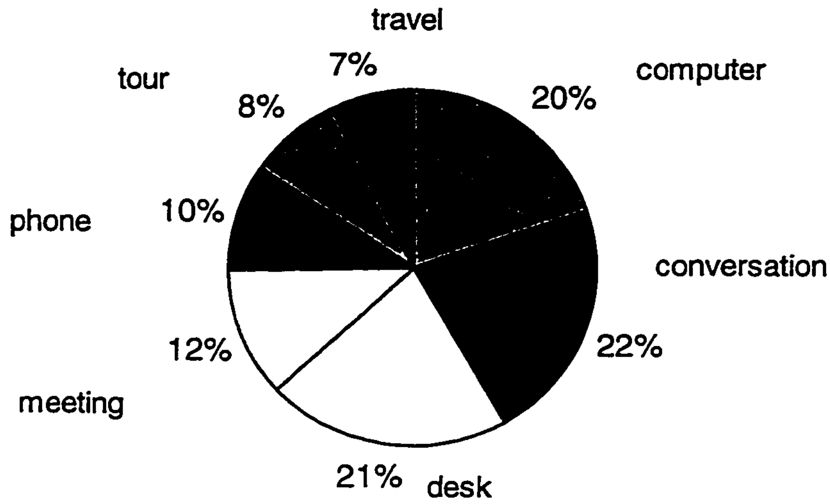
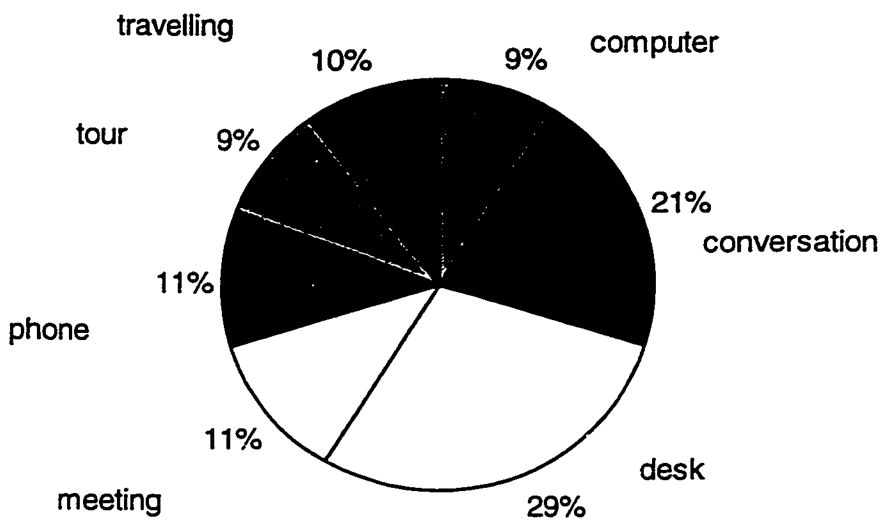


Figure 4.5 Ajusted Time Allocation of Activities



4.3 Analysis of Verbal Contact

Time allocation analysis shows that engineers spent about 44% of their time in verbal contact: phone calls, conversations, and meetings. We turn now to a detailed examination of each.

1. Phone Call

The analysis results of phone calls are presented in Figure 4.6, 4.7, 4.8, 4.9, and 4.10. It can be seen from Figure 4.6 that most phone calls are less than 5 minutes. The phone calls with the duration of 1 minute or less happened most frequently. The average length was about 5 minutes. In our observation, only 3 phone calls lasted more than 30 minutes. One (61 minutes) was placed by a project captain, in which he talked with a Financial Manager about hiring a new talent, his position, responsibilities, training, etc. Another one (50 minutes) was placed by a senior engineer, who is also the owner and manager of his company. He talked with the people in another office in Toronto about managerial issues. The third one (33 minutes) was placed by a partner of a small consulting company. He called the client for talking about new business opportunities. All these three calls dealt with non-technical issues.

Figure 4.7 shows that the quick and short phone calls account for 65 percent of the total phone time. Thus, the quick and short calls are major in both frequency and time.

Figure 4.6 & 4.7 only show the duration aspect of engineers' phone calls. To get a further understanding, we have to know that those phone calls were from/to whom, and for what. It will be very difficult for other research methods, such as survey and diary, to get necessary data to answer these questions relating to work contents. Our field research method allowed us to record the contents of those phone calls, and thus allowed us to explore the answers to these questions.

Figure 4.8 is presented to show the network of those phone calls. With the exclusion of the phone calls in which the opposite party was unknown in the field notes, the phone calls in our records went to 8 groups of people:

Clients This is where the engineer's job and task come from. In our records, 28 percent of phone calls were from/to this group of people.

Subcontractors/Suppliers This group of people get jobs and business from observed engineer's company. 13 percent of recorded phone calls were between engineers and subcontractors or suppliers.

Peers The phone calls between observed engineers and their peers could be inter-room, inter-office, or remote communication from the site or the trip.

Technicians/Draftsmen/Secretaries They can be called helpers for engineers. The phone communications with draftsmen and secretaries were mainly inter-room. The phone calls to/from technicians could be inter-room, inter-office, or from the site.

Superiors Many engineers were observed to have two bosses: a more experienced engineer and a manager.

Other Dept./Office In some large organizations, the engineers often had phone communication with the people from other departments, such as marketing, purchasing, construction, or from the office in another city.

City/Authority Much engineering work needs to be approved by the City Government, or other authorities.

Society/Community The engineers often belong to the community and some kinds of engineering society. During the study, one engineer was observed to make several calls for attending a conference. Another one placed many calls for arranging a meeting for her engineering society. Another engineer was observed to make calls to collect money for the United Way.

Service Communications with service companies, such as courier, film development, colour copy, travel agency.

Personal Calls from/to friends, family, classmates, etc.

It is clear in Figure 4.8 that the phone was used most frequently for contacting with clients and subcontractors. This is reasonable because they are outsiders, and the phone is the supposed communication way. What is surprising in Figure 4.8 is how often the phone is used in internal communication. Peers, helpers, and superiors are all insiders, and total calls between engineers and these three groups account for 36 percent.

Another finding is that engineers' contacts with peers and helpers are much more frequent than with their superiors. During the study, the engineers were observed to have no hesitation when they wanted to call peers and helpers, and vice versa. But they were very cautious to call their superiors. Usually, the phone was used to make appointments with superiors.

Figure 4.9 results from the analysis of purposes of those phone calls. After careful and repetitive categorization, it was found that the purposes of those phone calls can be divided into the following 8 groups: exchange information/data, clarify/explain, instruction, consult, inform/schedule, discuss, business/management, and personal reasons. It is clear that the phone is mainly for exchanging information and data, which accounts for 49 percent. Informing and scheduling is the second use, accounting for 18 percent. The third use is for clarifying and explaining, which accounts for 10 percent.

Considering the data presented in Figure 4.8 and 4.9, one can get some insights about why most phone calls were short, and why most calls are from/to clients, subcontractors, and peers. It was observed that engineer's phone calls were usually very specific and concrete, and seldom for general talking. In most cases, the phone call was just for asking or confirming a number. The phone calls, such as informing a coming fax, scheduling a meeting, also can not be long. In most engineering work, dealing with numbers is the core. The input data defines the task, sets up the limits and scope of the task. These data usually comes from client's requirement, subcontractor's output work, peer engineers' output data, technician's site investigation and test results from the laboratory. Since engineer's work depends largely on these data and information, the engineer frequently needs to contact these people to confirm, to clarify, and to change these data. The lack of one number about the dimension may stop all of the work, and the progress is not possible until this information is obtained.

Since 49 percent of phone calls were for exchanging data and information, naturally we would like to know what kinds of data and information were exchanged. Figure 4.10 is produced to answer this question. The recorded data and information can be categorized into 5 groups:

Technical Data such as pressure, hole depth, property dimension, etc. They are very specific, and sometimes very terminological.

Site Information Site conditions were often photographed or videotaped. Engineers and technicians were also often observed to exchange their own impression on site conditions.

Project Status The information about what changes have been made, what problems appear, what actions need to be taken.

Cost Data The data about how many hours are put into a certain task, what material and equipment are used, and their prices.

General Information The information such as phone number, email address, where and how to find a person.

As we can see, the data and information in an engineer's phone call were very specialized, and could be very terminological. Technical data accounted for 47 percent, project status for 25 percent, and site information for 9 percent. The total of the three is 81 percent. During the observation, the observers often found themselves unable to understand the technical meaning of engineer's phone calls.

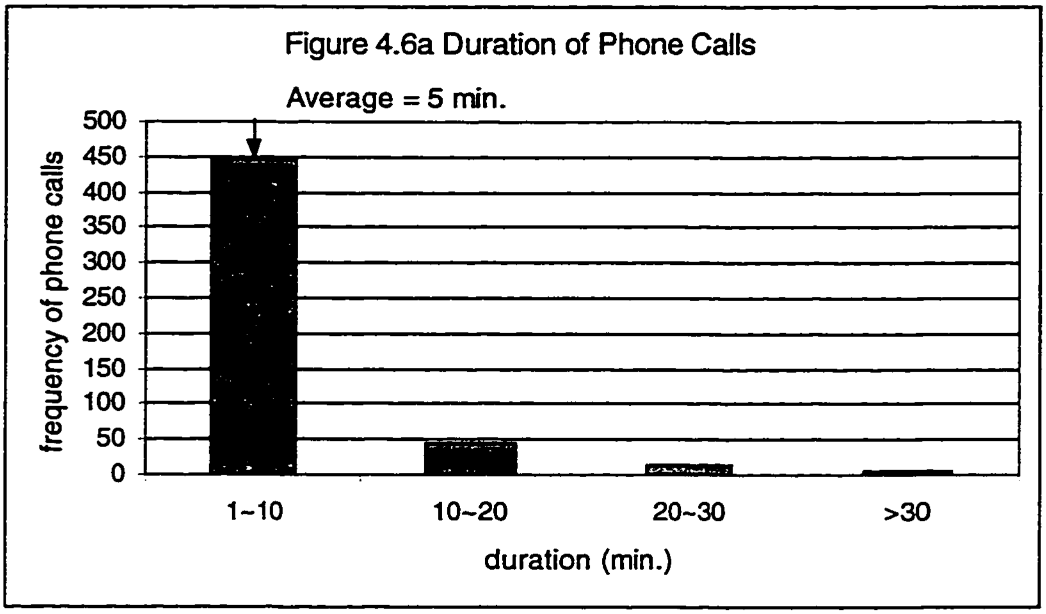


Figure 4.6a Duration of Phone Calls
Average = 5 min.
frequency of phone calls
500
450
400
350
300
250
200
150
100
50
0
1~10
10~20
20~30
>30
duration (min.)

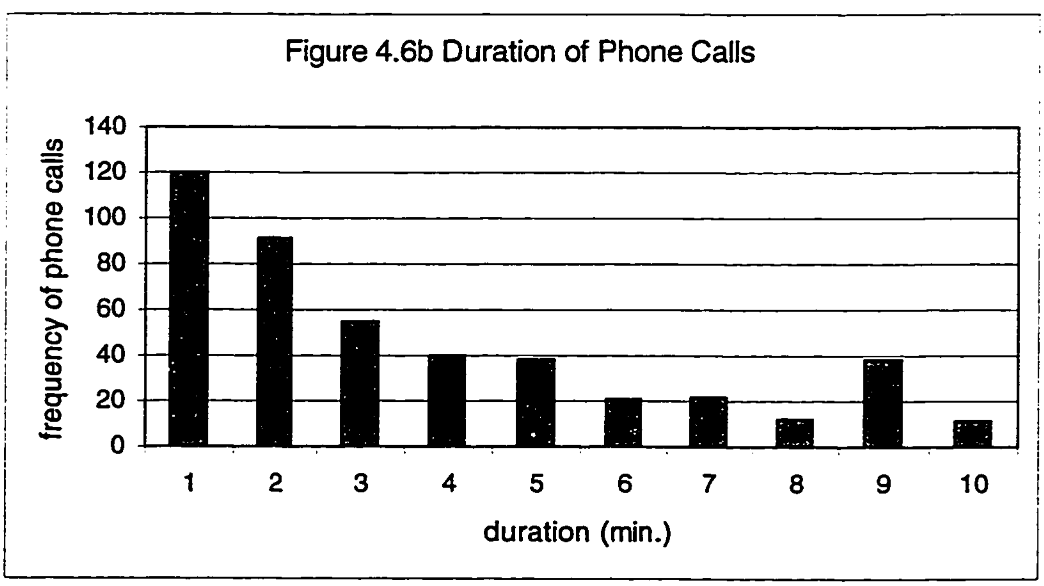


Figure 4.6b Duration of Phone Calls
frequency of phone calls
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
duration (min.)

Figure 4.7 Time Allocation of Phone Calls

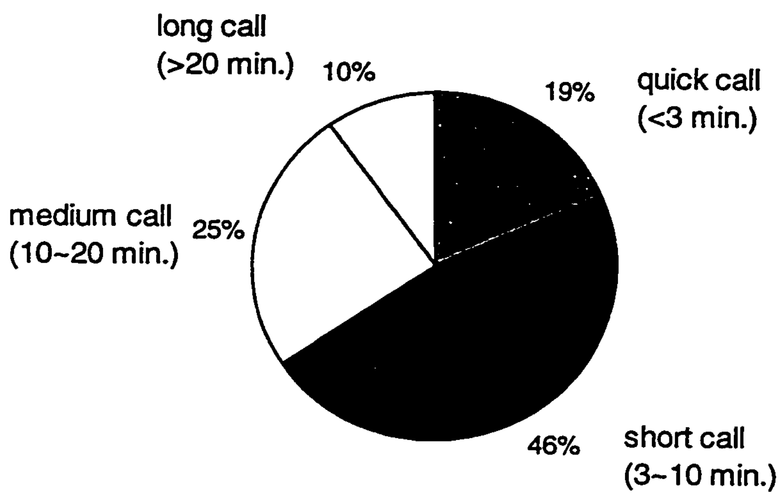


Figure 4.8 Phone Call Network

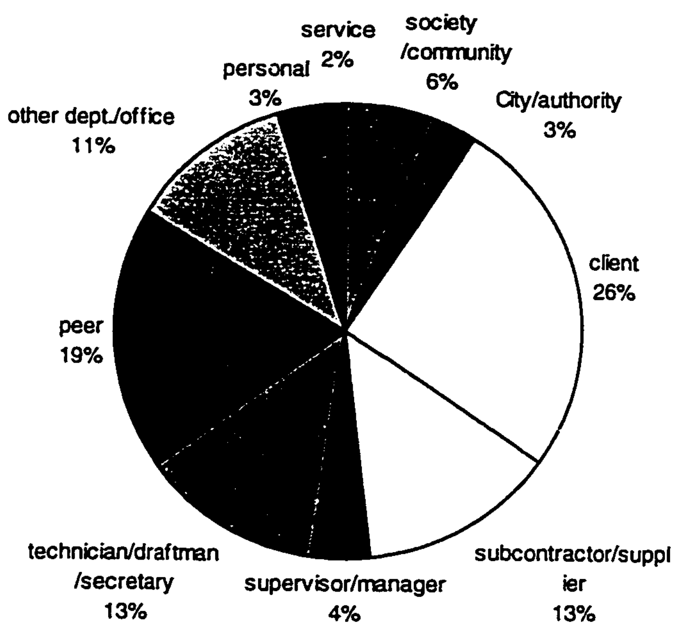


Figure 4.9 Kinds of Phone Call

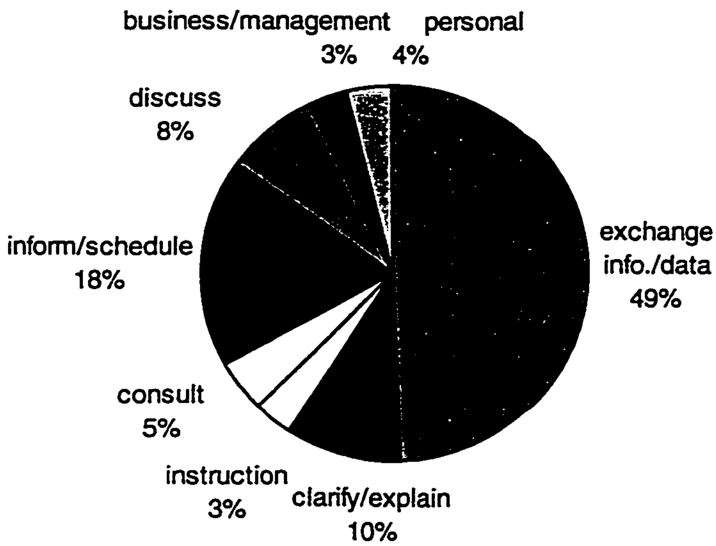
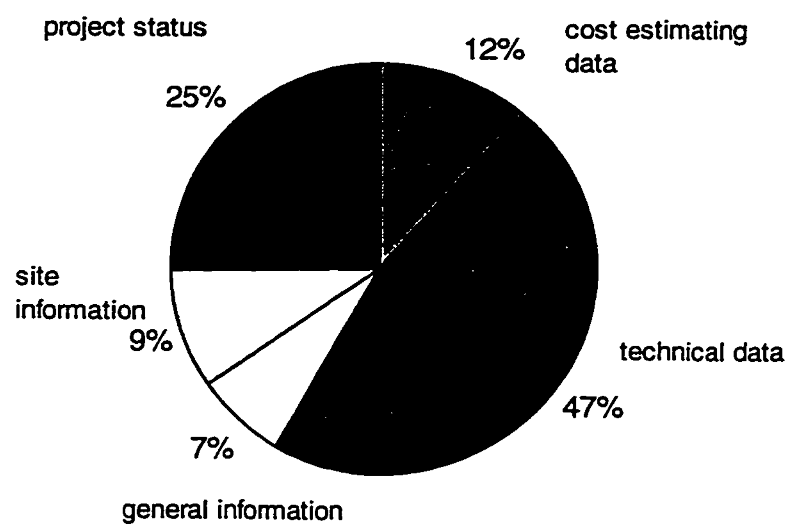


Figure 4.10 Kinds of Information in Phone Calls



2. Conversation

In our observation, the conversation was the most used means of communication. It accounted for about 20 percent of total working time, showed in Figure 4.4 & 4.5. During the study, the conversations were generally of short or medium duration, averaging 8 minutes. Figure 4.11 shows that most conversations were finished within 2 minutes. Those conversations with more than 60 minutes were observed only 4 times. One was between a telephone engineer and the observer. The engineer introduced his work, information management system, and projects to him. Another 3 conversations were recorded during the observation of a partner of a small consulting company. Two conversations were between him and another partner, talking about budgeting, planning, and administration of company. In another conversation, he and his partner talked with a client to explain and present their work.

