Geotechnical Design and Construction Automation in Taiwan

by

Berlin Wu

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Signature of Author: ....
Department of Civil and Environmental Engineering
May 10, 1996

Certified by: ....
Sarah Slaughter
Assistant Professor, Department of Civil and Environmental Engineering
Thesis Supervisor

Accepted by: ....
Joseph M. Sussman
Chairman, Departmental Committee on Graduate Studies

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Abstract

The developed countries, such as the United States, Japan, and France, have already applied automation technologies to a degree into construction industry and have made obvious improvements during the last decade. Taiwan, a newly developing country, seeks to improve its construction industry, especially in response to labor shortages and wage increases. In order to understand the applicability of construction automation in geotechnical engineering in Taiwan's construction industry, this thesis reviews a major project, Taipei Rapid Transit System (TRTS), in Taiwan's "Six Year National Development Plan".

A questionnaire was designed and sent to the typical geotechnical construction teams including contractors, architectural firms, engineering firms, and public agencies of the TRTS in order to identify the benefits and constraints of construction automation for the geotechnical field in Taiwan. Based on the results of this survey, the feasibility for construction automation in Taiwan is analyzed.

The results of this research show that the TRTS project has included the use of automation technologies. Although the general level of construction automation is regarded as high, the advanced construction technologies and equipment are mostly imported from abroad to meet the urgent requirements due to labor shortages, environmental concerns, construction schedule, and the quality of the projects. The benefits perceived from using construction automation technologies include saving work labor and time, and increasing project quality, and these benefits appear to increase over time among all four type of firms.

Thesis Supervisor: Dr. Sarah Slaughter
Title: Assistant Professor

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Research Problem

Construction has always been a highly labor-intensive and dangerous industry. As a matter of fact, the construction industry still faces labor shortages and a high number of industrial accidents no matter how high the salary and insurance fees are. In order to conquer these problems, the developed countries, such as the United States, Japan, and France, have already applied some degree of construction automation in the industry and have made obvious improvements during the last decade.

In the early 1980s in Taiwan, because the construction projects were small and less complicated, the construction industry did not suffer from the same problems. However, in recent years, it has also come to feel pressures from labor shortages, increasing wages, and increasing environmental and safety awareness. At the same time, the Taiwanese government has developed a "Six-Year National Development Plan," which proposes a huge number of public construction projects. It is obvious that the traditional methods of construction are unable to meet the current demands. In order to surmount these challenges, besides hiring foreign labor in the short term, introducing construction automation from developed countries has become the most promising method in Taiwan's construction industry.

1.2 Research Motivation

The Taipei Rapid Transit System (TRTS) is the major project within the entire Six-Year National Development Plan. Because Taipei, an international and highly civilized big city, is located on a soft basin, a large amount of construction work is underground and as a consequence will face some difficult challenges. Because of the uncertainty and instability of the subsoil, many newly developed construction automation technologies could be used in geotechnical engineering works in this project. Therefore, those who develop or introduce construction automation into Taiwan must determine the automation efficacy of their machinery or technologies, and identify the potential trends of Taiwan construction automation in geotechnical engineering.

1.3 Research Objectives

A study of construction automation in the developed countries shows that they have benefited from reduced labor requirements, improved safety, and stabilization of the work force. The question is: can construction automation also provide the same benefits to Taiwan? In view of this, this thesis has three major objectives. The first is to describe the current construction automation equipment in the geotechnical engineering related works of the TRTS. The second objective is to determine whether construction automation makes sense in Taiwan or not. The third objective is to provide recommendations to the construction industries and predict the future development of construction automation in Taiwan.

1.4 Research Methodology and Approach

This research proceeds through two parts: (1) data collection and survey, and (2) data analysis. The first part is performed through reviewing the relative literature and gathering information about the current situation of construction automation in Taiwan and the TRTS through interviews with the public owner and the contractors of the TRTS. Specifically, a questionnaire was designed and sent to the typical geotechnical contractors of the TRTS in order to identify the benefits and costs of construction automation for the geotechnical field in Taiwan. The questionnaire primarily asks the contractors about the following issues:

1. Current use of automation technologies in:
    a. design and planning
    b. construction management and control
    c. condition monitoring
    d. equipment
2. Relative success of current use of automation technologies;
3. Problems in current use of automation technologies;
4. Opportunities for construction automation;

Based on the results of the survey, the second part analyzes the effectiveness of geotechnical automation in Taiwan, the current accomplishments and future developments of geotechnical automated machinery, and the barriers of introducing and developing construction automation. It also examines the need for research with development activities of construction automation within Taiwan and the potential role of the Taiwanese government.

1.5 Thesis Organization

Chapter 2 reviews the background literature of construction automation. Chapter 3 gives a description of the general underground situation of the Taipei municipal distinct and an overview of the Taipei Rapid Transit System. Chapter 4 contains the results of a questionnaire concerning the current performance of construction automation in geotechnical engineering for the TRTS and the results and analyses of the questionnaire. Based on the survey of the questionnaire, Chapter 5 analyzes one step further the results of the benefits contractors received after exploiting construction automation and judges the appropriateness of construction automation technologies for the project. Chapter 6 draws conclusions and provides some recommendations for Taiwanese government and the contractors in Taiwan's construction industry.

1.6 Summary

The construction industry, which has always been regarded as the locomotive industry in Taiwan, is a very important component in the "Six-Year National Development Plan." However, Taiwan's industries face the problem of widespread labor-shortages, especially in the construction industry. Moreover, because of the insufficient manpower and capital invested in research and development for a long time, the construction industry cannot respond to the demands for wage increases and environmental protection. Therefore, it is hoped that with the aid of construction automation, Taiwan can strengthen the capability of and promote new technologies of its construction industry.

This thesis focuses on construction automation for geotechnical engineering activities for the TRTS. The four research categories, which are design and analysis, control and management, monitoring, and construction equipment, will be examined by interviewing the construction companies involved with the TRTS. Based on this analysis, this research tries to provide possible directions and some contributions for construction automation in Taiwan in order to increase the economic efficiency and overall performance of its constructed facilities.

CHAPTER 2

BACKGROUND LITERATURE

2.1 Introduction

The background of this research can be divided into two distinct areas. The first area is the definition of construction automation and current development of technologies of construction automation in general and specifically in geotechnical engineering. This section reviews the literature of construction automation and some specific automation technologies. The second area is the evolution of the construction industry in Taiwan, and the identification of general issues.

2.2 Construction Automation for General Conditions and for Geotechnical Applications

2.2.1 Definition of Terms

Construction automation, in the narrow sense, is construction that can be done with minimal human involvement. At its most extreme, "complete automation" would eliminate human involvement altogether. Complete automation is not easy to achieve and is sometimes not economical. Therefore, in the wider sense, construction automation can be regarded as the technologies to save labor, save working time, increase productivity, improve the environment for workers, and reduce industrial injuries. Figure 2.1 shows the general benefits expected from construction automation.

Tucker (1988) defined construction automation as "the work to increase the contribution of machines or tools while decreasing the human input." Murray (1989) defined construction automation as "the integration of design, construction, and service/operation within a high-technology environment such as to maximize productivity." Ben O. Uwakweh (1990) defined construction automation as "the technology concerned with the application of electronic, mechanical, and computer-based systems to operate and control construction production." The Construction and Planning Administration, Ministry of Interior the of Taiwanese Government, (1992) defined construction automation as "the process to decrease the demand of manpower, improve the working environment, increase the productivity, assure the project quality, and reduce the construction duration by understanding and exploiting the current technologies and through the steps of rationalization, standardization, mechanization, and intellectualization."

In this research, "Construction Automation" is defined as "all automatic technologies introduced to promote the productivity and quality of projects and improve the working environment during the construction process, which include systematization, standardization, modularation, mechanization, electronification, and computerization." This paper investigates these technologies applied specifically to underground construction, including analysis and design, control and management, monitoring, and construction equipment, which especially could be used in the construction of the Taipei Rapid Transit Systems.

The degree of construction can be divided into four categories: partial automation, operation automation, system automation, and complete automation. Every construction task contains both a physical processing component and an information processing component (Porter and Miller, 1985). The distinctions among the four categories above are based on the distribution of physical and information processes between man and machine.

Partial Automation means the machinery provides some of the physical component, force, or energy to perform the work. The craftsman should provide the information processing component. For example, a clamshell or a backhoe would not perform the physical work unless the craftsman operates it. This category contains the traditional construction machinery, such as shovels, draglines, and bucket wheel excavators.