Figure 4.12 demonstrated that short and medium length conversations consumed most of the time. They together accounted for 73 percent of total conversation time.

Through categorizing the people with whom engineers had conversations, it was found that engineers mainly had conversations with 3 groups of people: peer engineers, helpers (technicians, draftsmen, secretaries), and superiors. The conversations with other groups of people, such as clients, people from other departments, observers, were also observed and recorded, but they all together accounted for only 4.1 percent. It could be seen from Figure 4.13 that engineers had many more conversations with peer engineers and helpers than with superiors. It seemed that engineers were reluctant to discuss with their superiors when they only had fragmented ideas and partly completed jobs. When they were in conversations with their boss, the conversations were usually for reporting the project status, reviewing the whole project, or informing of important matters. In contrast, it seemed nothing prevented engineers from talking with their peers and helpers. No matter when and what they wanted to talk about, they just went ahead, even if only for one number or for a yes-or-no question. Furthermore, such a parameter or yes-or-no question could often lead to a medium length conversation covering many topics. It was observed that engineers have a very close relationship with the technicians and draftsmen. These helpers could go into the engineer's office at any time, search what they want, and take something without a word to the engineer. Their behavior is more like that of peers rather than subordinates.

From engineers' conversation network and phone call network, it indicates that it is the engineers who put all things together, and make sure the work gets done properly under the limits of time, cost, and schedule. They have the full responsibility for the job. They instruct technicians how to work on the site to get data; guide draftsman to generate the drawings; get approval from authorities when necessary; pay great attention to subcontractor's work and costs; and consult with clients to make sure that the job satisfies their requirements. This responsibility often causes engineers to work very cautiously. They always tried to get related information as much as possible, as correctly as possible. They spent significant amounts of time in studying and clarifying what they got, and instructed and explained their ideas to the helpers. They frequently discussed with peer engineers, often just to confirm that the ideas and methods were correct, to be sure every involved factor has been considered carefully. They spent a large part of time in reviewing projects with their superiors to make sure everything was proper.

Figure 4.14 is presented to explore the contents of conversations. Nine kinds of conversations were observed during the study: discussing technical issues, exchanging data and information, explaining and clarifying, informing and scheduling, reviewing and reporting the projects, instructing, talking about company's events and issues, talking about business and management, chatting, and personal conversation. Technical discussions usually happened between engineers, and could be either specific or general. Reviewing and reporting the projects happened between engineers and their bosses, sometimes between engineers and technicians. The conversations for instructing were recorded when engineers told technicians or draftsmen about how to do the job. In one case, the engineer spent great amounts of time in teaching a summer student to do the job. Most of his conversations with that summer student were included as "instructing" conversation. In another case, one engineer had several conversations with a junior engineer about how to use software. During the study, several company events and issues were recorded, such as golf tournament, barbecue, beer reception, Friday donuts, and anniversary dinner. Such events often caused many conversations, and they were included into the category of company's events and issues.

As we can see, about one-third of the conversations were for discussing technical issues. It was observed that such discussions between peers were often just for exchanging ideas and opinions. They did not necessarily reach any agreement or conclusion. Frequently, one engineer just went into another one's room, talking about ideas, methods, worries, and the opposite made some comments, reminded of something, talked about own experience and preference. These kinds of conversations between engineers often seemed to be just for getting confirmation and agreement, for releasing the pressure, or satisfying the desire to show others with ideas and means, or checking to see if some important factors are missed.

Most of these conversations were very specialized and technological. The conversations of exchanging data, explaining and clarifying, instructing, reviewing and reporting all contained significant amounts of specialized knowledge. They were often hard to understand for others without a proper engineering background.

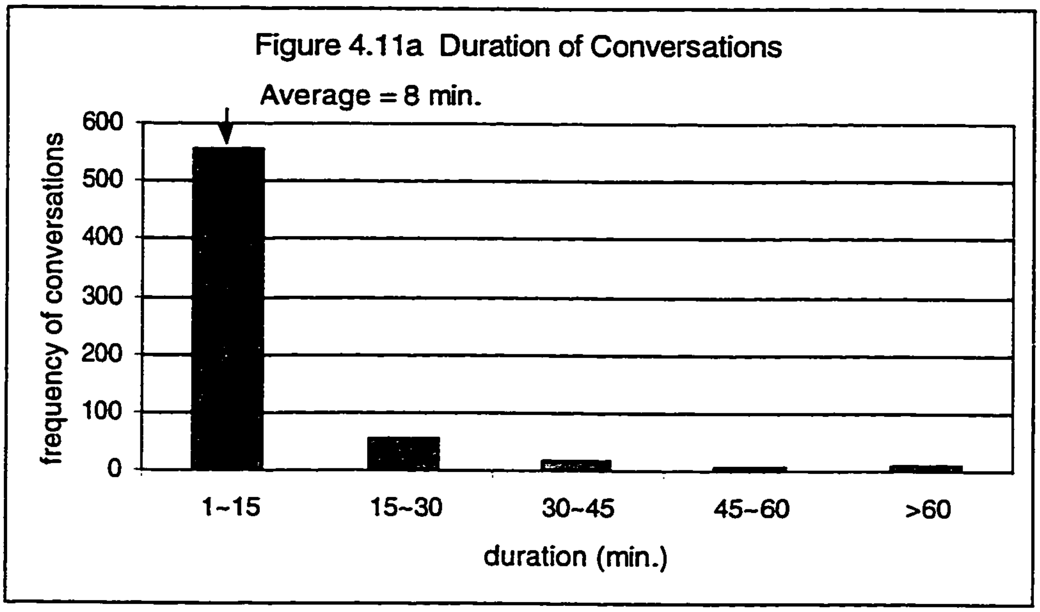


Figure 4.11a Duration of Conversations
Average = 8 min.
frequency of conversations
600
500
400
300
200
100
0
1~15
15~30
30~45
45~60
>60
duration (min.)

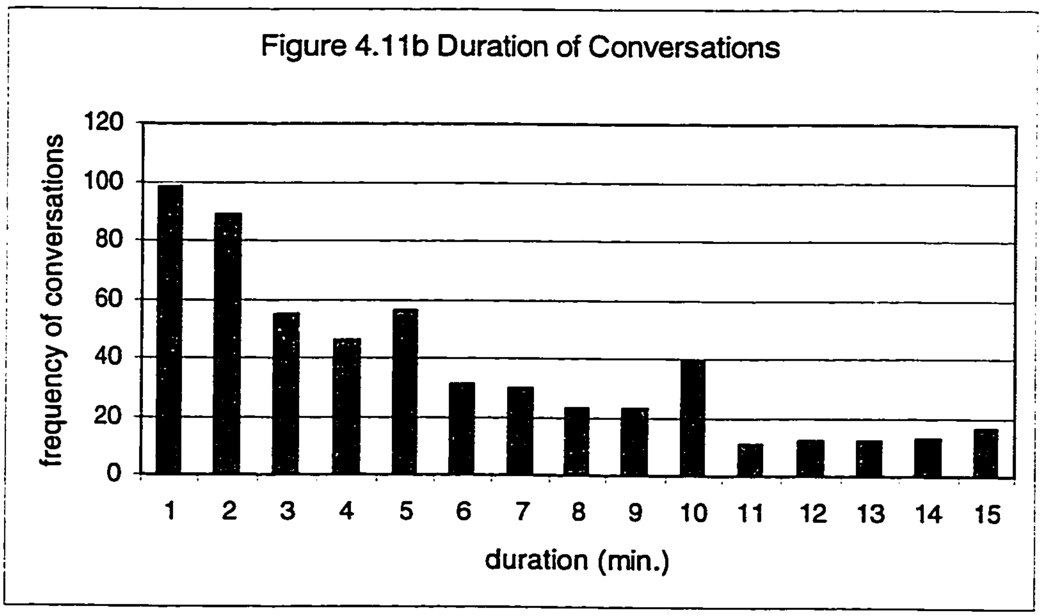


Figure 4.11b Duration of Conversations
frequency of conversations
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
duration (min.)

Figure 4.12 Time Allocation of Conversations

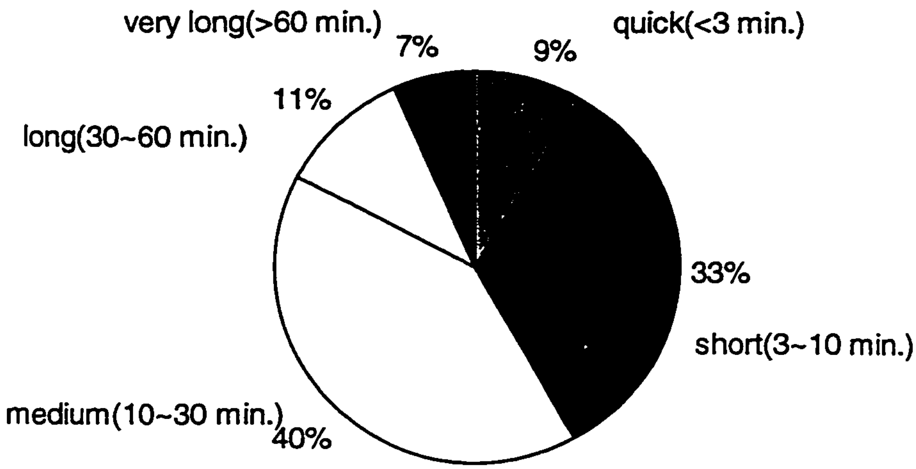


Figure 4.13 Conversation Network

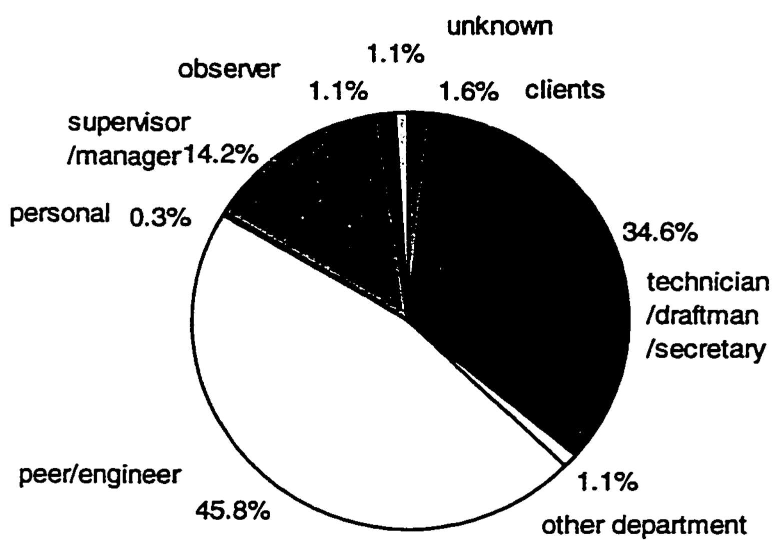
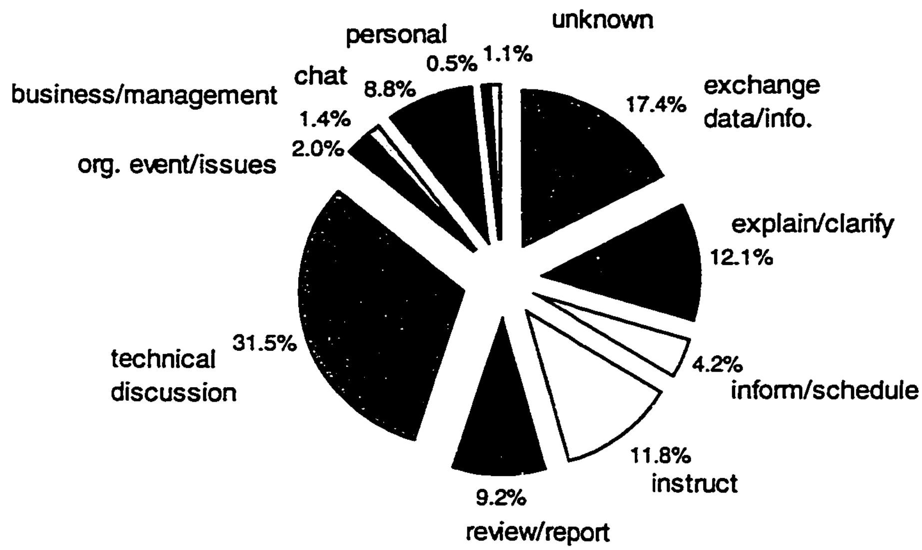


Figure 4.14 Kinds of Conversation



3. Meeting

During the study, 39 pre-scheduled meetings were recorded in the field notes. In most cases, the observers were unable to attend the meetings. However, the engineers were asked by observers to summarize the information that was needed in the study, that is, (1) time and length of the meeting; (2) who attended the meeting; (3) the purpose of the meeting. Because the observer was not allowed to attend the meeting, one meeting, which actually consists of many activities, was recorded as one activity. Thus, the detailed information about engineer's behavior in the meeting was lost. These scheduled meetings consumed 12 percent of engineer's working time. These contacts lasted relatively long. As showed in Figure 4.15, the average duration was about 68 minutes. These meetings provided the engineers with the opportunities to meet with large groups, and to meet people away from their organizations. Scheduled meetings were used instead of unscheduled conversations when large quantities of information had to be transferred. Thus, when engineers wished to exchange a small quantity of information, they used the telephone or conversation. When two or more parties wished to discuss several topics, and exchange large quantity of information, they scheduled a meeting.

Figure 4.16 shows that engineers have the possibilities to attend scheduled meetings with 6 kinds of people: clients, cooperating company or subcontractor, superiors, team member, whole company staff, and newcomer. During the study, only one meeting with a newcomer was observed. In this meeting, the project leader introduced him the organization, the information management system, and projects. Most of the meetings in the record were scheduled with clients and co-operation companies or subcontractors. They were outsiders, and scheduled meetings provided engineers with the chance to exchange large quantities of information, and to proceed with serious events such as reviewing and finalizing the project, promoting the business, negotiating the new job. The meetings with team members and with superiors were usually for reviewing the project status, for managing the interface, and for planning the next step's work. Surprisingly, the staff meetings were often called "safety meeting," although the meeting covered many topics about company administration. Maybe, safety is the first priority topic for administration in these engineering meeting. Four staff meetings in three companies were named "safety meeting."

As to the contents of these meetings, which are shown in Figure 4.17, project reviewing and planning dominated the meeting time, 62 percent. Those business meetings for promoting and negotiating new jobs accounted for 20 percent. It could be seen that about two-thirds of meeting time (site meeting + instruction + project review/plan) were for communicating for present tasks, one-fifth was for communicating for new jobs, and 10 percent for attending company events, and communicating with whole company staff.

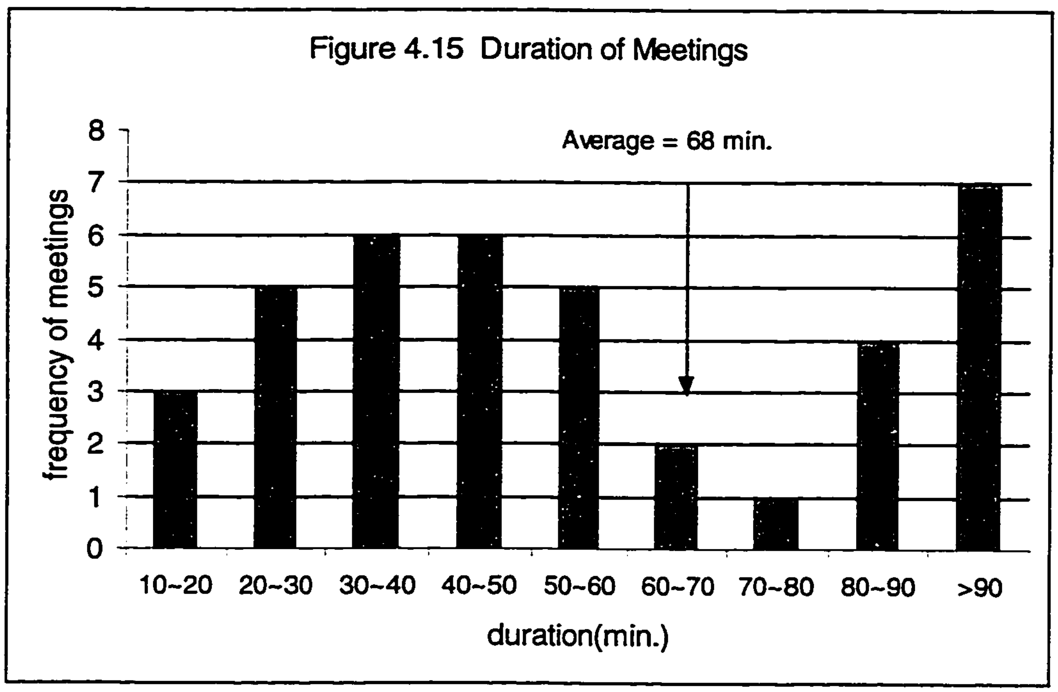


Figure 4.15 Duration of Meetings
Average = 68 min.
frequency of meetings
0
1
2
3
4
5
6
7
8
10~20
20~30
30~40
40~50
50~60
60~70
70~80
80~90
>90
duration(min.)

Figure 4.16 Meeting With Whom

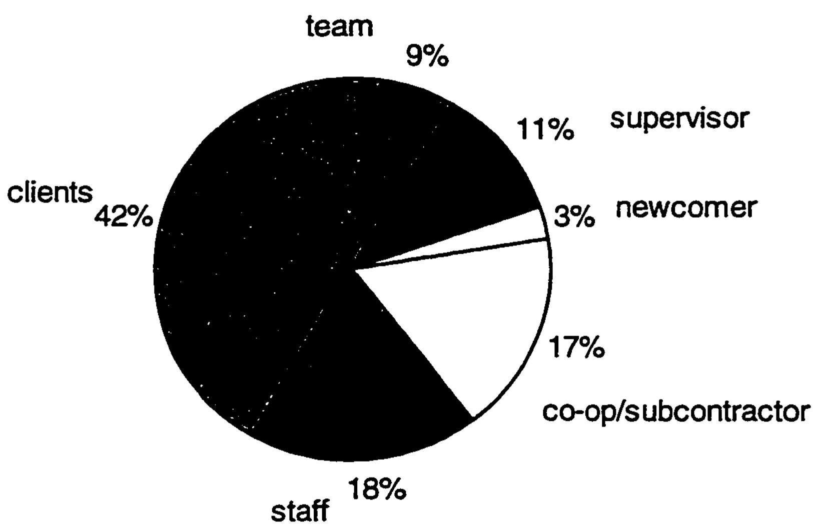
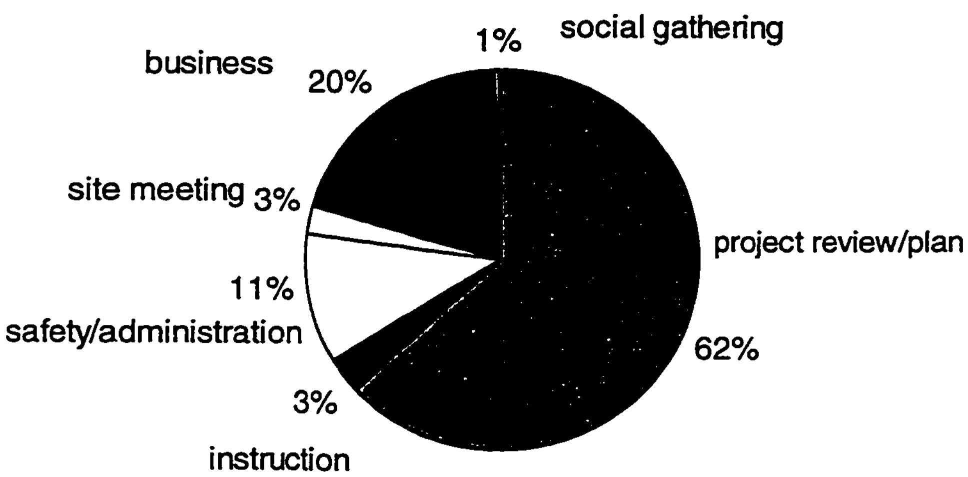


Figure 4.17 Kinds of Meeting



4.4 Analysis of Desk Work

According to Mintzberg's study (1973), "the manager does not leave the telephone or the meeting to get back to work. Rather, these contacts are his work. The ordinary work of the organization—producing a product, undertaking research, even conducting a study or writing a report is seldom undertaken by its manager. The manager's productive output can be measured primarily in terms of verbally transmitted information." That is why manager often spends as much as 80 percent of his time in communicating with others.

Unlike the manager, the engineers can not complete the work only through conversation. They have to get back to generate their products: drawings, reports, proposals, specifications, and cost estimation. Talking is necessary, but is not the ultimate goal. Engineers exchange ideas with peers, seek data from clients and sites, discuss proposals with the boss, but at last they have to sit down and put it all together to produce the product or technical documents. And this is done at the desk and computer.

During this study, the total observed desk work accounted for 21 percent of total of the observation time, showed in Figure 4.4. What surprised observers during the study was that engineer's desk work was frequently interrupted, and often ended in a very short time. Figure 4.18 shows the result of our observation and analysis. The average duration was about 9.4 minutes. Most desk work was completed or interrupted within 5 minutes, and very few lasted more than 30 minutes. Figure 4.19 showed that short and medium length of desk work consumed most of desk work time. The results are more surprising when they are compared to those of Mintzberg's study on managerial work. In his study, the average duration of manager's desk work was about 15 minutes, over 5 minutes longer than engineer's. This sharply conflicts the traditional image of engineers who work for long uninterrupted periods on complex problems alone in their own offices.

To explore the reasons, it is necessary to know what the engineers do on their desk. While the managers stay at their desk mainly for processing mail and reading reports, according to Mintzberg's study (1973), the engineer spent their time at the desk mainly for working on drawings and estimating cost. As Figure 4.20 shows, 34 percent of desk work time was for drawing or checking the drawing, and 18 percent for estimating costs. These two groups of activities often needed significant amounts of data, information and ideas, and thus required many interruptions to seek, as we discussed in the analysis of verbal contact. The other two groups of activities that involved the exchange of data and information were reading proposals/reports (12%) and reviewing the whole project (8%). These four groups amounted to 72 percent of the desk work. The other categories of desk activities, which accounted for the other 28 percent, were formatting/finalizing, sorting/packing/cleaning, searching/referring, processing mail and fax, planning/scheduling, and short writing. As we can see, all of these activities are probably not long. It was observed that calculating was very difficult to separate from the activities of drawing, checking drawings, estimating costs, writing reports, and proposals in the computer. So, it was not listed separately.

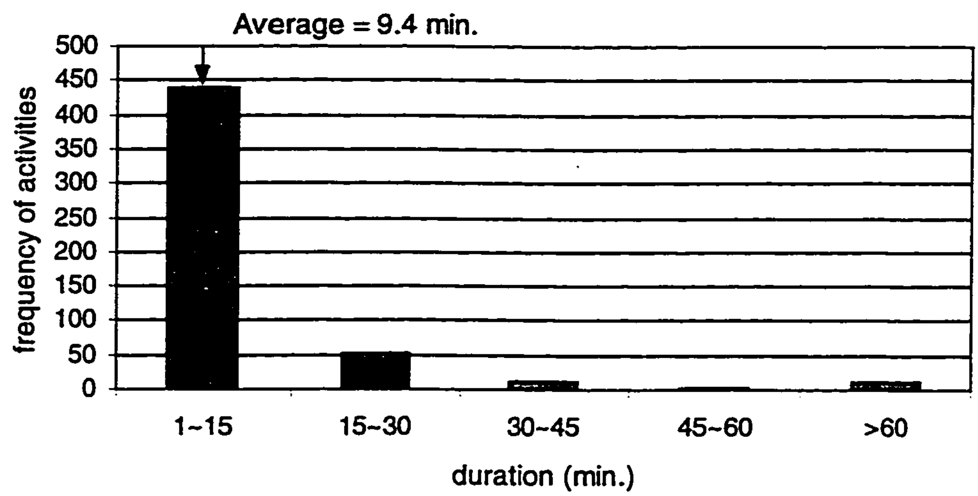


Figure 4.18a Duration of Desk Work

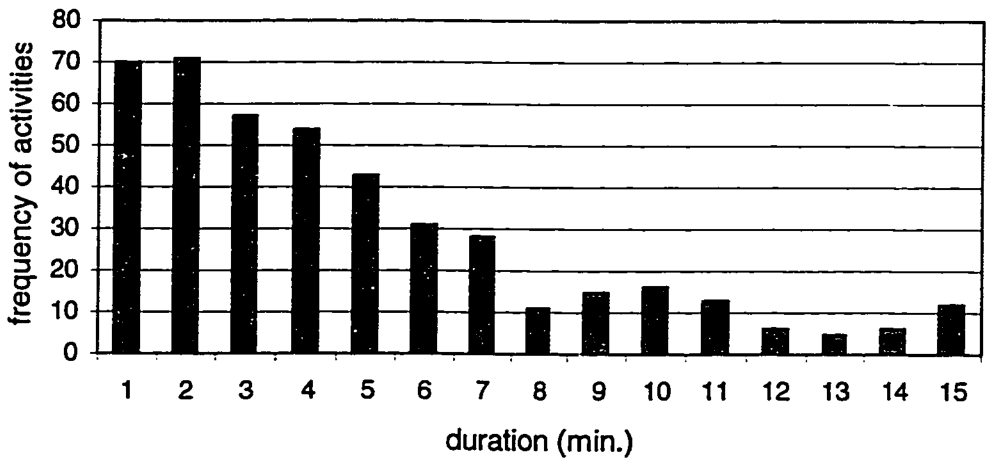
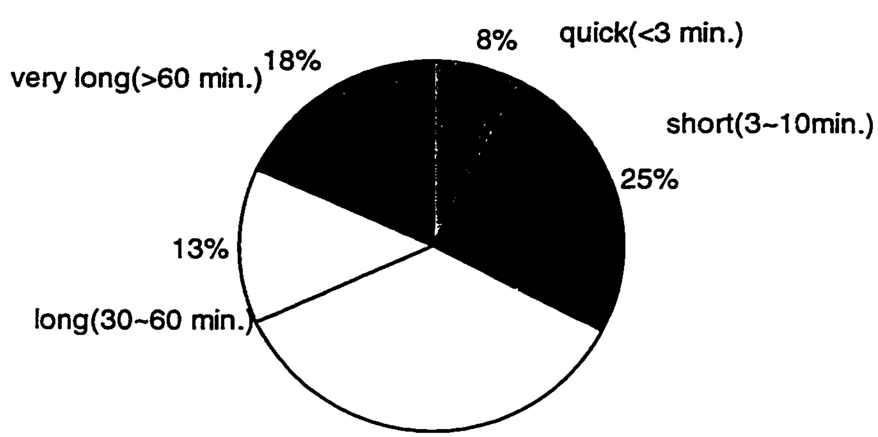


Figure 4.18b Duration of Desk Work

Figure 4.19 Time Allocation of Desk Work



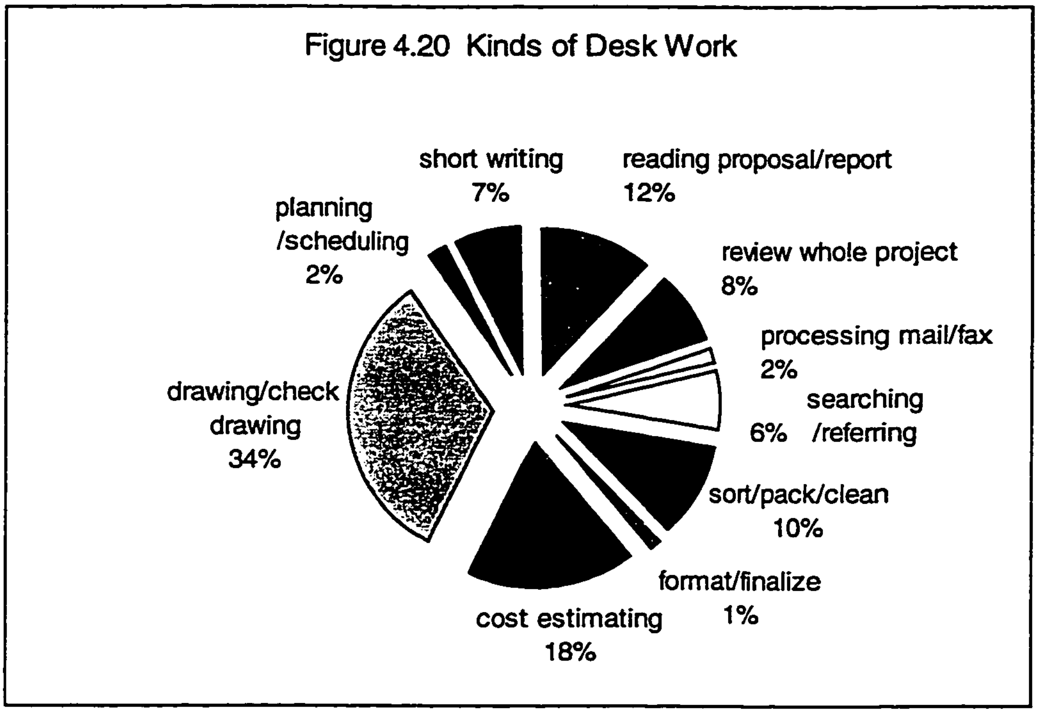


Figure 4.20 Kinds of Desk Work
short writing 7%
reading proposal/report 12%
planning /scheduling 2%
review whole project 8%
processing mail/fax 2%
searching /referring 6%
drawing/check drawing 34%
sort/pack/clean 10%
format/finalize 1%
cost estimating 18%

4.5 Analysis of Computer Work

While desk work was used mainly for drawing, reading, and cost estimating, the computer was used mainly for writing. During the study, 49 percent of computer use was observed for writing reports and proposals. The technical use, such as using special software for drawing and calculating, and processing data, surprisingly represented only 16 percent of the total time spent on computers. Actually only three engineers in two organizations were observed to use the computer for technical purposes. Two engineers in a mid-sized geological engineering company used their computers several times for processing the sample test data from the laboratory. In this company, there is a special person who uses a complicated software package for the engineers. Another engineer in a large utility company used special software a couple of times for drawing the pipeline and calculating the pressure. The field notes indicated that in engineering work, the most important thing seemed to be the understanding of the project situation, the limits and restrictions of the problem, and the relationship of all factors involved. During the study, it was observed that the computer, like draftsmen, was helpful on accelerating the procedure, after a whole situation was completely understood, and proper decisions and methods were set down. Just as Robert W. Mann (1989), a leader in engineering design education, states: "The sequence of steps is never known at the beginning. If it were, the whole process could be accomplished by the computer since the information prerequisite to the computer program would be available. Indeed, the creative process is the process of learning how to accomplish the desired result."

It was worth noting that it was seldom observed that engineers just sit in the office to figure out the solutions. The process of figuring out the solution was mixed into the process of sketching and drawing, writing reports and proposals, estimating the cost, and exchanging data and ideas with clients, peer engineers, and technicians.

In Figure 4.22, word processing means writing letters, fax covers, etc., and it is separated from writing reports and proposals, because it does not need special knowledge. The spreadsheet software was often observed to be used for budgeting and cost estimating. Other use of computers includes updating and searching information, and checking and sending email. Email was seldom used for communication with outsiders. Usually, it was used only for announcing internal organization news.

The average duration of computer work was about 16 minutes, about 6 minutes longer than desk work. Computer work, such as writing reports and proposals, budgeting and estimating costs, and technical use, also needed to seek data and information, to exchange ideas with peers, and thus was often interrupted. But comparing to desk work, it was more final work, which involved less in studying the questions. The computer work, which lasted less than 5 minutes, was often interrupted by searching the files, referring to the drawings, and responding to visitors and phone calls.