Operation Automation goes one step further by reducing the demand on the craftsman's skills. The operator supports and guides the machine and squeezes a trigger to start and stop, while the machine itself performs all the physical work. Remote control or remote sensing are the examples here.

System Automation provides some of the information component of the work. Most of such systems are computer aided, which means that the machinery relieves the craftsman of some decision making. For example, a laser guide grader eliminates the need for the operator to raise and lower the blade.

Complete Automation performs all the physical component and all the information component of the work. That means the task can be performed without manual work. An example is the application of artificial intelligence and robots.

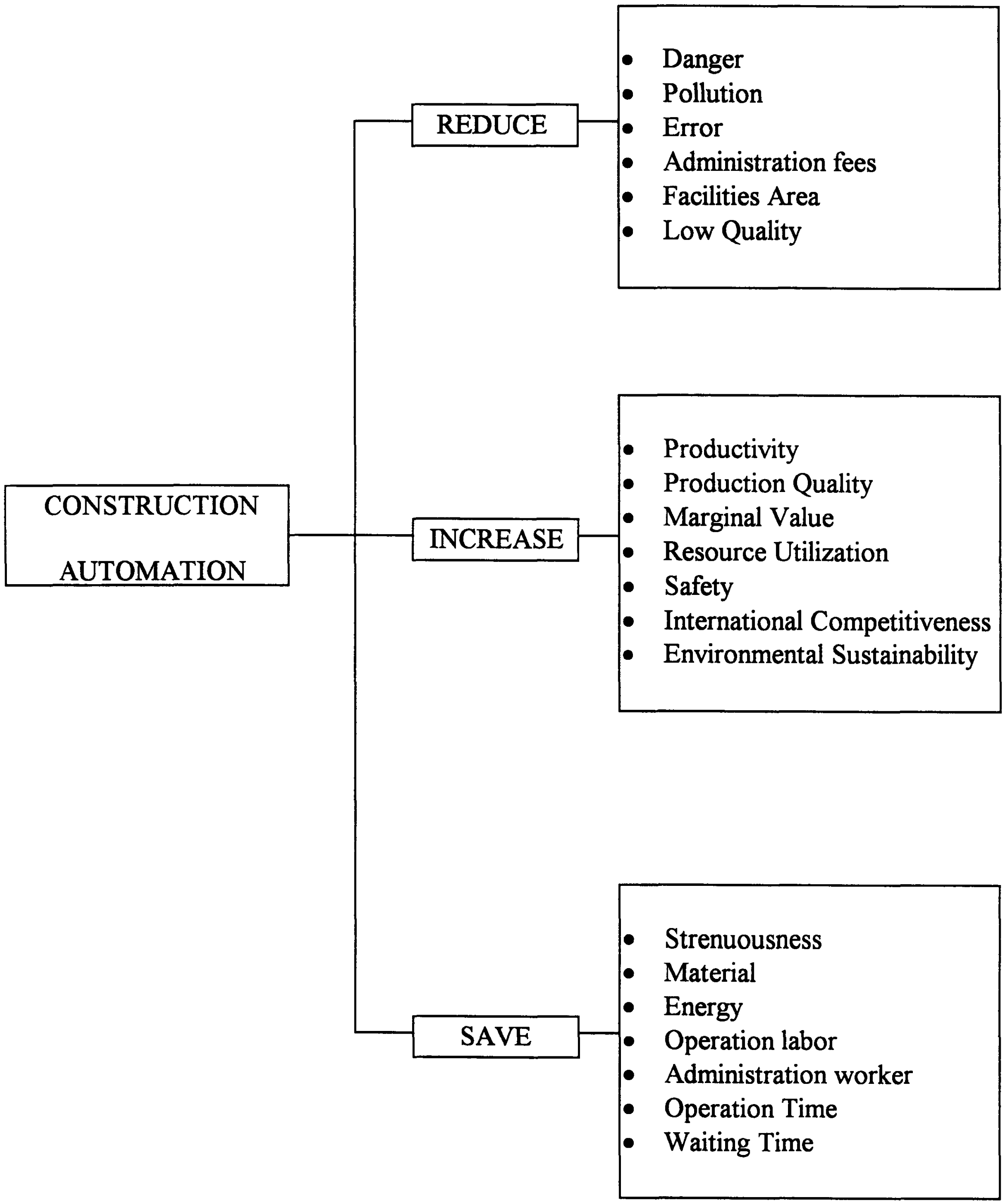


Figure 2.1 General Benefits of Construction Automation

2.2.2 Success to Date

a. In general

The success of construction automation in the world is tremendous. "To date, research has focused primarily on the mechanical aspects of robotics and control systems" (Higgins and Slaughter, 1993). The most advanced countries in construction automation are Japan and the United States. Japan has led the development of construction robotics for a long time (Groove, 1989), and the U.S. leads the research in artificial intelligence applied to control systems (Slocum, 1986). The international automation presented in robotics and construction conferences from 1984 can give us a clear picture of what is being working on.

For planning and design, Computer Aided Design (CAD) and Geographic Information System (GIS) are the main trends in the world. Taisei Corporation has begun development of work on PRISM (Project Representing Intelligent Site Modeler), an intelligent, object-oriented CAD tool that links to a knowledge base system. The PRISM will be initially used at the site to represent and simulate retaining wall construction (Aoki, Kimura, Momozaki, and Suzuki, 1993). Arc Site, a system which consisted of a GIS integrated with a database management system, assists the project manager in identifying suitable areas to locate temporary facilities. This research achieves the goal of developing an automated information system to enhance the temporary facilities layout design (Cheng and O'Connor, 1993).

In controlling and management automation technologies, Primavera Project Planner (P3) has set the standard in project control and management software for more than a decade. It offers an unlimited variety of ways to organize, filter, and compare project data and lets project managers track and record time sheet data within the schedule (Primavera Systems, INC,1995). The Move Cap Plan model, which was developed by the University of Michigan, integrates the construction process and aids in creating sequences of layouts corresponding to an activity schedule. Accordingly, control decisions, such as assessing desirability and feasibility of rehandling materials, determining the availability of rehandling means, or reassigning laydown space, can be made (Tommelein, 1994).

For monitoring, the Global Positioning System (GPS), a surveying system that takes advantages of artificial satellites, has attracted worldwide attention. Lots of monitoring systems will use GPS as a tool for receiving three-dimensional (3D) coordinates of observation points and performing measurement faster and more economically than the traditional measurement system.

For construction machinery, the Stewart Platform, which was developed by the National Institute of Standards and Technology and Lehigh University, is a computer-controlled hoisting system which may soon have vision and grab abilities (Slaughter and Higgins, 1993). The Drilling Robot, which was developed by TNO Building and Construction Research and Dutch industries, will be used for drilling holes for anchor bolts for fastening railways track to a concrete foundation (Kloek, Bos, and Marck, 1994). Taisei Corporation invented an automatic laser-controlled erection management system for high-rise buildings. This system replaces manual positioning of steel members during plumbing and straightening, and has a significant effect on labor reduction (Kanzaki, Nakano, and Matsumoto, 1994).

The issues for construction automation to date are not only exploitation but also commercialization and integration of end products within the design and construction processes incorporating it and the impact of the emerging technology on the culture and organization of the construction industry.

b. Geotechnology in particular

Because the automation technologies are generally compatible, during the planning, design, control, and management stages, there are only few programs developed for geotechnical engineering specifically. However, they still can be classified into parts of CAD. Stable 5, which is a typical example, is a geotechnical program which deals with slope stability on different site conditions (Purdue University, 1986). Rido, which provides the calculation of length and type of pile on different soil types, is another program package for geotechnical use.

In the monitoring stage, the Fujita Corporation has developed an Earthwork Progress Measurement System (EPMS), which can receive, analyze, and transform the data collected by GPS and therefore control and calculate the earth volume (Okano, Waku, Fujioka, and Kikuta, 1993). Monitors commercially available for standard geotechnical projects could also be employed.

Geotechnical engineering, particularly tunnelling, has made significant progress in automated equipment due to the requirements of heavy work and rough environment. In underground drilling, because extreme precision is required in the contours control and smooth wall blasting, some reliable microprocessor are now operating on many drill jumbos. The application of such automatically-positioned machines such as Atlas Copco drill jumbo is increasing and dominates the market (Robbins, 1995).

In tunnelling remote monitoring and control, some tunnelling machines in Japan are being driven by operators who are not in the tunnel, which indicates an engineer can operate the controls remotely. In tunnelling lining segment handling, an automated hydraulic arm and erector could be used. The erectors use lasers and infra-red measuring devices to determine the segment's position and thus reduce the human involvement (Robbins, 1995).