Figure 4.21 Duration of Computer Work

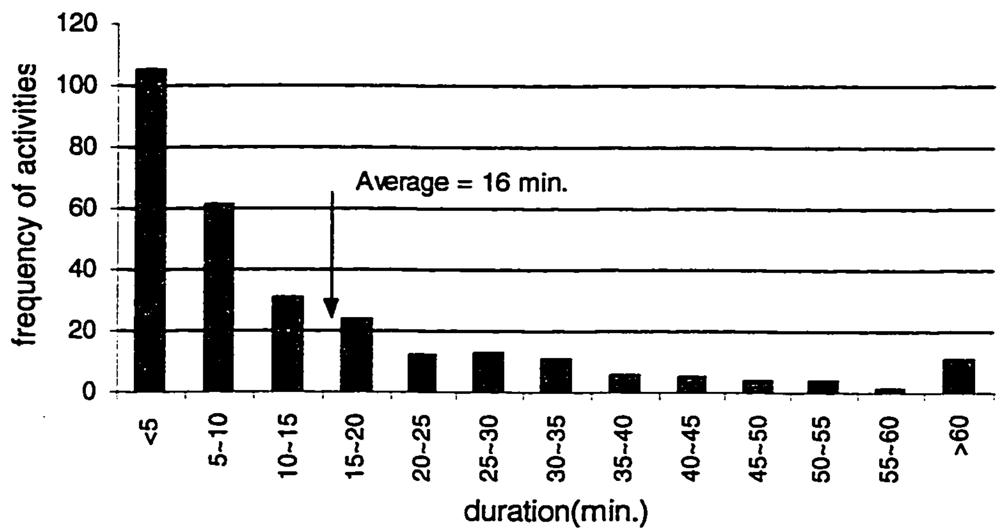
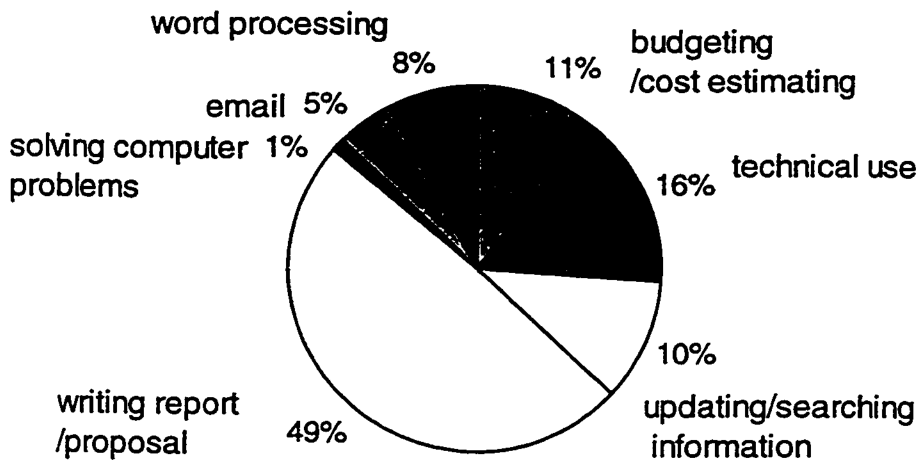


Figure 4.22 Use of Computer



4.6 Analysis of Tours and Travels

As shown in Figure 4.4, tour and travel consumed about the same percent of total observation time, 8 percent and 7 percent respectively, but in different ways. As defined in the beginning of this chapter, the tours are the activities performed out of the engineer's office, but within the company offices. The travels are the activities performed out of the company. The tours were the activities that frequently happened, but each lasted a short time. During this study, tours were observed 318 times. Most of time, engineers went out just for some files, sending faxes, and picking up the printout. Some unknown activities were also included in this category.

Travelling was a very time-consuming activity, and therefore could not happen frequently. During this study, 11 travels to sites were recorded. The shortest travel was about 52 minutes, and the longest one lasted more than 5 hours. The average duration was about 138 minutes. Except for the two computer engineers and one telephone engineer, who do not produce a physical entity that is installed somewhere, every engineer was observed at least one time to go to the site. The thing that impressed the observer was how much attention was paid to the site information. When the site photos were developed, when the engineer came back from the site, and when the technician called from the site, a group of people from the boss to all related engineers gathered immediately, and always had a long discussion. Site information is always important for the engineers whose ideas and methods will be installed and tested on the site. Due to time limit, they can not go to the site very often. So, they often need to call the technician on the site to get the information. And whenever necessary, they will go to the site by themselves to have a look.

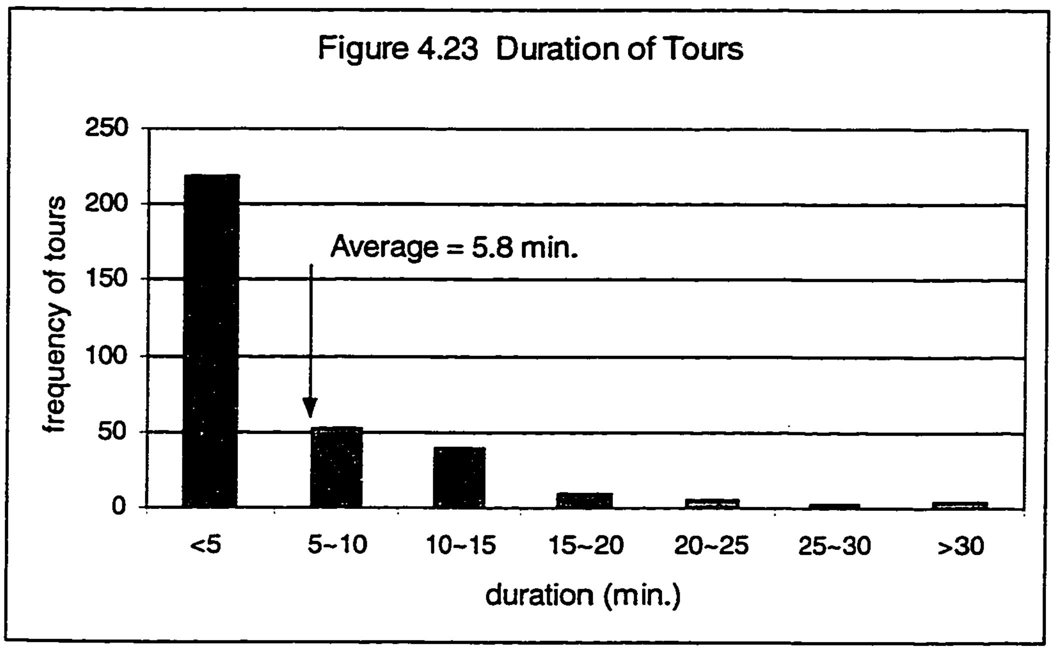


Figure 4.23 Duration of Tours
250
200
150
100
50
0
frequency of tours
Average = 5.8 min.
<5
5~10
10~15
15~20
20~25
25~30
>30
duration (min.)

4.7 Analysis of Variety Within Engineering Job

"Variety is the spice of life". But what is variety? What is a varied job? Clearly a person who performs an identical action upon identical products on a moving belt has no variety in the job. Unless the belt breaks down or the product changes, the manual workers on an assembly line not only do the same thing, they also do it in the same place and in contact with the same people. In our observation, no engineer's job is like that. The place of work will probably change, if only from one office to another. The contacts are likely to vary. The activities that the engineers perform will change, and not in a set way. Nor is the sequence of activities likely to be always the same. The engineer may be discussing the site conditions with technicians at 9:00 am, drawing at the desk at 10:00 am, and be in a conference with clients at 11:00 am. The engineers are unlikely to perform same activities day after day. The time span of the subjects that they are dealing with will also change. They may spend a whole day to go to investigate site conditions and spend hours in meeting with clients to review the projects. They also may spend a day performing many short activities such as finalizing the file package, correcting the drawings with technicians, writing the specifications, listing the material required, and estimating costs. This description gives some ideas of the different ways in which engineering job may be varied. Let us look at these varieties in more detail.

Place

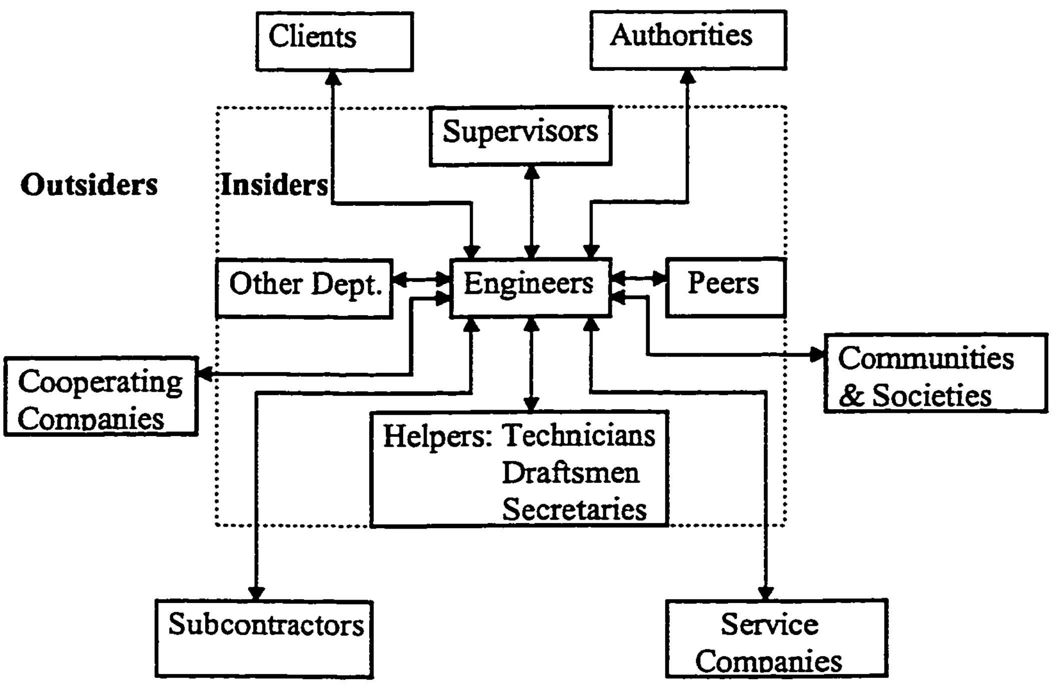
In many jobs, one's place of work is restricted. The postman has a definite round, the typist a desk and chair, and the number of square feet per office worker is specified. The engineer's work provides some varieties in place rather than the office. As we can see from Figure 4.4 and Figure 4.5, engineers performed the activities of desk work, phone, and computer in their own offices. The activities of conversation could happen in their own offices as well as in anywhere within the company, even in other departments. The number of tours indicated how often engineers left their own offices. The travel provided engineers the chance to go out of the company. The different meetings, such as promotion, presentation, reporting and reviewing projects with clients, society meeting, meeting with authorities, provided even greater variety in the place of work. During the study, one engineer was observed to spend some time to write a conference request to his manager for a chance to attend a conference in Chicago. Another engineer was observed to contact with a travel agency for changing his air ticket to Toronto for a meeting with a cooperating company. It is very possible for engineers to go to another place in the country and possibly abroad to look at new equipment and new methods.

People

For many jobs, the job holders may see very few people. They may see only those in their own department. They may work mainly with immediate colleagues and see no one but their boss and peers. Their contacts may be confined to their own company. Their variety of contacts may be limited in all ways, by number, by levels, and by department.

Unlike these jobs, the engineer's job provides great variety in contact with people. According to the analysis of verbal contact, the engineers' contact network can be drawn as Figure 4.24. The engineers were observed to have close relationship with their peers and helpers, because they frequently exchanged ideas and information with peers, and needed helpers to help produce the final products. The engineers often needed to contact

Figure 4.24 Contact Network



these superiors to get advice and approval from them, and to provide them with ideas and opinions. Engineers also had the opportunities to meet people from other departments such as construction, purchasing, and sales. Also, engineers often needed to contact 6 kinds of outsiders: clients, cooperating companies, subcontractors, authorities, community and society, and service companies. While the engineers' relationship with insiders are pretty fixed, the different project and task provide different clients, subcontractors, co-operation companies, and authorities, and thus frequently provide engineers with the chance to meet new people.

In this network, the engineers are the information centre for the task. They worked with their helpers, peers, and superiors to make sure that their ideas and methods were correct and were documented correctly. They contacted with clients to make sure the client's requirement was satisfied. If necessary, they would go to the authority to get approval for the job. They also paid close attention to subcontractor's work and costs. They often needed to co-ordinate with others such as the construction department to make sure the task could be done on schedule. One good example observed in the study showed how the engineer was the focal point. In this example, a land developer changed the space dimensions for the pipeline. This change required changes to the engineer's design. After he studied and reconsidered the situation carefully, and discussed it with his peers and boss, he decided to locate the pipeline in the middle of the road and remove some valves. When he finished his re-design, and asked the draftsman to detail and finalize the drawings, he contacted the construction department and found that the pipeline would not be able to be laid before the road is paved. At once, he contacted city authority several times to try to shorten the approval period. By that Friday, when he finally got the completed drawings from the draftsman, he quickly sent a copy to the construction department and told them to feel free to do whatever they can to accelerate the process of laying that pipeline. Then, he rushed to the city authority to get the design approved. The approval period needs 5 days.

Just as this example showed, the engineer needed to take full responsibility for the task, which resulted in the need to contact many people from different parties.

Content of Work

There is no lack of variety in an engineer's activities. Engineering work is a complex, multiple step process, needs many skills and knowledge, and necessarily involves many different activities. As discussed before, there are many kinds of activities in each of 7 main categories: computer, conversation, desk, phone, meeting, tour, and travel.

However, although there are many various kinds of activities with the engineer's job, the contents of all these activities gravitate to one point: solving a particular defined problem that has a "product" solution. Our observations indicated that most of the engineer's activities were related to several tasks. No matter how frequently they changed their work place and shifted their attention, no matter how many people they talked to, and how often, engineers maintained their focus. This was because the engineer's job restricted the range of problems. The content of a job may be varied in depth and in breadth. A specialist position such as engineer may provide considerable variety within its own speciality, particularly if the subject is developing rapidly. But it can not provide the variety in breadth, that is, in the range of problems. A general manager's job, or that of any senior line manager who takes part in the general management of the company, provides a variety in breadth. A manger may deal with a customer' complaint, may inspect the factory, may hold a discussion on how to launch a new product in six months' time, may hire a new talent, and may join a committee that is considering the possible implication of new products that are still at the research stage. Mintzberg pointed out in his study (1973) that there is a danger of superficiality inherent in a fragmented and brief pattern of work. That means managers tend to work superficially because of a fragmented and brief work pattern. Mintzberg identified it as a prime occupational hazard of the manger. As we can see from our study on an engineer's job, a job that is fragmented and brief may be very specialized, and without any superficiality, as long as it is restricted to a particular problem.

It is reasoned that the lack of variety in breadth of job content may also restrict the range of topics in an engineer's contacts with people. Although the engineer has opportunities to meet many people from different parties, the topic may be always similar. In section 4.3, the analysis of verbal contact shows that engineers contact other people to get information and ideas for their task. When the breadth of task is limited, the variation in the contacts is limited. This helps to explain why engineer's contacts are often very specialized, and not understandable to the outsiders.

In summary, an engineer's job is a varied one. It is varied in different ways: in the place of work, in the contacts with people, in its activities, and in depth of job content. But an engineer's job does not provide the variety in breadth of job content. The restriction on the range of problems allows engineers to maintain their focus while working fragmentarily and briefly, but restricts the variety of topics in their contacts with the people they work with.

4.8 Analysis of Control on the Job

The field notes provide three possible measures of engineers' control over their own job: one, the amount of time engineers stay alone; two, the number of periods spent alone that are long enough to provide time for an engineer to concentrate on a problem; and three, the number of activities that are initiated by the engineers themselves.

The amount of time spent alone can be derived from Figure 4.4 & 4.5, which is the total of desk work, computer work, and tours. The total of these three is about 50 percent.

According to Rosemay Stewart (1988), "if these periods alone are to be useful for sustained work, they probably need to be at least half an hour in length". By analyzing the field notes, it was found that 36 percent of those alone time were spent in the activities lasting longer than 30 minutes, that is, 18 percent of total time. But on the average, there were only 7 such periods. Comparing to Rosemay Stewart's result of 9 periods, it seemed to be a little surprising. But it was in agreement with the statement in her study: "The managers, who had very few periods alone of half an hour or longer, included most of the working engineers and production controllers." As analyzed before, engineers' activities may be more fragmented and brief in nature, and thus it is possible that the alone periods may not need 30 minutes to be useful for sustained work for engineers.

The third measure of the control over the job is the number of activities that are initiated by the engineers themselves. For the activities in desk work, computer, travel, and tour, it can be reasoned that all of them were initiated by engineers. Figure 4.25 shows that 61 percent of phone calls were initiated by observed engineers themselves. As to the conversation, about 41 percent were initiated by engineers themselves, 12 percent were initiated mutually, and 47 percent by the opposite. Even in the conversation initiated by the opposite, the engineers had some control on the length.

Now let us put all the number together. In this study, engineers had 50 percent alone, and 18 percent could be used for the activities lasting longer than 30 minutes. Among the rest 50 percent, 7 percent (travel) were controlled by themselves. 61 percent of phone calls (10% of total time) were initiated by themselves, that is, 6.1 percent of total time. 41 percent of conversation (22% of total time) were initiated by themselves, that is, 9 percent of time. Therefore, in about 72 percent of total time, the engineers had control over their activities. If returning phone calls and continuous conversation were considered, the number would be even bigger. It could be said that engineers had control over their activities. It is reasonable because the engineers take full responsibility for their tasks, as discussed before. Without such control, how can they fulfil their large responsibilities?

Another measure of the control over the job may be the amount of time engineers spent with their superiors. As shown before in Figure 4.8, 4.12, & 4.15, only 4 percent of phone calls, 14 percent of conversations, 11% of meetings were with superiors. In total, only 5 percent of time were spent with superiors.

The engineer's control over the activities could also be reflected by the capability to handle unexpected things. One computer engineer was supposed to develop a program, but he changed his schedule to spend two days in removing an unexpected software virus.