The Tunnel Boring Machine (TBM) was the most valuable invention in geotechnical engineering machinery in the last ten years. TBM replaces the traditional drilling and exploring method for constructing tunnels and increases the working speed by four or five times, saves lots of workers, reduces environmental impacts, and conquers difficult geological conditions. The Channel Tunnel Project (Tunneling, 1995a), Boston Harbor outfall Tunnel Project (Tunneling, 1994), and London Tunnels Projects (ENR, 1996) all used TBM as the automated technologies.

Other examples are the Boom Header Model RH-10J, which is a large-model, variable-cross-section tunnel excavator developed by Maeda and Nihon Koki corporation (Tunneling, 1995b) and HITACHI RX2000, which is a multi-jointed pile driving machine developed by Hitachi Construction Machinery Corporation (Uchino, Narisawa, Sato, and Kumazawa, 1993).

2.2.3 Existing technologies that could be used in the TRTS

In recent years, Taiwan's construction industry had introduced many automated technologies because of an increase in the number of projects. The TBM was first used in the Pinglin Tunnel of the Taipei- Ilan Freeway Project in 1992. The road header, which is a jumbo drill machine used in hard rock drilling, was introduced for the Hsintien Tunnel of the Second Highway Project in 1989. The shield machine, which is a kind of tunnel boring machine used in soft soils, was first used in the Taipei Sewerage System Project in 1976. It is anticipated that such automated technologies would be used in the TRTS. Furthermore, some bids for the TRTS were awarded to joint venture companies; even for those awarded to domestic contractors, the work could be accomplished through international technology cooperative agreements. Hence, many foreign contractors such as Shimizu, Taisei, and Kajima will enter this market. Such entry means that some advanced technologies they have used in other projects might be introduced to the TRTS.

Therefore, it is expected that some of the possible automation technologies used in the TRTS would include the following products:

For planning and design, CAD would be the major technology for the TRTS. In Taiwan, almost all projects require AutoCAD shop drawings. And, because of the educational training in Taiwan, some software, such as Excel, Stable 5, and Rido, would probably be used in the TRTS.

Primavera (P3) would be the major actor in project control and management for architectural and engineering firms of the TRTS. However, it is expected that simple bar chart and Critical Path Method (CPM) would be used generally by all contractors; probably some contractors would have their own management systems which are improved versions based on P3.

For monitoring, some GPS techniques might be applied in the TRTS, but the traditional monitoring equipment such as settlement indicators, strutted strain gages, and inclinometers still dominate the market. However, it is possible that this equipment is digital and combined by computer interface or is computer aided rather than working manually, which achieves the degree somewhere between operation automation and system automation.

For construction equipment, as mentioned above, the TBM, road header, and shield machine would probably be used in the TRTS. Certainly, these technologies are used only for drilling tunnels; a significant number of other geotechnical automation machinery still exist. In this research, we look only for the typical automation technologies.

2.3 Construction in Taiwan

According to the definition of the Taiwanese government, "the construction industry comprises trades that engage in building, setting, removing and fixing house structures, railways, highways, tunnels, bridges, dams, ports, reservoirs, channels, power plants, airports, communication lines and utilities" (The Administration Rules for Construction Industry, Ministry of Interior, 1989). In other words, construction projects include the facilities of living, communication, traffic, environment, and other industries.

Before the promotion of the Ten National Projects, the construction industry in Taiwan was still far behind the rest of the world. For example, the machinery and technologies were quite undeveloped and most projects were small-scale and used mainly manual tools. With the erection of the Shimen and Tzenwen reservoirs around 1969, which introduced the use of earth-working machines, the industry began to turn from traditional labor-intensive industry into a mechanization-construction one. Since 1973, the Ten, Twelve, and Fourteen National Projects, which included many large construction projects such as the CKS International Airport, the Chung-Shan Super Highway, Railway Tunnellization, the Taichung Harbor, and the Fei-Tsuey Reservoir, were the major impetus to promote Taiwan's construction industry. Since then, the industry has reached the construction mechanization stage. However, because of the development of the economy, universal education, and the evolution of society, the construction industry has been confronted with unprecedented impacts: lack of skilled labor, the implementation of labor laws, and higher requirements for site safety, project quality, and productivity. Meanwhile, the biggest project in Taiwan, the Six-Year National Development Plan (1991-96), which will spend US$ 223.7 billion and includes the TRTS project, is ready to begin. Therefore, construction automation becomes the most pertinent topic in the whole industry.

Through the years, the gross production and the working manpower of the construction industry in Taiwan have grown steadily. However, compared to manufacturing industries, construction is still a low productivity industry. Figures 2.2 and 2.3 show the construction working manpower and gross production. Both display a tremendous jump from 1990 or 1991, which was the time that the Six-Year National Development Plan began. Figure 2.4 shows the comparison of productivity between Taiwan's construction industry and manufacturing industry between 1982 and 1993. Although the productivity of the construction industry has increased significantly, it is still about two-thirds that of the manufacturing industry.

Taiwan's construction market primarily includes the owners, contractors, and architectural/engineering firms (Figure 2.5). Of the construction projects in Taiwan, 55.47% are publicly owned and 44.53% are private. This shows that the Taiwanese government can promote the development of the economy and drive private investment by investing in public projects.

The contractors are the units that actually work on construction. In Taiwan, they are classified into three classes: A, B, and C, each with its own undertaking limit according to their amount of capitalization. For example, a class A company is able to undertake the largest construction projects, while a class C company is limited to projects less than or equal to NT$ 1500 million. Table 2.1 shows the detailed figures of the relationships. According to the Taiwanese government, "the lower classes can upgrade to the higher classes" (The Administration Rules for Construction Industry, 1989, Ministry of Interior). Class C\B can upgrade to class B\A by undertaking a total amount of NT$ 75\150 million projects in the last five years. Figures 2.6 and 2.7 and Table 2.2 show the growth and change of Taiwan's contractors in the past fifteen years. There are over 1,000 architectural/engineering firms registered with the Ministry of Economy, employing about 15,000 workers, and 2,238 architects registered with the Taiwan Architects Association.

Although the construction industry in Taiwan is improving, labor shortages, low-level technologies, and lack of R&D ability are still problems. In order to face the competition of international contractors after entering GATT, it is urgent to promote construction technologies, which means working toward the direction of construction automation.

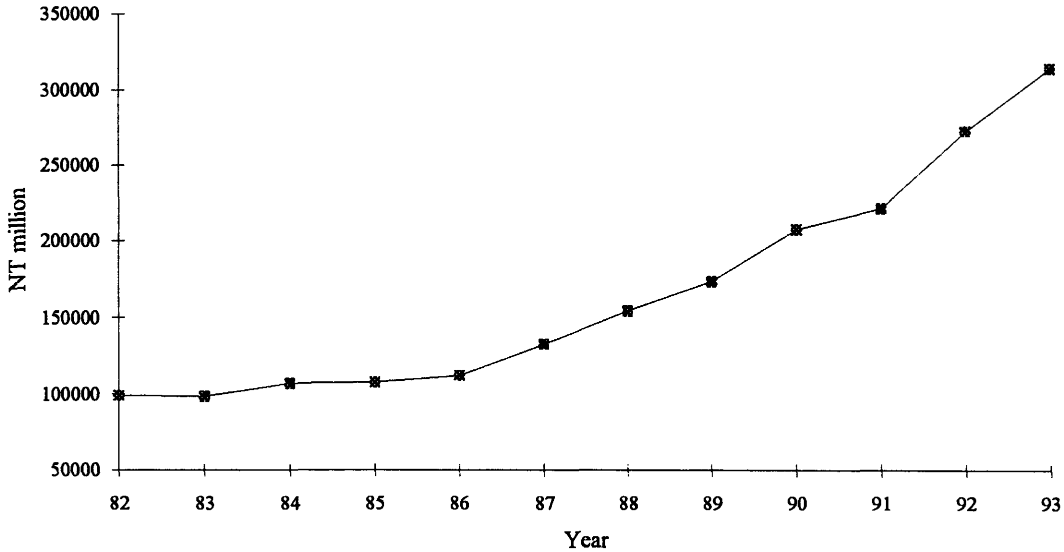


Figure 2.2 Gross Production of Taiwan's Construction Industry
(Source: Exec. Yuan, "The survey of construction industry, 1994")