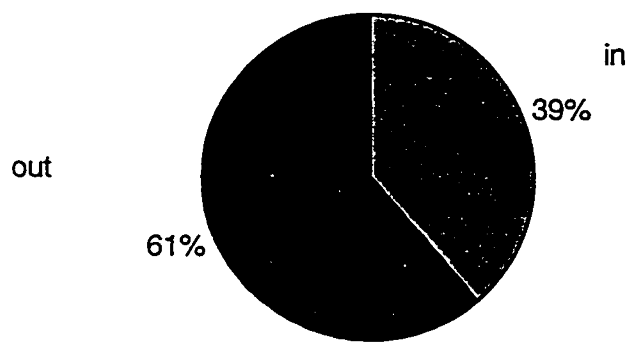


Figure 4.25 Phone Call Out & In

Another engineer spent one day to collect money for the United Way. One engineer was observed to search previous documents to find the location of a section of pipeline because the city authority can not find it according to the drawing. One engineer spent several hours to talk to an observer during one week to introduce his job. One engineer was observed to spent half a day to reclassify his files because he can not find one file. All of these cases suggested that engineers have enough flexibility on both schedule and work content to deal with unexpected things.

Chapter 5

DATA ANALYSIS II: THE ENGINEER'S WORKING ROLES

What do engineers do? This is a more complex question than "how do engineers spend their time?" In this chapter, the grounded theory of what engineers do is developed by analyzing the data from the field observations on ten engineers.

The first thing to be determined is how to organize the description on engineer's behavior. The usual way is to use a metaphor, that is, ideal-typical occupation. An ideal-typical occupation is an observation that captures key attributes of a cluster of occupations. As Weber (1968) noted, ideal types are useful not because they are descriptively accurate---actual instances rarely evince all of the attributes of an ideal type, but because they serve as models that assist in thinking about social phenomena. In much the same way that Weber used the ideal of a bureaucracy to develop his theory of industrial society, occupational sociologists have employed images of ideal-typical occupations as bases for developing theories of work. Ideal-typical occupations are also useful in everyday life, where they structure images of the division of labour. "The-worker-on-the-assembly-line" is one such ideal type. It evokes images of an individual, often in an automobile factory, standing beside a swiftly moving conveyer, repeatedly performing the same operation on each assembly that flows by. Boredom, fatigue, routine, lack of autonomy, and little need for thought or education are the hallmarks of such work. Although factory jobs have always been more varied than this, the ideal type nevertheless evokes a set of attributes that capture the family resemblance among many factory jobs. The clerk, the professional, the secretary, the farmer, and the manager are other prominent ideal-typical occupations.

Ideal-typical occupations are culturally and theoretically useful. By reducing the diversity of work to a few model images, ideal types assist us both in comprehending how the division of labour is structured, and in assigning status to individuals. They help parents shape their children's aspiration. They provide designers of technologies with images of users. They assist sociologists in developing formal models of attainment. It is not clear how we could think in general terms about worlds of work without these ideal types.

However, it is very difficult to find a single metaphor to describe engineers' behaviour. From the analysis of the last chapter, it can be seen that engineers' behaviour displayed many unique features. Engineers worked fragmentarily and briefly, but without any superficiality. They contacted many people from many different parties, but they still did significant amounts of paper work. They dressed in clean and nice suits, but they frequently needed to go to the site. They had full control over their own activities, but can not be independent from the organization. Their work contained some components similar to manager, professional, office worker, but none of these ideal types could describe an engineer's work properly.

Therefore, instead of using one single metaphor, a set of metaphors, that is a set of working roles, are used to describe an engineer's behavior. In other words, the theory of what engineers do is developed through developing the engineer's working roles from the original data collected from field research. A role is defined as an organizational set of behaviours belonging to an identifiable office or position (Sarbin and Allen, 1968).

Individual personality may affect how a role is performed, but not what is performed. Thus, managers, engineers, and others play roles that are predetermined, although individuals may interpret them in different ways. For example, from his observational study of the work of five chief executives, Mintzberg (1973) derived a set of roles that all managers must perform in their work. The most basic and most simple of all managerial roles is that of figurehead. Because of his formal authority, the manager is a symbol of his organization, and obliged to perform a number of duties. He must preside at certain events to add dignity and status. He may have to process the mail addressed to "The President," and he must make himself available, "to those whose feeling is that the only way to get something done is to get to the top." None of these incidents appears to be central to the job of managing. A different manager may have a different attitude and a different way in handling this role. Yet, in every case the manager, simply because of the title of manager, must be involved.

It should be made clear that the view of an engineer's roles presented here is one among many that are possible. The delineation of roles is essentially a categorizing process, a somewhat arbitrary partitioning of the engineer's activities into affinity groups. The result must ultimately be judged in terms of its usefulness.

The statement of roles was derived initially from the observational study of ten working engineers. Each activity observed during this study was analyzed in terms of one basic question: why did the engineer do this? The answers, gathered together in logical groupings, emerged as a statement of these roles.

The observations are supplemented by various studies and anecdotal materials, taken from the sociology of engineering, industrial engineering, bibliography, and cases. These materials are used to enrich the theory and to support the contention that these roles are performed by all engineers.

According to the purpose, engineers' activities may be divided into 6 groups: collecting information, providing helps to others, administrating their own time and task status, overseeing technicians and workers, studying precedent and other people's doing, and figuring out the solutions. Each of these six group activities is explained in detail below:

1. Collecting information

For each engineering task, the engineer must get enough information to start it, such as input parameters, output parameters, performance requirements, specifications, time and cost requirements. In the end, for example, dimensioned drawings must be supplied to the shop. Arriving at these concrete results requires a wealth of data of many kinds. To get these data, the engineer must perform many activities such as calling the client and subcontractor, exchanging information with peers, going to sites to investigate site conditions, and testing samples in the laboratory. In the procedure of collecting data, it is often necessary to clarify, explain and confirm data. Sometimes, the collected data need some kind of treatment and updating for being used later. All these activities are included in this category. Sometimes it looks easy and natural to perform these activities such as calling to ask the client for a parameter, but it can not be done by others. Within an organization, these activities must be and can only be performed by engineers. The engineer knows what to ask, that is, what information is necessary for solving the problem and finishing the task. Often, the engineer needs to exercise some judgement on whether the data is acceptable. The process also often involves some data processing skills. The process can not be delegated because it is interactive and accumulative. Each query further clarifies the problem, and leads to other queries. One question and answer lead to another question. Through directed inquiring, the problem is defined, revised, re-structured, and sometimes eliminated. As analyzed in the last chapter, such activities as seeking data often happened as an interruption in engineer's drawing, reviewing the project, writing reports, and calculating. It is not a process that can be separated from other activities, and thus can not be delegated to another person as an independent task. It must be part of an engineer's job.

2. Providing Help to Others

The engineers were observed to be frequently sought by their colleagues, supervisors, managers, and people from other departments such as marketing, purchasing, and construction, to provide their ideas, experience, and comments on technical issues, and the information in their domains. Within an organization, the engineers are the people who know their specialized areas and their tasks best. Engineers have the responsibility to make themselves available to provide information about the task such as project status necessary for other engineers and cost information for accounting. As analyzed in the last chapter, informal face-to-face discussion is the main way that engineers helped each other, and very important for them to get the job done. This category includes the discussions, in which the observed engineer was sought by others and discussed other people's tasks. The engineer's knowledge and skills can often provide the organization with the help in marketing products and promoting new jobs, by means of presentations. These types of activities are also included in this category.

3. Administering and Facilitating Own Job

This category includes the following activities: exchanging the project status, estimating costs, seeking general information, informing/scheduling/planning, sorting/packing/cleaning, formatting files, consulting the use of computer and solving computer problems, and participating in the organization's events. In order to get the job done within the budget before the deadline, the engineers need to track the time and control the cost. They also need to report the task status to the management frequently, and communicate with clients and subcontractors about project status. They need to inform related parties about problems and necessary changes, schedule and plan any event and necessary actions. Sorting, packing, and formatting files are considered the activities that the engineer performed to get the work organized. In order to do the job quickly, the engineer also needs to make sure that the tools (computer) work well.

As a member of an organization, engineers were observed to participate in some organizational events, such as staff meetings and social gatherings. These events often led to some chats between engineers. Considering that the purposes and effects of these events were to facilitate engineer's work, these activities are also included in this category. Staff meetings were for passing organization news, policies, and information to engineers. Social gatherings helped to create a better atmosphere and relationships among the people, and thus were able to facilitate an engineer's work. For the same reason, the community events such as United Way, and society events such as society conference were also included in this category. Better relationship with the community helps to promote new jobs and company image. Society events help engineers to acquire new knowledge and information.

4. Overseeing the Helper's Work

The engineers take the responsibility for the work, but it is the draftsman who does the detailed drawings, and it is the technicians who do the physical work and laboratory test. When the engineers delegate these tasks to helpers, they must make sure that their ideas are carried out correctly by the helpers. Their contact with helpers was basically for this purpose. The activity of writing specification for technicians is also included in this category. It is possible for some engineers, such as two system engineers in this study, not to perform this category of activities, because they did all associated activities by themselves without the help from others.

5. Studying Precedent and Other People's Ideas

In the study, it was observed that engineers spent significant amounts of time in searching and reading previous files, studying old drawings, referring to books and other materials, and asking and discussing with colleagues and the boss about their experiences. The purpose of these activities is considered to study how other people worked on the similar tasks or related tasks or what has been done on a specific project. Through studying other people's doing, one can understand one's own situation more completely. It often brings to some factors neglected in one's previous consideration. The agreement with others confirms one's own solution, and thus increases the confidence, and helps to remove pressure and worries. Often, other people's idea in similar tasks can be used as a framework of one's own task.

6. Figuring Out the Solution to the Task

This category includes the activities of sketching, drawing, checking drawings, calculating, discussing with colleagues and boss, reviewing and reports the project with the supervisor, attending the meeting for problem solving, and writing the reports and proposals. It was seldom observed that engineers just sit in the office, thinking about a solution. The process of making a decision and figuring out a solution is mixed into all above activities.

Correspondingly, six working roles are derived from these six groups of activities: collector, consultant/mentor, administrator, overseer, historian, and adapter/inventor. Before the detailed discussion of these six roles, three points should be made clear.

First, each role is observable. For example, one can witness an engineer searching the old files like a historian and directing technicians like an overseer. The description of each role is derived from a set of observable activities. It should, however, be noted that some activities may be accounted for by more than one role.

Second, all of the activities observed in the workplace are accounted for in the role set. There is a tendency to exclude certain work that engineers do as inherently non-engineering work, such as writing reports, updating information, tracking budgets, and taking part in community events. If an engineer engages in an activity, we must begin with the assumption that this is the part of the job, and seek to understand why this engineer does it in the broadest sense of the responsibilities.

Third, the roles are described individually but they can not be isolated. As shown in Figure 5.1, these six roles form an integrated whole. One can not arbitrarily remove one role and expect the rest to remain intact. An engineer who, for example, ceases to perform a collector role loses the information necessary for problem solving, and so, can not provide consultant/mentor's valuable information and ideas to the others, and will not perform the historian role.

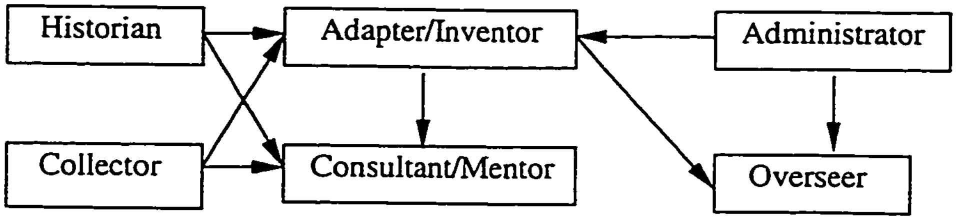


Figure 5.1 The Engineer's Roles

It is believed that only engineers play all these six working roles in the daily work. Others, such as scientists, technicians, and craftsmen, may play some of these six roles, but not all of them. The scientists usually do not play adapter role and overseer role. The technicians do not play inventor role, and seldom play consultant/mentor role. Because of the lack of scientific knowledge, craftsmen have no ability to play historian role. Therefore, these six working roles form an integrated whole capturing all features of engineering work.

5.1 Information Roles

Engineering work involves making decisions about how to deal with the material world. To make good decisions, one must have enough information. Consider the following activities performed by engineers: measurement in the field, phone call to confirm a parameter, providing the report and analysis to managers, and providing the specifications for an operation. The common feature to all these activities is that all of them deal with the information and data. From a broader view, all of engineers' activities are related to information flow, as showed in Figure 5.2. This diagram makes clear that it is the information flow that ties all engineering work together. In the data collector role, engineers seek the information about the task. In the consultant/mentor role, they provide their ideas, experience, and analysis to others. In administrator role, they manage the information related to the task. In overseer role, they instruct and explain their ideas to the helpers. In historian role, they get ideas and data from old files and reference materials. Their products, which include drawings, specifications, calculations, proposals, are used as a formal instruction that guide other people's work.

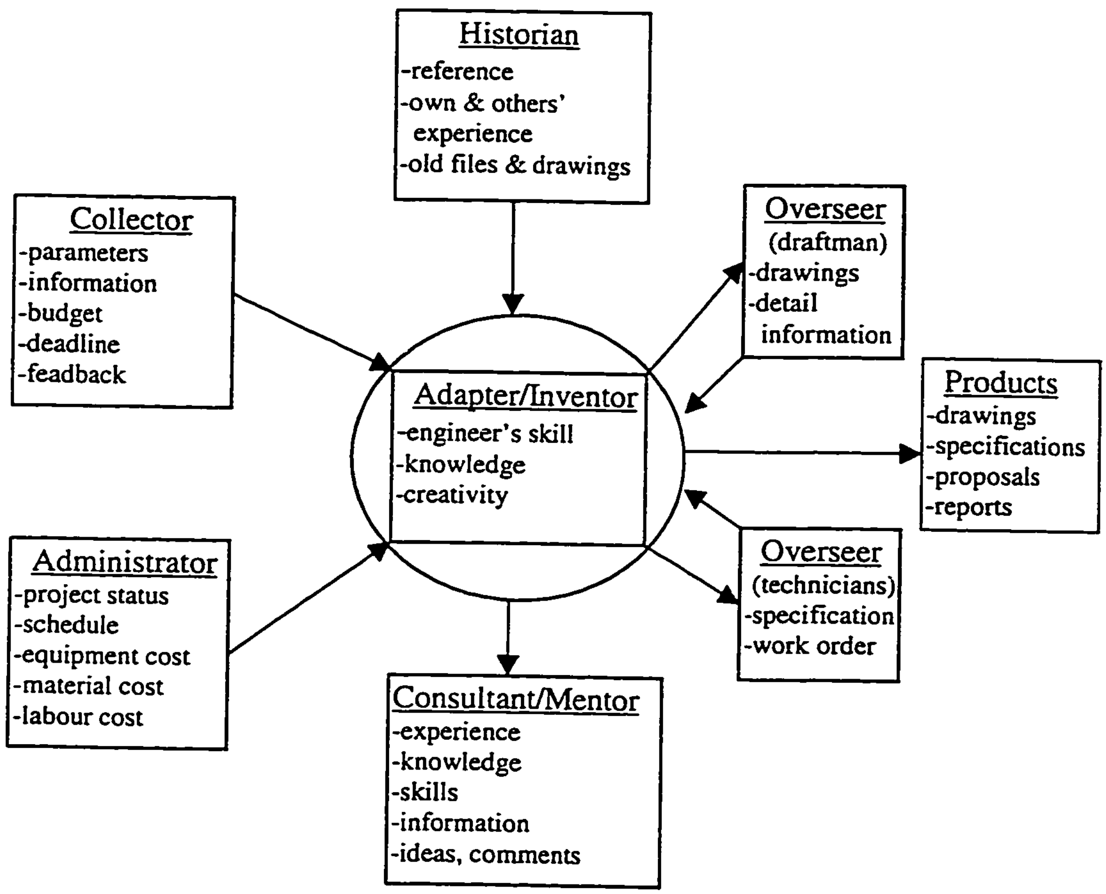


Figure 5.2 The Engineer in the Information Flow

5.1.1 Engineer As Collector

The engineer as collector gathers the information from a number of persons or places to understand what is the situation and requirement of the task. The engineer seeks information in order to define and to identify the problems, to initiate changes, to make decisions, and finally to solve the problems. The information received and collected by the engineer falls into 4 categories:

1. Original Data. Information on the input conditions and output requirement for the task. It may be collected from the field measurement and investigation, from the boss when the task is assigned, from the other department, from the peers working in related parts of a project, or from the outsiders such as subcontractors and clients.
2. Intermediate Data. As observed in the field, the engineer often stopped the work in process to seek information necessary for future work. The information such as a valve performance, the hardness of material, and the gas pressure in a specific point of pipeline was necessary for making decisions.
3. Feedback. This kind of information includes the advice about the proposal from the boss and colleagues, the necessary changes requested by clients and workers, and test results. These information help engineers to refine and change the solutions.
4. Cost and time. The engineer must finish the work under the constraints of time and cost. Before the task is started, the engineer needs to know what these constraints are. The information, such as component cost, labour time,

and labour cost, is also necessary, so that the engineer can control the cost and time.