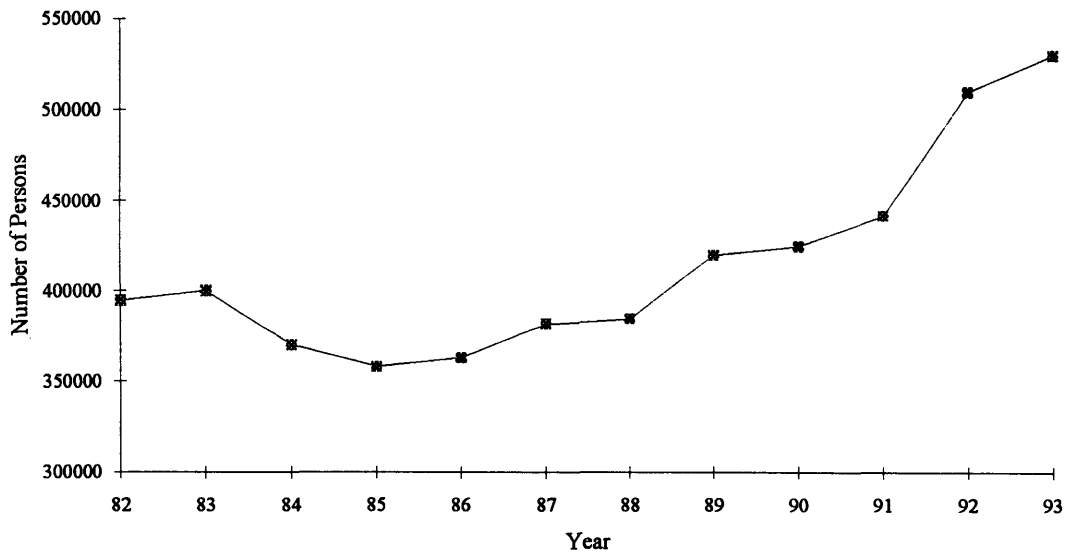
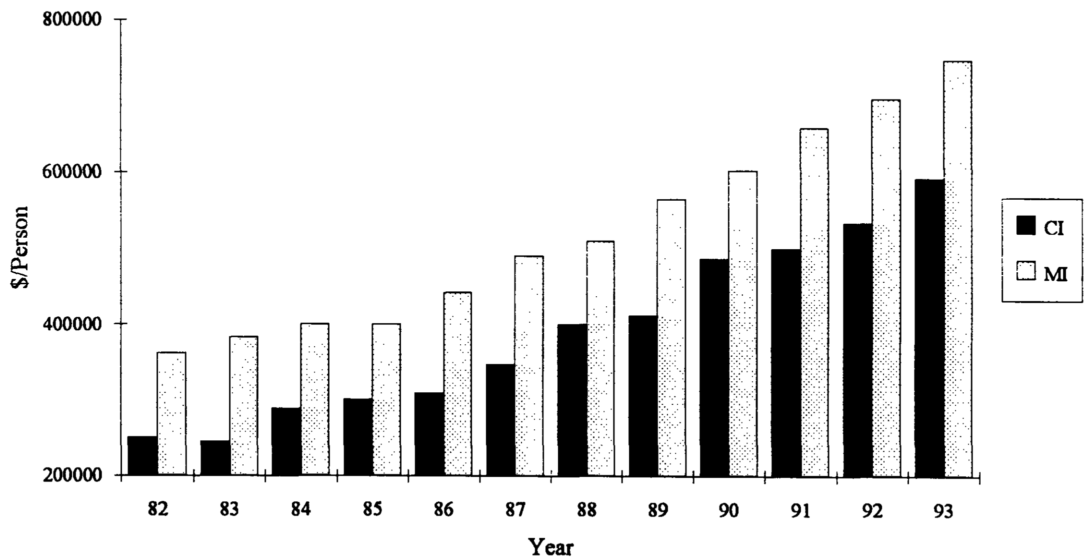


Figure 2.3 Working Manpower in Taiwan's Construction Industry
(Source: Exec. Yuan, "The survey of construction industry, 1994")



* CI: Construction Industry MI: Manufacturing Industry
Productivity = Gross Production / Working Manpower

Figure 2.4 Comparison of Productivity between Taiwan's Construction Industry and Manufacturing Industry
(Source: Exec. Yuan, "The survey of construction industry, 1994")

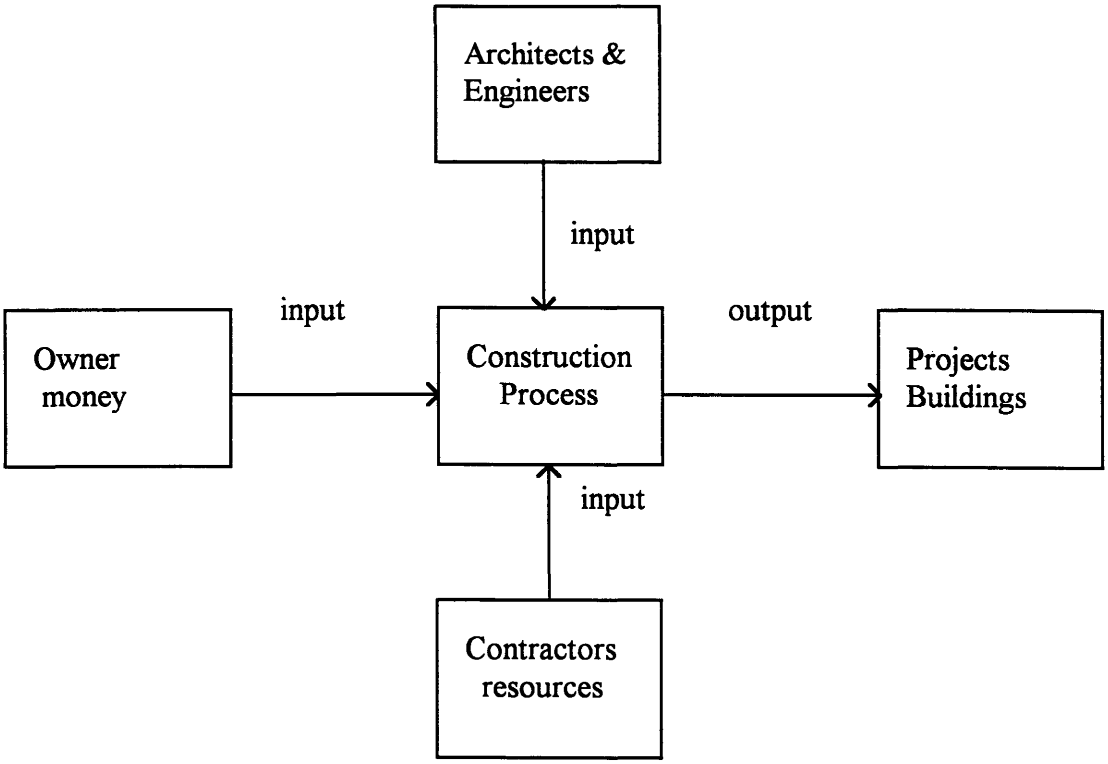


Figure 2.5 The Construction Team

Table 2.1 The Basic Discipline to Classify Taiwan's Contractors

Class	A	B	C
Lowest Capital Amount	2250	750	300
Project Undertaking Limit	None	3000	1500

(Unit: NT 1/100 million)

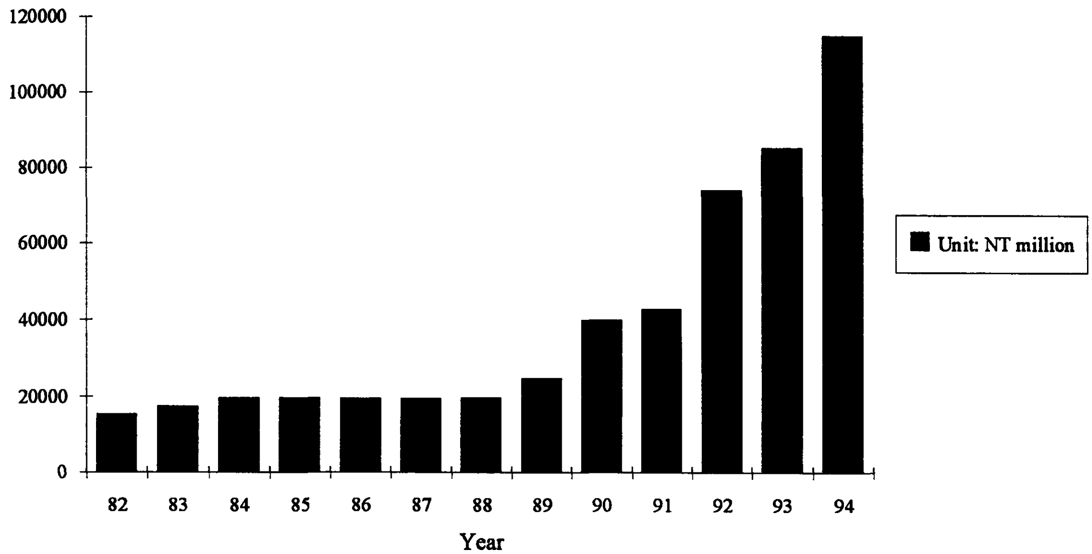


Figure 2.6 Growth of Taiwan's Contractors -- Total Capital Assets
(Source: Construction and Planning Administration, Ministry of Interior, "The yearly report of construction statistics, 1995")

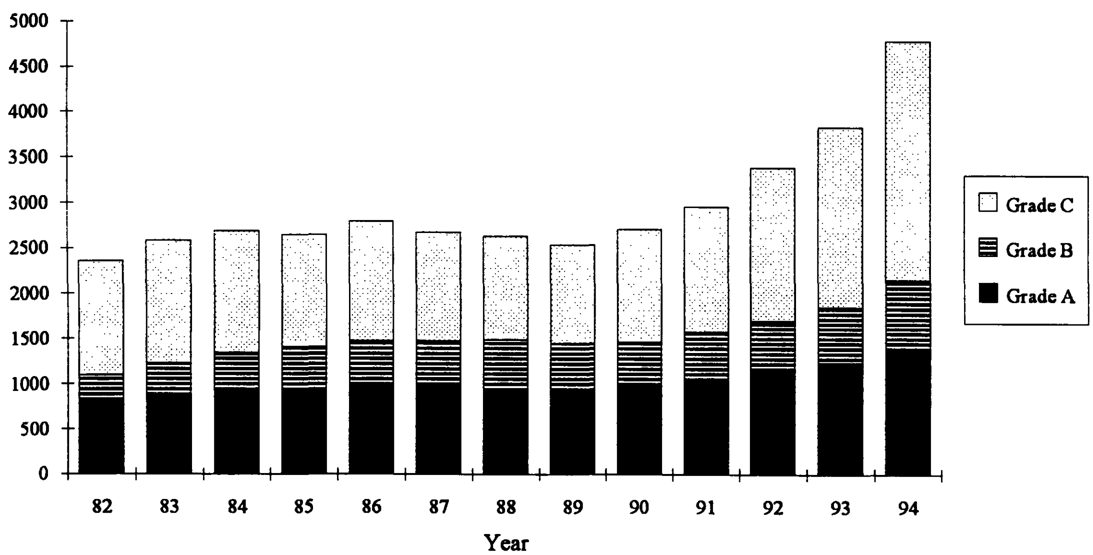


Figure 2.7 Growth of Taiwan's Contractors -- Number of Companies
(Source: Construction and Planning Administration, Ministry of Interior, "The yearly report of construction statistics, 1995")

Table 2.2 Change in Taiwan's Three Classes of Contractors
(Source: Construction and Planning Administration, Ministry of Interior, "the yearly report of construction statistics, 1995")

Year/Class	A	B	C	Total
82	795	298	1263	2356
83	874	351	1356	2581
84	922	415	1350	2687
85	938	467	1244	2649
86	988	486	1321	2795
87	978	497	1197	2672
88	940	550	1139	2629
89	943	499	1100	2542
90	976	487	1245	2708
91	1043	527	1387	2957
92	1147	559	1684	3390
93	1234	623	1976	3833
94	1398	756	2631	4785

(Unit: Numbers)

CHAPTER 3

DESCRIPTION OF PROJECT FOR APPLICATION OF CONSTRUCTION AUTOMATION TECHNOLOGIES

3.1 Introduction

This chapter describes the underground situation of Taipei and gives an overview of the Taipei Rapid Transit System (TRTS), which is the project examined explicitly for the application of construction automation technologies.

The Taipei basin was formed mainly by the quaternary unconsolidated sediments. This is not a comfortable soil for geotechnical engineering and will be a big challenge for the subsurface work. Therefore, to conquer the instability of underground conditions in Taipei, it is expected that there will be some automation technologies used for the TRTS.

The TRTS, the first subway system in Taiwan, started its construction work in 1989 with an initial network of six primary lines. Fifty percent of the network contains underground work, which means that geotechnical automation technologies could be adopted to a high degree.

3.2 The Underground Situation of Taipei

According to the analysis report by the geotechnical consulting company (Moh & Associates, geology surveying report for TRTS, 1988), we can understand the history and geology situation of the Taipei basin as follows:

The Taipei basin was formed by the normal fault slide in the tertiary orogeny. After the sea withdrew, the Taipei basin emerged from the water and started to deposit sediment from the rivers in the Tamshui river system. Except in the northern side of the basin, which is composed of volcanic rocks from Datun volcanoes, the rock mass in the base of the basin is tertiary sedimentary rock. Figure 3.1 shows the geotechnical zoning in the Taipei basin. Beyond the tertiary rock mass are the quaternary unconsolidated sediments, which are 400 meters thick and can be divided into the Hsinchuang formation, the Chingmei formation, and the Sungshan formation.

The Hsinchuang formation is the lowest; its thickness can vary from 0 to 120 m. It is composed of gray and blue mud-fine sand, and several meters of gravel can be found in this formation. Above the Hsinchuang formation is the Chingmei formation, which is 200 m thick and is composed of yellow-brown gravel 10 to 20 cm in diameter. The quaternary deposits which fill the basin comprise upper recent deposits of the Sungshan formation, which are up to 70 m thick in the city center area. Table 3.1 gives the soil descriptions of the three main formations. Table 3.2 shows the physical properties of the Sungshan formation, which is divided into six layers. Above this formation is a yellow topsoil of silty clay about 1-6 m in thickness.

Most of the TRTS underground construction work in the downtown area will take place in the Sungshan formation. The bottoms of the tunnels in the TRTS are generally located in the fourth or fifth layer in the Sungshan formation. The deepest construction of the underground work can reach the second layer. However, most underground construction is in the fourth layer. The permeable and water-bearing Chingmei gravels also have a major impact on the project in terms of groundwater control requirements.

Therefore, the construction of the TRTS would face some major uncertainties such as the unstable soil conditions and the potential groundwater pressure. Furthermore, since Taiwan is seismically active, so the safety considerations of the underground structures are also important. Hence, some traditional construction methods and equipment would not be accepted by the contractors. For example, the traditional drilling machine would be replaced by a shield machine owing to the variable soft soil conditions. The automation technologies, which can reduce the risk and impacts of such uncertainties, are expected to play an inevitable role in the TRTS.