Within an organization, all of the information about one specific engineering task usually goes to the engineer who is in charge of this task. As Figure 4.24 shows, the engineer is the centre for the contact network for the task. It is the engineer who puts all the necessary information together. For an organization, the engineer functions like a special channel to receive and collect information, and functions like a data processing unit, who generates the products from the information. Most data and information about engineering work are in the form of parameters and drawings, and they are not understandable by the other people who lack an engineering background. The secretary can offer little help for handling these kinds of information. The technicians can help a lot in collecting site data and performing laboratory tests, but can not complete these tasks independently. Engineers were often observed writing specification to guide and oversee their activities. Thus, this information collector role can only be done by the engineer. Only the engineer knows what kind of information is needed to finish the task. The engineer must be active to collect the related information. Another reason that the collector role can not be delegated to others because the process of collecting data is interactive and accumulative, and not separable from the other activities such as drawings, calculating, writing reports, and discussion with peers. Each query further defines and sometimes changes the problem, and leads to other queries. One question and answer lead to another question. Through directed inquiring, the problem is defined, revised, restructured and sometimes eliminated. During this process, significant amounts of confirming, clarifying, explaining, negotiating, and changing is involved. As analyzed in the last chapter, such activities as seeking data often happened as an interruption in the engineer's drawing, reviewing project, writing reports, and calculating. It is not a process that can be separated from other activities, and thus can not be delegated to another person as an independent task.

Furthermore, data collecting sometimes involves judgement and the use of theoretical knowledge and skills. Sometimes the necessary data for a task is very easy to get. Maybe when the engineer is assigned the task, the data is provided. Sometimes, the engineers have to spend significant amounts of effort to collect the necessary data for a task. For example, the engineers in a geological engineering company were observed to have to go to the field to investigate and take photos. Then, they located the position on the map for digging the holes to take soil samples. They also had to work out the specifications of work procedure for technicians about how and where to get soil samples. After getting the samples, they specified the test procedure and method for technicians. They could not get the required data until the test was finished. When they found the test results were not acceptable or not enough after data analysis, they had to get more samples. This data would be used for next task: foundation and earthwork design.

From 1916 to 1926, William F. Durand and Evesett P. Lesley, Professors of Mechanical Engineering at Stanford University made a study of aircraft propellers. This primarily empirical study supplied much of the data used by airplane designers in the 1920s to select the best propeller for their new designs. The choice of propeller was routine in the design of all airplanes until the appearance of jet engines in the 1940s. By 1916, knowledge required for propeller design was reasonably well in hand, but systematic propeller data for the airplane designer were almost non-existent. The work of

Durand and Lesley actually was data gathering in nature. But this process involved many skills and knowledge such as experimental and theoretical parameter variations, scale modelling, and laws of similitude. Their work was described by a distinguished contemporary as "the most perfect and complete... ever published."

In data collecting, technicians were observed to give engineers great help in site work and laboratory test, but they could not complete these tasks independently. It was observed that engineers often wrote specifications and work orders for technicians to guide the work, and often had to talk to them to instruct the procedure. As mentioned before, only the engineers know what kind of data they want to get from the site and test. Stephen R. Barley's study (1996) on technicians indicated that the core of a technician's work lies in creating the linkage between the material world and the symbol. This study shows that technician's creating these linkages is not independent and often needs to be guided and overseen by engineers.

In conclusion, this collector role can only be played by the engineers themselves. Because the process is interactive, accumulative, and inseparable from the other activities, and often involves the use of engineering knowledge and skills, it can not be delegated to others. Engineers, because of their understanding of the problem, their involvement in problem solving, their position in the contact network for the task, their skills and knowledge, are the only persons to perform this role within an organization.

5.1.2 Engineer As Consultant/Mentor

The Oxford English Dictionary defines the consultant as the person whom people go to for information, advice, and opinion. The mentor is the adviser and helper of an inexperienced person. In the study, it was observed that engineers were often asked by their managers, supervisors, peers, people from other departments about their ideas, experience, comments on technical issues and the information in their domains. In an organization, the engineers are the persons who know their specialized area and their task best. For example, during the observation on a utility engineer, his manager came into his office several times to ask advice for dealing with customer complaints. To solve the problem, it was necessary to lay an additional short piece of pipeline, which they called "sleeves." After asking many questions on how to lay the "sleeves," how difficult it is to dig a hole, and what is the cost, the manager asked him to take part in the next negotiation meeting with customers, and explain the technical issues. On another day, the people from the marketing department called him first to ask if they can increase the load of gas distribution, and what is the cost for the increase, and then came to his office for discussion. Referring to some files and doing some calculation, he answered the question. In another case, a person from the Land Department asked this engineer's opinions on purchasing a site, regarding the environment and site conditions. They discussed the difficulty of building a gate station and laying the pipeline in there. In these three cases, the engineer provided his advice, opinions, and comments from the technical point of view, based on his experience, knowledge, and skills. It was noted in the last chapter that providing data and information to peers, bosses, and managers were the activities that frequently happened.

As analyzed in the last chapter, talking to each other was a very important part of the engineers' daily work. They helped each other by providing their own ideas, experience and information to each other. Just like one system engineer's comments on telecommuting during this study, he could not work without people to bounce ideas around. In the study, it was observed that engineers were accustomed to being sought by their peers, and probably did not even think much of personal privacy. In one company, an object oriented program was installed to divide the project and have more resources (i.e., system engineers) working on it. With this program, it is possible to reduce the need for close co-ordination, which is required with the traditional way. But the engineer in this company said that you still needed to "turn ears in the office" because much system integration occurred through overheard conversation. "hey, how do you do?" often leads to major insights. In another case, the observer was told that at the start of a job, the project manager and consultant were away in a distant office, and it did not work well until they moved into physical proximity. The engineer continued to comment that the distance was very critical. The arrangement such as adjacent cubes and same aisle was all right. Two aisle over did not work well. It changed the type of communication, and cut out the all important casual comments.

In this analysis of engineer's working roles, the conversation was classified as consultant's activities when the observed engineer was sought by other peers to discuss their problem. When the observed engineer sought peers to discuss own problems, then it was classified into the activity of figuring out the solution, which belongs to the role of adapter/inventor.

It was noted that the discussions among engineers often needed to refer to some kinds of written form information. Even in the informal discussion, it is often necessary to refer to the drawings, files, etc. The engineers in a geological engineering company always carried folders when they were going to discuss with somebody. The system engineers' discussions always happened around the computer screen. An engineering problem often involves many factors. The ideas and analysis about how to relate all these factors together are usually too complicated to be only verbally communicated. The drawing is the engineer's language. It may be the reason that engineers prefer face-to-face discussion to the discussion through the phone and e-mail. For example:

Engineer I in a geological engineering company wanted to talk to the subcontractor about his proposal. He faxed a drawing to the engineer in this subcontractor company, and then discussed with him through the phone, with the drawing in front of him. During the discussion, he frequently referred to the drawing. After 14 minutes' discussion, they decided to meet next morning to talk in detail.

For senior engineers who have subordinate engineers, their technical conversations and meetings with subordinates are also classified into this consultant/mentor role. It was observed that in conversations and meetings---whether between an engineer and his supervisor, between two engineers of roughly equal position, or among a larger number of engineers of unequal position---the style, atmosphere, and attitude of decision making were predominantly consultative and consensual. Information was gathered, with each participant providing data or experience to which he had special access. Typically, the decision as to what course of action this information suggested (if there is any decision to be made) fell to the engineer whose responsibility it will be. Even when there was disagreement at meetings, it was usually resolved by discussion and eventual consensus. While the engineer did have one supervisor to whom he/she reported. In technical issue, a supervisor of an engineer was only an older, more experienced engineer who acted as a senior colleague. "Reports" meant many things and different things at different times. In some cases, it meant that the supervisor determined pay and promotions. In some cases, it meant that the supervisor had authority for expenditures beyond a specified dollar value. It rarely meant that the supervisor handled and oversaw the daily assignment of task to his subordinates.

In summary, by playing this consultant/mentor role, the engineers make their experience, knowledge, skill and information available for their boss, peers, and organizations for additional use, usually in an informal way. By this way, the organization gets additional contributions from engineers, which are usually not recognized, and difficult to measure. But, this role is important in an engineer's daily work, in both quality and quantity.

5.2 Organization Roles

The second set of engineer's activities relates to engineers' managing their work: to finish the work at acceptable cost before the deadline, the administrator role; and to make sure that technicians and workers carry out the engineering task correctly, the overseer role.

Many studies (Robert Zussman 1985, Peter Whalley1986, Stephen Crawford 1989) find that engineers enjoy a high degree of autonomy, although they frequently need to report the task status to and get approval from the boss. Just as one engineer in Whalley's study said: "It is not my boss who tells me: allot so much time to this task, so much time to this, do that. Myself, I reckon I have a task to accomplish, and for this task I organize my time according to the results I want to obtain. Of course, I must attend the meetings which are organized because it is important that we all meet regularly. But aside from those, I organize my schedule as I please."

While the engineer enjoys the autonomy, in the meantime, the autonomy also means many responsibilities. It is an engineer's responsibility to get the job done, and done well. To reach this goal, engineers have to play these organization roles.

5.2.1 Engineer As Administrator

The engineer's activities as an administrator include exchanging project status with others, gathering general information, solving computer problems and consulting the use of software, sorting/packing/cleaning, formatting files, communicating with authorities, informing/scheduling/planning, estimating and controlling costs, and participating in organizational events. The common feature for all these activities is that the purpose of all is to facilitate and accelerate the other activities, and make sure the job can be done within the budget before the deadline. The general information, such as a phone number, email address, whom to contact, and where to find a book, is often necessary and helpful to collect data, to schedule meetings, to negotiate, to find the equipment and materials, and to consult. Sorting and packing the materials, cleaning the desk, formatting files were activities frequently observed in the study. They often happened at the end of an event. The purpose that engineers perform these activities were considered to get the work organized and facilitate other activities such as referring, reviewing, checking, and discussing. The proper use of tools such as the computer, obviously can increase the work efficiency.

As analyzed in chapter 5, the engineering task often relates to many parties. The engineers often need to contact other parties in order to deliver the product within the cost limit before deadline. They has to exchange project status with related parties, inform any changes, progress and delays, planning and scheduling the various activities in the project, and getting approval from authorities.

It was observed that the activities of estimating the cost and tracking the time cost significant amounts of engineer's time. They often not only estimate the amount of time they put into the task, but also pay attention to the cost of materials and equipment, the cost of construction, and the cost of subcontractors' work.

In order to facilitate cost estimating and time tracking, all participant companies have some kind of forms and systems. However, the meaning of cost and time control is far beyond just filling those forms. The nature of time and cost control is that the engineers must do their job under the constraints of time and cost. This means that for a practising engineer the search for perfection becomes self defeating. In the *Soul of a New Machine*, Tracy Kidder recounts how the engineers designing a computer must forego the luxury of constant refinement of their work. Instead of trying to make the perfect computer, they strive to make a good machine that they can get "out the door." They live for the moment when they can merely say, "Okay, it is right. Ship it."

The influence of cost constraints in the engineer's work is universal. It would be a lot easier for engineers if their fellow citizens would clearly stipulate that performance should be the paramount concern, whatever the cost. But the people do not say this. They want automobiles that are affordable and attractive. They want airplanes that are light enough to conserve fuel, and power plants that will turn out cheap electricity. They appear willing to pay for relatively fool-proof backup system for space vehicles, but little else.

Working under the conflict between the performance and the constraint of time and cost makes the administrator role necessary in engineer's work. Since the cost and time control involve deeply in the technical aspect of engineer's work, playing the administrator role also involves the use of engineer's knowledge, skills, and experience. Therefore, others without proper background, such as accountant and manager, are not able to do the work for engineers. In this study, it was observed that one engineer was able to know quickly that the cost estimation by a summer student for a task was not reasonable. In his teaching her how to estimate the cost, it related to labour, materials, equipment, how long can the pipeline be laid per day, the cost of digging a hole, and how to select a valve. After the summer student left, he explained to the observer that such knowledge could only be learned and accumulated through work because it involves so much practical experience, and so many factors.

For an organization, the control of cost and time usually begin with the engineer's effort because usually only the engineer can involve the cost and time control into every piece of work in the project.

For a senior engineer, who has subordinate engineers, in addition to the control of time and cost for own work, the administrator role includes some personnel management activities. First, interdepartmental relations are sometimes difficult to manage. The supervisor manages these relations for the subordinate engineers, linking the engineers to and protecting them from the rest of the organization. One of engineers in Zussman's 1985 study said about his supervisor, "He is a buffer. I actually have very little contact with Tom, but he is the one goes to all the meetings and find out what new projects the company's starting and what the parameters are." Second, the projects within the department also have to be allocated and scheduled on a rational basis. The supervisor has an overview of individuals' capacities and responsibilities, and co-ordinates activities within the group.

The reason that the activities of participating in organization events are included into this administrator role is that the purpose of these activities can be considered to facilitate and accelerate other activities. Staff meetings help to improve organization administration, and coordination among different departments and project groups. Engineers working in a better administered organization will be better informed, and have better communication with the organization and colleagues. Engineering society conference provides engineers with the chances to meet and discuss with those having same background and doing same jobs. It helps to improve their skills, update their knowledge, and build a network to get news and information in their field. Social gathering such as a golf tournament, beer reception, anniversary dinner, and barbecue helps to release the pressure and build better personnel relationship, and thus build a better working atmosphere. Community participation, such as United Way, helps to improve company image and promote marketing. Participating in these activities facilitates and accelerates the activities such as collecting information, discussing with others, consulting, and figuring out solutions, and thus helps engineers to get their job done within the cost limit before the deadline.

5.2.2 Engineer As Overseer

Engineering itself is essentially a mental activity. Engineers manipulate symbols that refer to physical objects, mostly equipment and products, but they do not manipulate those objects themselves. A few engineers may occasionally set up a laboratory experiment, but few physically repairs or operate machinery or build models of products and components. Physical manipulation is now the work of machinists, repairmen, mechanics, operators, and technicians.

Thus, engineers' ideas in the form of drawings, specifications, and proposals can only come true through these physical workers. Although those drawings and specifications are the formal instruction that guide their works, frequently the engineer has to play the overseer role to make sure that his ideas are understood and carried out correctly. As Zussman's study (1985) indicated:

> "Only a minority of Precision Metals engineers (30 percent) and a slight majority of the Contronics engineers (53 percent) currently have official line responsibilities—whether for production workers, technicians, or other engineers. However, these figure understate the extent of supervisory responsibilities the engineers at both companies exercise. Many, even without official line responsibility, have occasional defacto responsibility for production workers or technicians in the course of working on particular projects. Although these engineers do not hire and fire, oversee promotions and pay raises, or even receive reports, they are nonetheless responsible for the deployment, coordination, and motivation of manpower."

In this study, engineers were observed to have very close relationship with technicians and draftsmen. They were more like peers rather than the subordinates. They provided a great help to engineers. However, in technical aspects, the engineers were frequently observed in instructing their helpers. They wrote specifications for technicians' site work and laboratory, explained the work procedure to them, and were called to sites to guide their work. They worked with closely with draftsman, checked the drawings, sought the detail information for the draftsman. When these helpers met problems, they went to engineers without hesitation. When technicians reported the result, engineers had to analyze these data, and might make some necessary adjustment and change. It seemed to the researcher that the main difference between engineers and technicians, was that the engineers were able to analyze the whole situation, find out all the factors involved, and understand the relationship of all these factors. Thus, they are able to explain why, and know how to change and adjust. In contrast, the technician seemed to have rich experience and enough knowledge to know how to use instruments and equipment and how to perform the work procedure to get the data, but lacked the knowledge to understand why. Thus, the technicians often can not work independently. In working with technicians, the engineers often have to play the overseer role to make sure their ideas are applied correctly.

5.3 Problem-Solving Roles

The third set of engineers' activities involves solving problems---studying files, recalling their own experience, discussing with experienced engineers, reviewing the project with clients and bosses, referring to books and other material, calculating, sketching, drawing, and writing.

This part of the engineer's work is the most recognized, and usually considered the most valuable part. In most of the literature, the ambiguous word "design" is used to describe engineer's problem-solving process.

Traditionally models of engineer design are similar to the model in Figure 2.1. As abstractions from experience, these images express on ideal upon which to pattern the design effort, express how many believe the progress ought to work. But as models of practical engineering activity they are deficient. As one can see, "design" includes everything. The word "design" has become like the word "manage," too broad and inclusive to provide the specificity needed to describe an operational activity. It does not tell the true activities that are performed by engineers in their daily work to solve the problems.

The purpose of this study is to describe the activities performed by engineers in their working day. This purpose is reached by describing the roles which all derived from observable activities. Therefore, "design" or any other words, which can not describe the actual observable activities are abandoned.