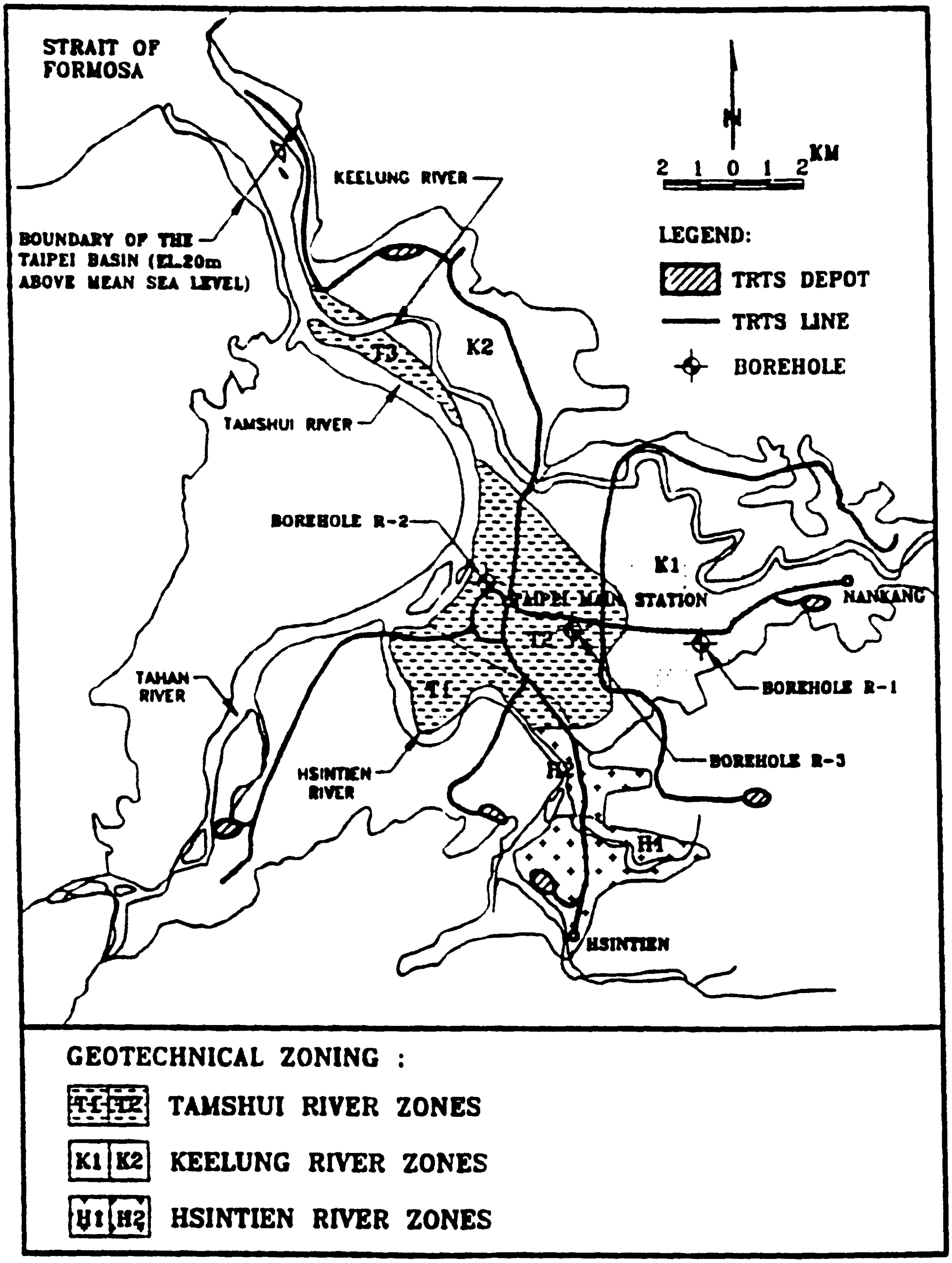


Figure 3.1 Geotechnical Zoning in the Taipei Basin
(Source: Chin, Crooks, and Moh, “geotechnical properties for TRTS”, 1989)

Table 3.1 Profile of Sedimentary Deposits in the Taipei Basin

Formation	Classfication	Thickness(m)	Soil Description
Top Soil	(CL/ML)	1~6	Yellowish Brown Clay
Sungshan Formation	Layer VI(CL/ML)	2~8	Grayish Black Clayey Silt/Silty Cay
	Layer V(SM)	2~20	Gray Silty Fine Sand
	Layer IV(CL)	6~29 40~70	Gray Silty Clay
	Layer III(SM)	0~19	Gray Silty Fine Sand
	Layer II(CL/ML)	0~19	Gray Silty Clay
	Layer I(SM)	0~15	Gray Silty Fine Sand
Chingmei Formation		0~200	Yellowish Brown Gravel
Hsinchuang Formation		0~120	Gray to Yellowish Brown Sandy
			Clay w Occasionally Interbedded
			Thick Gravel Layer
Tertiary Sedimentary Rock (Volcanic Rock in Peitou, Shinlin, and the Vicinity of Kungkuan)			

Table 3.2 Physical Properties of Sungshan Deposits

Sub layer	Soil Description	Wn (%)	Wl (%)	Ip (%)	Particle Size Distribution (%)			
					Gravel	Sand	Silt	Clay
VI	Grayish Black Clayey Silt/Silty Clay	31.2	35.8	12.9	0	10	58	32
V	Gray Silty Fine Sand	26.3	\	\	1	75	19	5
IV	Gray Silty Clay	32.1	34.3	12	0	8	61	31
III	Gray Silty Fine Sand	23.9	\	\	0	60	34	6
II	Gray Silty Clay	27.2	30.3	9.2	0	9	67	24
I	Gray Silty Fine Sand	20.3	\	\	1	63	29	7

3.3 Overview of Taipei Rapid Transit Systems (TRTS)

After the economic miracle, Taipei, the biggest city in Taiwan, has encountered serious traffic problems. In the last ten years, there has been a rapid growth of population and vehicles in the Taipei metropolitan area. The roads cannot accommodate such big growth, and traffic has become worse and worse. The parking, traffic jams, and air pollution problems have seriously reduced the quality of life and city development. Thus, the rapid transit system is seen as the solution. Preparations for the Taipei Rapid Transit Systems (TRTS) got under way back in early 1986, when the Executive Yuan completed preliminary plans for the network and approved their implementation. On June 27, 1986, the Taipei Municipal Government established the Preparatory Office of Rapid Transit Systems, which, on February 23, 1987, was officially reorganized as the Department of Rapid Transit Systems (DORTS) for the specific task of handling this ambitious, US$ 18 billion dollar project. Figure 3.2 shows the organizational structure of DORTS.

The TRTS network will meet the transportation needs of eight major corridors in metropolitan Taipei, strengthen the link between downtown and satellite towns and cities, and promote the overall development of the Taipei metropolitan area (Figure 3.3). The network, which includes six primary lines and a maintenance line, spans 88 kilometers in Taipei City and Taipei County and contains 34.3 km of elevated rail, 9.5 km at ground level, and 44.2 km of underground portion.

Figure 3.3 shows the map of the TRTS network, of which the following are significant details:

1. Tamshui Line (Red Line): It will run at grade or elevated from the Tamshui station, along the Tamshui-Taipei railroad through Shihlin and Yuanshan, and then continue underground from Yuanshan to Taipei main station. The whole line will be 22.8km, with 20 stops, and will be completed by June, 1996.

2. Hsintien Line (Green Line): The Hsintien Line will join the Tamshui Line at Taipei main station, and run south along Roosevelt Road to Hsintien. The whole line will be 10.3km, with 11 stops, and will be completed by June, 1997.

3. Mucha Line (Brown Line): This line goes from Taipei City Zoo in Mucha to Fuhsing station. The whole line is 10.9km, with 12 stops. It was completed in August, 1995 and opened for use in March, 1996.

4. Neihu Line (Brown Extension): This line is an extension line from Fuhsing station under the Sungshan Domestic Airport to Tachih, and then continues elevated on to Neihu and Nankang. The whole line will be 13.1km, with 11 stops, and will be completed by December, 1998.

5. Chungho Line (Orange Line): Moving north from Chungho will be the Chungho Line, which will run north along Chungho and Yungho road, under the Hsintien River, joining the Hsintien Line at Kuting station. The whole line will be 5.4km, with 4 stops, and will be completed by June, 1997.

6. Nankang Line (Blue Line): From Nankang to Tucheng, the whole line will be 23.9km, with 21 stops, and will be completed by June, 1999.

7. Maintenance Line: A 1.6-km maintenance track will facilitate trains serving the Nankang Lines to transfer to the Peitou main depot for maintenance.

Most of these lines are in the Taipei soft basin. Because about 23% of the net work would be geotechnical engineering-related work (Table 3.3), the geological condition of the Taipei basin is important to the contractors. Tables 3.4 to 3.8 show the bid date, contractor, and money amount of each geotechnical construction bid (The yearly report of TRTS, 1994). Nankang, Hsintien, and Chungho lines are the lines with the highest geotechnical bids, since these lines pass through different geotechnical zones and have many uncertainties to overcome, which increases the high amount of the bid budget.