5.3.1 Engineer As Historian

A historian is the one who collects, studies, and interprets the historical data. Many of the engineer's activities in the process of problem solving are very similar to those of historian's. It was observed that engineers frequently searched for the historical data from previous files and drawings. They often need to refer to books and other material to see what other people have done, and what is the standard way to do it. They recall from memory and seek the experience and data from supervisors and colleagues, who have had experience with similar problems. By playing the historian role, the engineer learned more about the problem---more aspects and more detail. Studying historical cases often suggests different options and opinions, and thus often stimulates an engineer's own imagination and creativity. "Too often engineers move rapidly from the statement of a problem to a specific solution only to find later that another available solution would have been better. Some engineers never overcome this habit." (John R. M. Alger & Carl V. Hays 1964).

Maybe, a more important reason to play this role is that engineers want to find a practically proved solution. Engineers take full responsibility for their job, and every mistake or misjudgement must be rooted out before plans are turned over to the shops for fabrication. As Samuel C. Florman wrote in his book, The Civilized Engineer (1987),

> "In other words, people are willing to take risks, but naturally, do not want to pay the penalty for taking these risks. In such a world, it requires a certain amount of moral toughness, something that verges on bravery, to say, all right, I will take the responsibility, and if the worst should happen, I will accept the blame. ...... It has been said that doctors bury their mistakes and architects plant ivy. Most experts have a way of avoiding blame by claiming that their ideas were not given a fair trial. Economists are famous for this ploy. Politicians, as is well known, never make a mistake. Engineers have no such easy evasions. Well, so be it. Somebody has to step forward to do what needs doing. We can not all sit around being critics, supervisors, and second-guessers. Thus, a principal feature of the engineering view becomes the willingness to accept responsibility."

Such a big responsibility makes engineers work very cautiously. They study the situation carefully, try to consider all factors involved, analyze the relationship of these factors, discuss the method with peers and bosses. However, "even the most cautious engineers recognize that risk is inherent in what he does. Over the long haul the improper becomes the inevitable, and accidents will happen. The unanticipated will occur." (Samuel C. Florman, 1987). Alen Colquhoun (1969), a British architect, argues convincingly that no matter how rigorously the laws of science are applied to the solution of a design problem, the risk still exists. "(Scientific) laws are not found in nature," he declares. "They are constructs of the human mind; they are models which are valid as long as events do not prove them wrong." Most engineering, Colquhoun reminds us, must meet requirements that are logically inconsistent. For example, he writes:

> "All the problems of aircraft configuration could not be solved unless there was give-and-take in the application of physical laws. The position of the

power unit is a variable, as is the configuration of the wings and tailplane. The position of one may affect the shape of the other. The application of general laws is a necessary ingredient of form. But it is not a sufficient one for determining the actual configuration."

An engineering solution combines formal knowledge and experience, and always contains judgement. Despite the enormous amounts of effort and treasure that have been poured into creating analytical tools to add rigor and precision to complex systems, and despite all the care exercised by individuals and all the systems that have been used to ensure that all the choices made in selecting parts and arranging them to work together will be correct, the evidence of faulty judgement shows up again and again in some of the most expensive and most carefully designed and tested engineering projects of the twentieth century. In the last chapter of his book (1992), Eugue S. Ferguson analyzed a number of design failures, such as the Hubble space telescope, a rotary-compressor refrigerator produced by General Electric, and the U. S. Navy's Aegis air-defense system. He said, "Engineers need to be continually reminded that nearly all engineering failures result from faulty judgements rather than faulty calculation."

Obviously, the best way to prevent failure and misjudgement is to refer the solution for similar tasks that have been proved in practical use. This drives engineers to play the historian role in the process of figuring out the solution.

5.3.2 Engineer as Adjuster and Inventor

The engineer usually tackles only new problems. Problems that have been solved before are usually turned over to the technicians and physical workers. The new task results from the new input conditions, output requirements, and budget limits. These new problems require that the engineer gets an idea---a new idea or an old idea applied in a new way to his problem. He needs to formulate a way, a method, or a concept of how to get the task done. Sometimes this requires a great deal of imagination, ingenuity, and inventiveness. But most of the time, for most engineers, it is quite a routine application or revision of an existing idea.

Engineer's work usually is described as full of excitement, demanding creativity and inventiveness. If one takes a close observation on an engineer's work, he can find this is just one side of the engineering work. On the other side, where the majority of engineering effort takes place, the work is quite routine. The engineer's working role as an adjuster reflects this side of engineering work.

In most engineering work, such as distributing gas to a new subdivision or a foundation design in a new location, problems are usually well defined, and the activity tends to be highly structured. What engineers do is only adjustment. They process the data and information in a routine procedure, and make some adjustment during the processing, so that the end products (drawings, specifications, etc.) meet the new task's conditions. In these situations, playing a historical role to study the situation carefully against previous cases is very important in making sure that proper adjustment is made.

For many engineering tasks, it is the consequences of decisions made early in a task that are most likely to be called "creative." In the beginning of a task, the engineer faces an enormous number of possible courses of action. It is often impossible for him to evaluate explicitly each alternative. "The truly creative individual has the uncanny ability to suggest a line of endeavor or potential problem solution which is not only unusual and novel, but turns out on further investigation to be especially effective in solving the problem." (John R. M. Alger & Carl V. Hays, 1964).

The observable activities in the adapter/inventor role includes drawing, calculating, checking and reviewing drawings, discussing with peers, reviewing project with bosses, writing reports and proposals, and using special software. It was noted in the observations that the process of decision making and figuring out solutions was not separable from these activities. It was seldom observed that engineers were just sitting in the office and figuring out the solution. Calculation is often performed during writing and drawing. Discussion often interrupts drawing, and writing often needs to refer to the drawings. Thus, figuring out a solution is a contingent process, and judgement and decision are made in the process of performing these observable activities.

Chapter 6

DATA ANALYSIS III: WHAT ENGINEERS KNOW AND HOW THEY KNOW IT

What engineers do depends on what they know. Analyzing an engineer's knowledge components helps to provide another dimension of picture about what engineers do in their daily job. The development of this chapter is basically derived and reasoned from Chapter 5, analysis of engineer's working roles. Much anecdotal data is used to support the analysis. Some are from the observation in this study, some from the literature. From the analysis it was found that an engineer's knowledge could be categorized into the following five components: theoretical tools, solution stock, symbol-material linkages, operational consideration, and access to distributed knowledge.

Given the breadth and complexity of engineering knowledge, the analysis that follows does not attempt to be exhaustive. It is developed by analyzing what kind of knowledge is necessary to play those working roles, and what kind of knowledge might be generated if engineers keep performing these activities everyday. Some items of knowledge are clearly distinguishable, others are not. In the categorization mentioned above, the components are not entirely exclusive. Some items of knowledge can embody the characteristics of more than one category. They are also probably not exhaustive.

6.1 Theoretical Tools

As analyzed in the last two chapters, during the process of figuring out the solutions, engineers spent a large part of time in studying other people's work, and trying to understand the situation as well as possible. It is reasoned that engineers must possess some kinds of theoretical tools to allow them to perform these analyses and calculations.

Engineers play adapter/inventor role to solve engineering problems. To adjust a system, or to invent a new way, the engineer must be able to know not only how, but also why. Without complete understanding of the situation and considering all factors involved and their relationship, initiating a change is dangerous. Theoretical tools provide engineers with the ability to read the literature in their field, to think about why physical phenomena does not always respond as protocols predict, and to predict the consequence of the change. For example, when a utility engineer planned to extend a pipeline to a new subdivision, he needed to know if the pressure at a gate station was enough to overcome flow resistance caused by this new section of pipeline. Then, the flow resistance depends on many factors such as gas load, diameter of the pipeline, the pipeline material, and the number and kinds of valves. The engineer must know the relationship of all these factors. Furthermore, the other issues, such as stress, should also be able to be predicted, which depends on the length, diameter, and materials of the pipeline, and kinds and number of valves. To complete such an engineering problem, engineers needed to be able to analyze all these factors and relationships and use formulas to make calculations.

It was observed that the knowledge of theoretical tools was not only used in the process of figuring out the solution, but also in the activities of playing other roles. In collecting data, in playing the roles of consultant/mentor, overseer, and even administrator. For example, for controlling and estimating costs, the utility engineer was observed to list the valves and their price. In one case, the engineer found the cost was too high for a certain length of pipeline. So, he decided to change to another kind of valve, and reduce the number of valves. During this process, he must be able to evaluate the consequence of change, such as pressure, resistance, and stress. It was observed that the theoretical knowledge was the base for developing any other kind of knowledge and experience, and might possibly be used in any situation at any time.

Most of the theoretical knowledge comes from the University, frequently referred to as the engineering sciences. Some may be learned from peers, or by the engineers themselves, or by reading literature. There is a tendency in literature to devalue the knowledge from the university. In the studies of Zussman (1985), Crawford (1989), Peter Whalley (1986), and Stephen R. Barley (1996), the engineers and technicians in these study all claimed that the theoretic knowledge had no or little value for their work. To support this point, researchers asked these engineers' opinions, and supported with the number of engineers who did not have engineering degree. As mentioned at the beginning of this chapter, some items of knowledge are often not distinguishable. Theoretical knowledge is the base for developing other knowledge, and then it is mixed with the experience. When the engineers are asked the question of "what kind of knowledge do you use in you daily work?" engineers may recall recent additions or only the most important judgements and experience. Just as Professor Whiting, commented on engineers' claiming little use of theoretical knowledge, "this is often because they can not figure out the importance of the stairs after they are sitting on the top floor." Another problem exists in the evidence used in those studies is that the number of engineers without an engineering degree can not prove theoretic knowledge is useless. Although the usual way to get theoretical knowledge is from a university, it may be obtained also from other ways. No university degree does not necessary indicate no theoretical knowledge. It is hard to image that a mechanical engineer without knowledge of thermodynamics and fluid mechanics designs engines, and a computer engineer does his work without an understanding of how computers and software function. In today's society, it is very difficult for the people without an engineering degree to become an engineer.

6.2 Stock Solutions

It was observed that the engineers could often present several solution options quickly. For example, an utility engineer went to another engineer's room to ask if he had experience in the use of plastic pipe, and what kind of valve should be used in the plastic pipeline. That engineer could quickly provide several configurations about what kind of valve should be used together with what kind of pipe and explain the advantages and disadvantages of each option. It is reasoned and analyzed that those solutions must be stored in his mind. When engineers figure out solutions, they probably begin with searching their solution stock, find a suitable qualitative stock solution as a framework, then do some adjustment, detail and quantify the solution, and at last get the solution for specific task. If so, the most basic framework should be the configuration principle.

According to Walter G. Vincenti (1990), the configuration principle is the general shape and arrangement that are commonly agreed to best achieve the purpose. It may exist only implicitly in the back of an engineer's mind, but it must be there. It is given for the project even if unstated. It is observed by engineers in the course of growing up, perhaps even before entering formal engineering training. For example, automobile engineers of today usually assume without much thinking about it that their vehicle should have four wheels and a front-mounted, liquid-cooled engine. Other features may be left open to be decided in the course of adjusting and inventing. At sometimes, these configuration principles had to be learned deliberately by the engineers, and they form an essential part of engineering knowledge. For example, the configuration principle of turbines has to be learned deliberately. In Polanyi's words (1962), the configuration principle is "how its characteristic parts fulfil their special function in combining to an overall operation which achieves the purpose" of a device.

It is proposed that the solution stock is a collection of various usual configurations that have proved to be effective in solving problems. It is accumulated in the process of playing historian and adapter/inventor roles. It is the solution base. Such qualitative solution stock plays a strongly determining role. It is the base that engineers adjust and invent to solve problems. Once the stock is large enough, engineers only need to adjust these configurations, re-combine configurations, or assemble several configurations. The configuration principle and solution stock provide a framework within which engineering work takes place. The bigger the solution stock, the more effective the engineer.

Since the collection of configurations depends largely on personal experience, the engineer's solution often exhibits a personal style. The historian Reese Jenkins (1984), who perceived a thread connecting Edison's various inventions, described that thread as composed of "elements of style." Edison used again and again an array of mechanical combinations that he adapted to such diverse machines as the phonograph, the printing telegraph, the electro-mechanical telautograph (which reproduced at a distance a written input), and the kinetoscope (predecessor of motion pictures).

One combination of elements of style that appeared in several of Edison's designs was a rotating drum or cylinder, generally mounted horizontally, whose surface was sensitive to a stylus. Although a flat-turnable machine appears among Edison's sketches of ideas for his phonograph, he preferred a rotating cylinder and built his system around it. He used a narrow treated ribbon or paper tape for the recording surface in his printing telegraph and stock ticker, and he considered using the same principle in one version of his phonograph. Jenkins concludes that a creative technologist possesses a mental set of stock solutions from which he draws in addressing problems."

A "stylistic analysis," advocated by Jenkins, can often identify the "elements of style" and "stock solutions" that give a distinctive "family" resemblance to diverse technological artifacts. The machines, structures, and devices of the Victorian period, for example, can often be identified and dated by one who has developed intimate familiarity with a wide range of Victorian examples. The diversity that is found in a particular style again points up the wide range of acceptable solutions that a given design problem can elicit.

The effectiveness of team work and "brainstorming" may be partially explained by engineers' knowledge of stock solutions. When a team of engineers are put together, the stock solutions are increased many times. Thus, it is possible to find a better solution. It is easily reasoned that increasing the diversity of engineers in the team will increase the effectiveness of team work.

6.3 Symbol-Material Linkages

The purpose of all engineering tasks is to produce artifacts, but an engineer's task is to produce the ideas about how to produce artifacts. Engineers play working roles of collector, consultant/mentor, administrator, overseer, historian, and adapter/inventor in their daily work. All of these activities are essentially mental activities. Engineers manipulate symbols in their daily work that refer to physical objects, mostly equipment and products, but they do not manipulate those objects themselves. "When those important symbols represent material phenomena, symbolic work will lack accuracy unless the symbolic and the materials are linked." (Stephen R. Barley, 1996) Thus, the symbol-material linkages are reasoned to be necessary component of an engineer's knowledge.

As discussed in chapter 5, one important purpose of engineer's playing collector role is to collect the data such as input limits and performance requirements to define the task. These task definitions may be in the form of general and qualitative description. The engineers need to be able to translate these general qualitative goals and requirements for the device into specific and quantitative goals couched in concrete technical terms. The necessity for a bridge to carry traffic over a river has to be translated into specific span and loading requirements. The electricity demand from a power station has to be translated into steam volume, and steam temperature and pressure for engineers working in the boiler and turbine. Without such translation, the engineer can not start to contrive the detail and dimensions that must ultimately be supplied to the builder. The symbol-materials linkages provide engineers with the ability to do these translations from the material world to the symbols. In this study, it was observed in two different companies that engineers investigated the site conditions and took photos and videotapes. Later, referring to these photos and videotapes, they were able to work out specifications for site work to guide technicians to take the sample, and finally they got the data by testing these samples in the laboratory.

It is widely noted that today's society is putting more and more safety, economy, and environmental requirements on engineering projects. These requirements are often made as administratively or legally binding regulations. For the engineering community, these are part of specifications, and they must be translated into various criteria in technical terms. An example is the boiler code the American Society of Mechanical Engineers promulgates for all engineers working with such devices. Such universal specifications become part of the stored body of knowledge about how things are done in engineering.

Symbol-material linkages are not only necessary in translating general and qualitative requirements into technical specifications, but also necessary in figuring out the solution for engineers. As emphasized in an important book by Eugene Ferguson, engineers are able to assemble and manipulate in the mind devices that as yet do not exist, through "the mind's eye." He stated, "Visual thinking is necessary in engineering. A major portion of engineering information is recorded and transmitted in a visual language that is in effect the lingua franca of engineers in the modern world. It is the language that permits the "reader" of technologically explicit and detailed drawings to visualize the forms, the proportions, and the interrelationships of the elements that make up the object depicted. It is the language in which designers explain to makers exactly what they them to construct."

The ability of visual thinking is from the knowledge of symbol-material linkages. It is reasoned that after long time of interaction between the symbol and material world, the engineers would be able to connect the symbol such as a drawing to the real productions, and think of the products when manipulating the symbols, and translate the information of the material world into the symbols. For this reason, experienced engineers, unlike engineering students, do not just perform a set of formulas to get answers, but also are able to "see" the device corresponding to the answer. Thus, they are often able to quickly realize if his solution is reasonable and feasible before a final product comes into being.

6.4 Operational Considerations

It was observed that engineers often needed to consider the operational procedure when they played the roles of administrator, overseer, and adapter/inventor. When the utility engineer estimated the cost of laying a section pipeline, he was able to know how much soil needed to be excavated, how many labourers were needed, and how much pipe they could lay per day. When a geological engineer wrote specifications for technicians, he must be able to know the procedure for taking samples. The civil engineer would not be able to work on the work order without operational knowledge. When the engineer played the role of adapter/inventor, he also often needs to consider the convenience of manufacturing or construction, assembling, and accessibility for maintenance.

Such operational considerations that frequently do not lend themselves to theorizing, tabulation, or programming into a computer. They are mostly learned on the job rather than in school or from books. They tend to be carried around, sometimes more or less unconsciously, in an engineer's minds. Frequently they are hard to find in writing.

In nature, the consideration for economy, manufacturing, and construction put another dimension of limits into the engineer's solution, but in an informal format. Once these consideration are translated into technical term, they are more logically put into another category of knowledge, symbol-material linkages, instead of in this category.