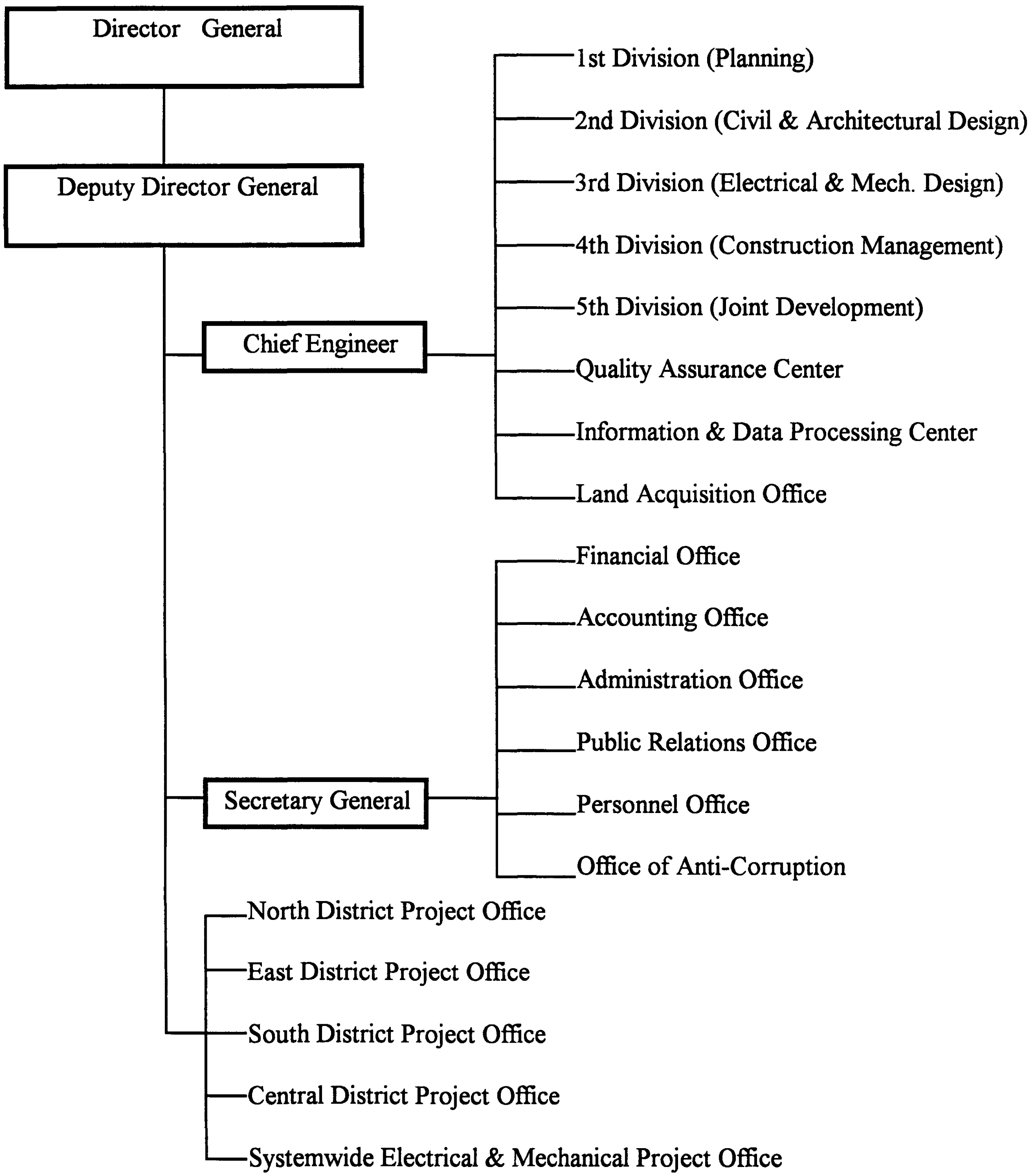


Figure 3.2 Organizational Structure of DORTS
(Source: DORTS. "The yearly report of TRTS, 1988")

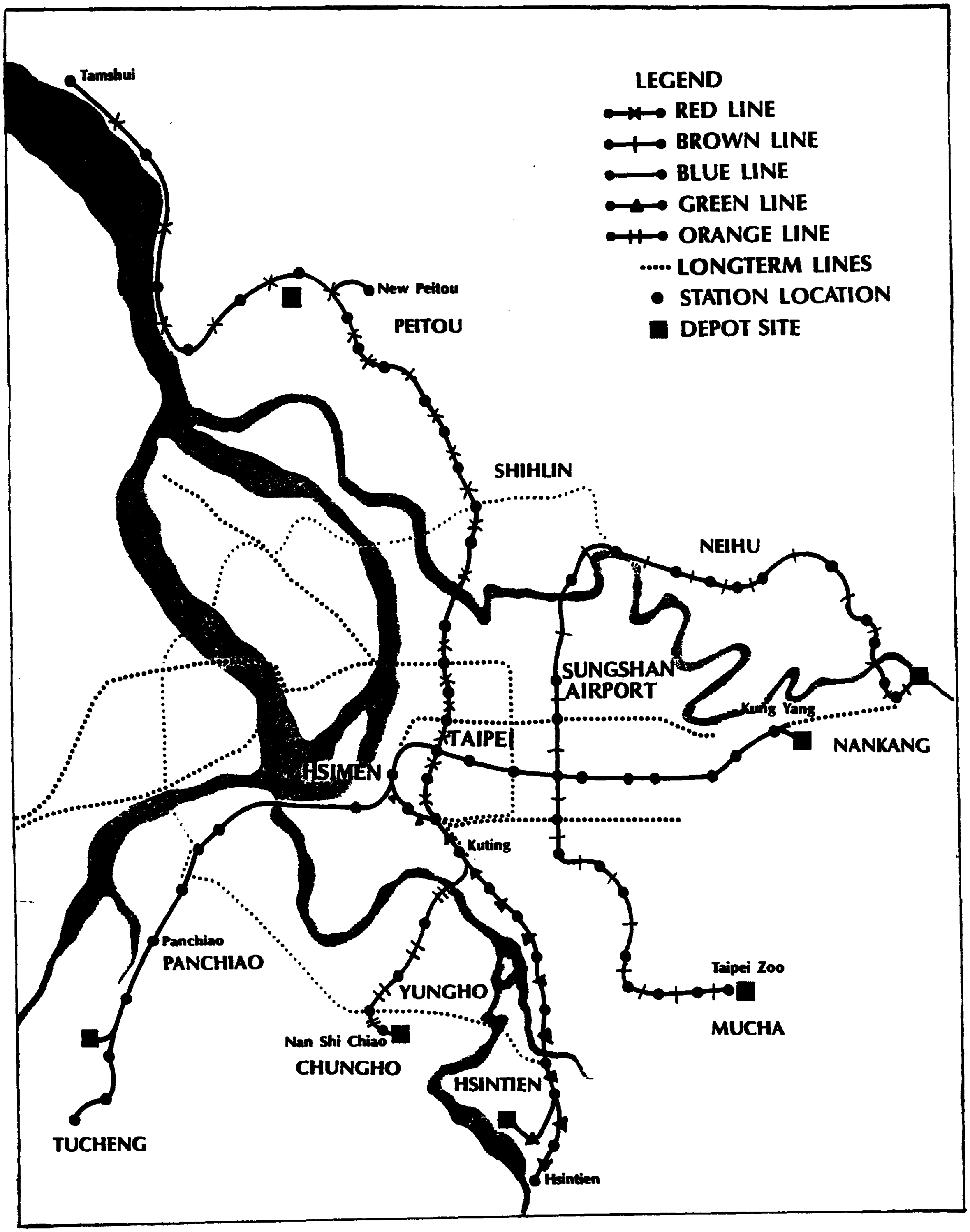


Figure 3.3 The TRTS Network
(Source: DORTS, "the yearly report of TRTS", 1987)

Table 3.3 Geotechnical Bid Packages vs. Total Bid Packages for in the TRTS

Line Name	Total Number of Bid Packages	Geotechnical Bid Packages	%
Mucha	30	7	23
Tamshui	74	8	11
Hsintien	35	12	34
Nankang	40	13	33
Chungho	5	1	20
Neihu	NA	NA	NA
Total	180	41	23

(Neihu Line is still under design and has not yet decided the bid numbers)

Table 3.4 The Geotechnical Bids for Tamshui Line, TRTS

Tamshui Line			
Serial Number	Bid Date	Contractor	Money Amount (NT$)
CT107A	1988,01,08	Jong-He Construction Corp.	232,256,513
CT107B	1989,05,31	Jong-He Construction Corp.	412,550,000
CT201A	1989,07,25	Samsung/Li-Chung/Zublin *	2,632,336,000
CT201C	1989,08,23	R.S.E.A.	1,519,500,000
CT202A	1989,08,23	R.S.E.A.	2,776,000,000
CT202B	1989,09,15	Chinese Construction Corp.	1,565,000,000
CT216A	1990,12,10	Feng-I Construction Corp.	117,000,000

* Joint Venture

Table 3.5 The Geotechnical Bids for Mucha Line, TRTS

Mucha Line			
Serial Number	Bid Date	Contractor	Money Amount (NT$)
CM401	1990,01,04	New Taiwan Foundation Engineering Corp.	383,240,000
CM404	1990,01,23	Tsang-I Construction Corp.	510,000,000
CM405	1988,12,05	Tsang-I Construction Corp.	83,600,000
CM408	1989,12,06	Jong-Li Foundation Engineering Corp.	306,600,000
CM409	1990,02,05	Hon-Ya Construction Corp.	201,000,000
CM411B	1990,03,10	Tong-Fa Construction Corp.	45,000,000
CM412	1989,05,20	Jong-Li Foundation Engineering Corp.	173,500,000