6.5 Access to Distributed Knowledge

When the stored knowledge is not enough to solve the problem, engineers were observed to be able to know where and how to get necessary new knowledge. It was observed that there are mainly three ways to get necessary knowledge.

The first is from reference materials. It was observed that every engineer stored many reference books in the office. Usually, more experienced engineers had more reference materials on the bookshelf. Both activity study in chapter 4 and the analysis of working roles in chapter 5 showed that engineers frequently needed to refer to these materials, thus, behaving like a historian. Often when a senior engineer played mentor role to help his subordinate engineer, he ended with giving a book or some materials to the subordinate. Such events were observed many times during this study. The phenomenon suggested knowing more about where and how to get knowledge was often an indicator of more knowledge.

The second way is from peer engineers and supervisor, from the engineers in subcontractor and client companies. Both analysis I and II showed that talking to peers and supervisor was an important part of engineer's daily work. From the conversations, the engineers learned many things that they were previously unknown, unfamiliar, not clear, and not sure. For those inexperienced engineers, learning from more experienced engineers is the main way to accelerate the accumulation of experience in practice.

The third is from engineering society's events. Engineer's taking part in the engineering society's events, such as presentation, seminar, and conference, helped a lot in creating the access to distributed knowledge. In the observation, a geological engineer was asked by a society member about where to buy a reference book. A utility engineer expected to discuss a new method to do the job with the conference attendees. A junior engineer was observed to call several times to professors in the university for consulting. After a civil engineer found the data table posted in the office was not right in trouble-shooting, he spent significant amounts of time to call many different numbers to find the right formula, and finally got it from the City authority. All these cases indicate that engineers are able to get necessary knowledge from outside of their companies.

It was noticed that a couple of organizations had some kinds of program to help engineers to acquire new knowledge. A utility engineer told an observer he would have two courses next week, which were organized by the company. His boss was taking a course this week. In another geological engineering company, professors and experts in this field are regularly invited to the company to give engineers presentations and seminars.

The challenges of technological and knowledge advances, competitions, and changing work environments make it increasingly important for engineers to be able to acquire new knowledge, and maintain their continuing competence. This is important, not only for the protection of the public, but also for the individual's continual employment. Public, government, employer and clients are increasingly aware of the rate of change in knowledge based industries. These groups require evidence that demonstrates the continual competence of professional members. In the September/October 1996 issue of Engineering Dimensions, Peter Ridont, President of Professional Engineers of Ontario (PEO) notes, "Several ministries are now asking PEO to assure the quality of members by providing lists of competent practitioners." The government of Alberta has released policy documents related to professional legislation and stated that self-governing professions must "establish a range of mechanisms to ensure that registered or licensed practitioners maintain acceptable standards of competence and conduct".

Thus, the necessity of acquiring new knowledge results not only from the need to carry out daily work, but also from the need to protect the public and maintain personal employment. Besides an engineer's personal effort, the society and company also have the responsibility to help engineers to create more access to distributed knowledge.

Chapter 7

SUMMARY, CONCLUSIONS, AND IMPLICATIONS

This final chapter tries to present an integrated review of the basic research results presented in Chapters 4 through 6. This summary is followed by two sections that present some implications of these research results on engineering management and engineering education.

7.1 Contribution: Theory of What Engineers Do in Their Daily Work

The key to this study was the categorization of the purpose of engineers' activities. The purpose describes the essential content of engineers' activities, and it is what leads to the development of working roles. The theory of what engineers do was formed through developing the engineer's working roles.

Engineering activities and engineer's roles may be grouped into three categories: those that deal primarily with data---two information roles; those concerned primarily with organizing and facilitating work---two organization roles; and those that involve finding solutions, creating ideas, and making significant judgement---two problem solving roles. These six roles can not be isolated. They form an integrated whole. One can not arbitrarily remove one role and expect the rest to remain intact. To perform two problem-solving roles, engineers must collect data and organize the activities. This leads to the four other roles.

As a data collector, the engineer continually gathers information from a variety of sources in order to define a situation, to advance the work, and to control the time and cost. In an organization, all the data related to a specific task goes to the engineer who is in charge. The engineer is the center in the contact network for the task. The engineer functions like a data processing unit within a large organization, who collects, receives, processes the data, and generates the products from these data. This role of data collector must be played and can only be played by the engineers themselves. Because the process of data collection is interactive, accumulative, and inseparable from other activities, and often involves the use of engineering knowledge and skills, it can not be delegated to others as an independent task. Most of the data and information about an engineering task are in the form of parameters and drawings, and are not understandable by other people who lack an engineering background.

The consultant/mentor role defines the engineer's interpersonal relationships with other engineers. By playing this role, the engineers make their experience, knowledge, skills, and information available for peers and the organization for additional use. In conversations and meetings, whether between an engineer and his supervisor, between two engineers of roughly equal position, or among a larger number of engineers of unequal position, the style, atmosphere, and attitude of decision making are predominantly consultative and consensual. The person, who has better ideas, more experience and information, and greater technical capability, acts as an expert.

In the administrator role, the engineer performs a series of activities to organize and facilitate the work to make sure the job can be done within the budget before the deadline. The control of cost and time is a big part of engineering work. Since an engineering task often involves many parties, it is often necessary for engineers to interact with related parties in order to complete the job within the budget before the deadline.

In the overseer role, the engineer interacts with the helpers to makes sure the ideas are understood and carried out correctly. Some engineers may not perform the overseer role if they do not have helpers.

In the historian role, engineers search for the data and ideas from previous files and drawings, and from experience. They frequently refer to books and other materials to see what other people have done, and what is the standard way. They recall their own memory, and seek the experience and ideas from supervisors and peers. By playing this role, they learn more about the problem---more aspects and more detail, and new ideas are often stimulated. It is reasoned that an important reason for the engineer to play the historian role is to find a practically proved solution for a specific task. It reflects that engineers usually work very cautiously.

In the adapter/inventor role, the engineer produces ideas by adjusting an old solution or inventing a new idea, to solve the problem. The ideas for solving problems are produced through actions, such as drawing, calculating, and discussing. Decisions, adjustment, and judgement are made in the process of performing these activities. The ideas are included into engineer's products, which are drawings (or software), reports, proposals, and specifications. The adapter/inventor role reflects two sides of the creativity in engineering work. While the engineer does frequently need creative ideas, the work of most engineers most of the time is quite routine, normally doing some adjustments based on an old solution.

7.2 Findings: Characteristics of Engineers' Activities

Through the analysis of how engineers spent their time, some characteristics of engineers' activities were found in this study. Engineer's activities can be grouped into the following categories: desk work, computer work, phone calls, conversations, meetings, travel, and tours.

One important finding is that the activities of the engineer are characterized by fragmentation, brevity, interruptions, and no pattern. The vast majority are of brief duration. There is great fragmentation of work, and interruptions are commonplace.

Another finding is that engineers spend a surprisingly large part of their time in talking (over 40% in this study): informal face-to-face conversations, scheduled meetings, and talking on the phone.

The phone was used mostly for contacting clients, subcontractors, and authorities. However, it is also often used for internal communication with peers and helpers. The call to the supervisor is often for making appointments. The phone is used to exchange data and information. The information exchanged through the phone can be grouped into the following categories: technical data, site information, project status, cost data, and general information, such as a phone number and email address.

The informal face-to-face conversations are mainly for technical discussion, and exchanging data and information. The engineer has much more conversations with peers and helpers than with the supervisor. The engineer usually does not have any hesitation to break into peer's and helper's office for conversation, and is accustomed to being interrupted by others. The topic of the conversations between them is diverse. Casual conversation in the office often lead to important topics, and often result in important comments and insights. However, the engineer goes to the supervisor only for serious conversation, such as reporting the project status, reviewing proposals, or informing the supervisor regarding important matters.

The contents of both engineer's phone call and conversation are very specialized, and technical. The people without a proper engineering background are unable to understand the meanings of those phone calls and conversations.

The pre-scheduled meetings are relatively long (average 68 minutes in this study). Most meetings are for project review and planning (62%), and are with clients (42%) and co-operators/subcontractors (17%).

Desk work is another large part of engineering work. In this study engineers spent about one-third of their time at their desks. While at their desks, the engineers mainly perform the activities of drawing/checking drawings, estimating costs, reviewing the whole projects, and reading proposals and reports. Desk work is often interrupted by other activities such as phone calls and conversations. In this study, very few activities in desk work last more than 30 minutes without an interruption.

It is surprising that the use of computers is only a small part of engineering work (9% in this study) for non-computer engineers. The computer is used mainly for writing reports and proposals (49%). The technical use of the computer is only a small percentage (16%) of the total time spent on the computer.

For those engineers whose products will be installed and tested on the sites, travelling to the site is necessary. The engineer pays great attention to the site investigations.

To summarize, while engineers have to spend some time alone at their desks and computers to generate the products such as drawings, specifications, and proposals, their activities are characterized by frequent interacting with others. They get the job done through accumulating information and ideas from others and reference materials. It is inconsistent with the traditional image of the engineer, who is portrayed sitting in a quiet office, working alone on complex problems for long, uninterrupted periods.

7.3 Propositions: Engineer's Knowledge

The propositions about engineer's knowledge are developed by analyzing what kind of knowledge is necessary to play those working roles, and what kind of knowledge might be generated if engineers keep performing these activities everyday. It is proposed that an engineer's knowledge be categorized into the following five groups: theoretic tools, stock solutions, symbol-material linkages, operational considerations, and access to distributed knowledge.

Theoretic knowledge enables engineers to read the literature, to analyze the situation, and to perform calculations. Theoretic knowledge is the base for developing any other kinds of knowledge and experience, and may possibly be used in any situation at any time.

Solution stock is a collection of various usual configurations proved to be effective in practice. It is accumulated in the life of the engineer by playing problem-solving roles. It is the "database" of qualitative solutions, from which the engineer searches for a suitable one, makes adjustments according to specifications, and applies to a new task. The larger the solution stock, the more effective the engineer works. The collection of configurations, namely the solution stock, depends largely on personal experience. Therefore, the engineer's solution often exhibits a personal style.

The symbol-material linkage is the connection between the abstract scientific symbols and real artifacts or process. It enables engineers to translate the general and qualitative goals and requirements into quantitative specification in concrete technical terms. It also provides engineers with the ability to "see" the real artifacts and processes, when they manipulate the symbols.

Operational consideration is the knowledge of operation procedure and method, such as fabrication, assembling, construction, and maintenance. This knowledge enables engineers to know if their ideas are all right both theoretically and operationally. Operational considerations are another kind of limit to engineering work. It can not be theorized, or translated into quantitative specifications in technical terms. Such considerations are mostly learned on the job, and tend to be carried around, more or less unconsciously in an engineer's mind.

Access to distributed knowledge is the knowledge of knowing where and how to get knowledge. There are mainly three ways to get necessary knowledge: reference materials, peers and supervisors, and the engineering community.

7.4 Conclusions

Present knowledge of what engineers do is limited to several functional words, such as designing, manufacturing, planning, and evaluating. While these function words are supposed to be abstracts of engineers' behavior, the real situation is that the knowledge base of engineers' behavior does not exist. So, these function words are more prescriptive than descriptive. This study emphasized the process and activity, and thus was able to contribute to build the knowledge base of what engineers actually do in their daily work. This study provides detailed information about what kind of activities are performed, and how. The six working roles are developed through the categorization of activity purposes. Unlike functional words, these working roles are able to capture the features of engineering work, and describe the engineers' behavior in the workplace.

The engineer's knowledge and skills are generally grouped into theoretic knowledge and experiences. But it is not clear what knowledge components are contained in the experiences. In this study, through the analysis of engineer's working roles, it is found that engineer's experiences contain the following four components: stock solutions, symbol-material linkages, operational considerations, and access to distributed knowledge. The six working roles also provide clues to how knowledge and skills are used and developed in the engineering practice.

Three dimensions of descriptions in this study on engineering work provide a base from which we can start to analyze actual working practice and organizational schemes.

However, to get complete understanding of engineering work, further research is required to identify the variations in engineering work, and to test the grounded theory in the whole engineering community. Both of these two aspects of research need great amount of effort. Thus, this study is just the beginning. Hopefully, it can stimulate other researchers' interest in this topic.

7.5 Implications for Managing Engineers

The findings indicate that engineer's work is fragmented, brief, and has a great variety in activities. There is no pattern. Therefore, the manager should not try to monitor, to control, or to rationalize engineer's activities, but focus on facilitating those activities to improve an engineer's productivity.

(1) The manager should realize that an engineer's activities are driven by the task. Engineers schedule their time according to the necessity of finishing a task on time. Thus, it is not proper to evaluate an engineer's performance according to working hours. If the task is heavy, engineers will extend the working time automatically without management's requirement, even working late into the night at home. If the task is not heavy, it is difficult for the manager to tell whether the engineer is working productively or not. Therefore, the management focus should be put on how to assign the task rationally.

(2) The study indicates that engineers frequently need to refer to reference books, search the data, and ideas from previous files. While most engineers have their own collection of reference materials, a well-established library by the company will facilitate engineers' work. Similarly, a well-established company's contact network will facilitate engineer's communicating with different parties relating to company business.

(3) Considering the necessity of engineer's talking to each other, and the importance of casual conversation, it will be helpful to put the engineers, who work in the related tasks, into near rooms. The distance changes the type of communication. Considering the frequency of the contact between engineers and technicians, sometime it may be good to arrange technician office near to engineer office.

(4) The engineer's value as consultant is hard to measure. Team work does not only mean that all team member sit together for discussions, but also including all kinds of casual conversations, information, and comments. To motivate and evaluate an engineer's

performance, it is necessary to find a way to identify an engineer's contribution to others in this informal way.

(5) The manager should realize both sides of the creativity in engineering work. For most engineers most of the time, the work is routine. In assigning the task, the manger should try to provide some variety in tasks, such as different degree of difficulty, some new fields, or larger scope. For example, one engineer in this study was very happy to be given an additional responsibility of helping peers to solve computer problems. This engineer told the observer that playing with computers was his hobby. Always doing similar task makes people tired and leads to low productivity and motivation.

(6) It is suitable for an engineering organization to be designed with fewer hierarchy levels. As found in this study, the engineer's authority depends largely on his/her capability in solving problems, in providing quality ideas and information to peers. All engineers need help from others, even senior engineers. An organization with fewer levels facilitates engineer's helping each other.

(7) Engineers should be encouraged to attend the events organized by the engineering community because this helps engineers to establish access to distributed knowledge, and to be aware of the latest technology in their discipline. Organizing some courses and seminar for engineers costs little, but will help engineers to keep their continual competence.

(8) The study shows that engineer's work provides engineers with not only the chance to practise analytical ability and theoretical knowledge, to know if a thing can be done and how a thing can be done best, but also the chance to negotiate with and co-ordinate different parties, to control time and cost, to co-operate with peers, helpers, and engineers

from other companies. All these skills, ability, and experience prepare engineers well for a management position. This may help to explain why so many engineers are promoted to management positions.

7.6 Implications for Engineering Education

Most engineering training in the colleges focuses on the use of theoretic knowledge, especially selecting and applying a correct formula for a given problem, which is usually perfectly defined with just as much information as necessary. As Russell L. Ackoff (1994) said, "Through their formal education students are evaluated by their ability to solve problems given to them. Therefore, it is not surprising that they go out into the real world assuming that problems will continue to be given to them." While such training is helpful and effective for engineering students to grasp the theoretic knowledge, it ignores a large part of engineering activities. As found in this study, engineers spend a great amount of time in searching data and studying and defining the situation. It is suggested that the instructors in some senior courses train students with "messy" cases, which consist of complex systems of strongly interacting problems, rather than well defined problems. Students are given the context of the case, instead of the data. Such "messy" cases may help students to get the ability to analyze the complex situation, extract the problems from the reality, search the necessary data, make personal judgement, deal with ambiguity and uncertainty, and be aware of all kinds of issues relating to the problem, such as social issue, budget limit, and deadline.

This study indicates that engineers need to contact many people from different organizations. Frequently, the engineer must discuss, co-ordinate, co-operate, and negotiate with many parties to get the job done. This communication necessity is not sufficiently recognized in the present education system. Student's marks often depends on individual effort on assignments and exams. To overcome this shortage, in some courses such as design course, it is suggested that students be assigned different parts of a same project. While each individual or each group has own goal to reach, the overall goal of the project must be reached by all participants' effort. In this way, the communication necessity is established, and the students may get the necessary skills to work with others.

Many engineer's knowledge components, such as symbol-material linkages, stock solutions, and operational considerations, come from the frequent interactions between theoretic knowledge and the real world. To increase this kind of interaction, it is suggested that the engineering colleges provide more chance for students to "touch" the real world. Shop courses, as well as courses dealing with design and with the art and practice of engineering should be strengthened and increased. In some courses such as machine design, the instructor may require students to submit the real product instead of just the design drawings so that students have the opportunity to deal with and experience all kinds of problems appearing in the process of transforming the knowledge into final product. Exclusive emphasis on scientific knowledge tends to lead students to think that is all about engineering. Students have no reason to believe that curiosity about the physical meaning of the subjects they are studying is necessary.

In conclusion, once the knowledge of what engineers actually do in their daily work, we can start to analyze the gap between the present engineering education and daily engineering practice, and endeavor to connect what engineers do with what and how they are taught.

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