Table 3.6 The Geotechnical Bids for Hsintien Line, TRTS

Hsintien Line			
Serial Number	Bid Date	Contractor	Money Amount (NT$)
CH218	1991,02,23	Fu-Tzu Construction Corp./ Dai-Lin *	2,483,000,000
CH219	1991,07,04	Jeou-Tay Construction Corp.	3,998,800,000
CH220	1991,06,25	Gong-Shin Construction Corp.	2,900,000,000
CH221	1991,05,01	Aoki/ New Asia Construction Corp.	5,578,000,000
CH222	1991,05,18	Tarng-Rong Construction Corp./ M.K.*	3,743,000,000
CH223	1991,01,25	Pan-Asia Construction Corp.	2,367,120,000
CH224	1992,01,14	Aoki/ New Asia Construction Corp.*	3,225,000,000
CH225	1992,04,27	Ju-Jiang Construction Corp.	1,496,800,000
CH226	1992,05,02	Ju-Jiang Construction Corp.	1,436,800,000
CH226A	1991,12,18	Gong-Shin Construction Corp.	267,900,000
CH227	1992,09,15	Chinese Construction Corp.	1,737,000,000
CH228	1992,04,11	Tong-Shun Construction Corp.	1,463,950,000

* Joint Venture

Table 3.7 The Geotechnical Bids for Nankang Line, TRTS

Nankang Line			
Serial Number	Bid date	Contractor	Money Amount(NT$)
CN251	1991,03,04	R.S.E.A.	3,764,000,000
CN252	1991,04,08	R.S.E.A.	6,678,000,000
CN523A	1991,07,31	Wei-Sheng Construction Corp.	3,048,000,000
CN253B	1991,12,18	Pacific /Shimizu Construction Corp.*	3,900,000,000
CN254	1990,12,04	New Asia Construction Corp.	3,848,500,000
CN255	1992,01,17	Fu-Lian-Sheng Construction Corp.	5,280,000,000
CN255A	1994,10,17	Bao-Chyuan Construction Corp.	146,838,000
CN256	1991,05,15	Continental Construction Corp.	2,486,000,000
CN256A	1993,10,06	Chian-Shin Industrial Corp.	86,900,000
CN257	1992,01,31	Pan Asia / Chizaki Construction Corp.*	2,898,000,000
CN258	1991,08,05	Ju-Jiang Construction Corp.	3,977,700,000

* Joint Venture

Table 3.8 The Geotechnical Bids for Chungho Line, TRTS

Chungho Line			
Serial Number	Bid Date	Contractor	Money Amount (NT$)
CC560	1992,05,13	Eastern Constr / Bilfinger+Berger *	18,880,000,000

* Joint Venture

CHAPTER 4

THE DESIGN OF QUESTIONNAIRE AND THE RESULTS OF SURVEY

4.1 Introduction

The first part of this chapter describes the design of the survey questionnaire. The survey subjects, which include contractors, architectural firms, engineering firms, and public sectors, have an overall response rate of 38%. Most of the respondents are medium -to-large-scale companies in Taiwan's construction industry; which provides a fairly accurate representation of the industry as a whole.

The questionnaire is designed to understand the automation technologies currently used in the geotechnical portion of the TRTS. Specifically, the questionnaire examines the advantages and difficulties faced when exploiting construction automation technologies, and what the companies expect of the Taiwanese government. After the discussion of the survey subjects and response rates, section 4.4 describes the questionnaire more specially. Section 4.5 gives a general analysis of the results of the survey. From these results, it appears that Taiwan's construction industry has achieved a certain degree of automation in analysis and design, control and management, and monitoring. The usage of automated construction equipment is also tremendous. However, there are still some difficulties to conquer, such as instability of future work and the lack of a reward system for Taiwanese construction companies. Also, some major expectations, such as reducing taxes and providing technology help by the Taiwanese government, are revealed in this chapter.

4.2 The Survey Subjects

The survey subjects in this questionnaire are those institutions directly involved with the TRTS. The public sectors are represented by the four District Project Offices of the DORTS. The design and planning teams are separated into architectural and engineering firms. The geotechnical contractors who have been awarded bids for the TRTS are also surveyed. The questionnaire is in appendix A.

The objective here is to include all companies and agencies which could provide direct information about the potential and actual use of automation in Taiwan, specifically with respect to the TRTS geotechnical projects.

4.3 Response to the Questionnaire

The first step for the survey was mailing the questionnaire to 50 contractors, 20 architectural firms, 15 engineering firms, and 4 District Project Offices in DORTS. The second step of the survey consisted of contacting the companies which had responded in some way to the previous mailing by telephone and asking each respondent the questions. When necessary, the respondents supplemented their verbal answers with written material sent either by mail or facsimile.

The overall response rate is 38%, which includes 14 contractors, 8 architectural firms, 8 engineering firms, and the 4 Project Offices. While all four Project Offices and over 50% of the engineering firms responded to the survey, only 40% of the architectural firms and 28% of the construction companies participated. Because most of these companies are medium to large firms in Taiwan, the distribution of the samples is fairly representative of the whole industry. Table 4.1 shows the details.

Table 4.1 The Reclamation Rate of Questionnaire

	Possible Interviewee	Actual Reclamation	Reclamation %
Contractor	50	14	28
Architectural	20	8	40
Engineering	15	8	53
Public Sector	4	4	100
Total	89	34	38

4.4 The Essential Points of the Questionnaire

In order to measure the current situation of Taiwan's construction automation technologies in geotechnical engineering, this questionnaire focuses on the following areas. Detailed results are presented in the following section, and comprehensive analyses for the benefit categories are discussed in Chapter 5.

4.4.1 The specific automated technologies currently used in the TRTS

This part of the survey focuses on the current accomplishments of automation in geotechnical engineering in the TRTS. There are four automation categories: analysis and design, project control and management, monitoring, and construction equipment. Also, to understand the degree of automation of these technologies, interviewees were given five different levels to choose: (1) complete automation; (2) system automation; (3) operation automation; (4) partial automation; and (5) no automation. Furthermore, there are five different degrees to which the technologies are needed: (1) needed urgently; (2) needed and developed by the company itself; (3) needed but no economical justification; (4) cooperation with other companies; and (5) no need at all.

4.4.2 The advantages of construction automation

This part of the survey focuses on the perceived benefits to companies when they introduced or developed the automated technologies and examines the incentives of using automation technologies. The categories here are:

a. increase productivity;

b. reduce the project cost;

c. increase project quality;

d. save work labor and time;

e. promote employee's knowledge;

f. increase site safety;

g. reduce environmental pollution;

h. establish the company image;

i. promote competitiveness.

The results will be discussed in section 4.5.2.

In order to understand the feasibility of construction automation in Taiwan, the questionnaire also examines five different alternatives to the degree of benefits for those respondents ranging from no benefits (0) to significant benefits (4) over several years (1993 to estimated 1996). Details will be shown in Chapter 5.

4.4.3 The difficulties when introducing construction automation

The difficulties encountered when introducing automation technologies are examined with respect to two aspects, those encountered inside and outside the firm. The purpose here is to see the barriers for introducing or developing construction automation technologies in Taiwan's construction industry. Inside the firm we have 8 different choices:

a. design activities cannot support the use of automation technologies;

b. regulations or laws;

c. insufficient capital;

d. lack of skilled labor;

e. the instability of future work;

f. no access to relevant information;

g. no international cooperation experience and ability;

h. no priority to negotiate the bid price.

Outside the firm we have 7 different choices:

a. no reward system;

b. no professional construction system;

c. big-contractor system hasn't been established;

d. no construction automation service;

e. no high-level construction automation research institution;

f. project scale is not big enough;

g. difficulties in technologies transfer.

The detail results will be shown in section 4.5.3.

4.4.4 How to introduce construction automation

This part of the survey focuses on how each respondent introduced or developed construction automation. Here are the choices:

a. purchase directly;

b. purchase and research;

c. development by international cooperation;

d. technology transfer from other countries;

e. research by cooperating with domestic institution;

f. no demand.

The results will be shown in section 4.5.4.

4.4.5 The role of Taiwanese government

The government usually plays a critical role in introducing a new technology in Taiwan. This part of the survey examines what the construction companies want the Taiwanese government to do. The choices of the questionnaire are the following:

a. reduce tax and set up investment reward system;

b. capital loan from government;

c. technology help;

d. education improvement;

e. revise the relevant laws;

f. establish construction automation information center;

g. subsidize R&D expenditures;

h. market protection from foreign companies.

The results will be shown in section 4.5.5.

4.5 The Results of Questionnaire

The results are analyzed by sample segment, specifically by separating the government agencies, architectural and engineering firms, and construction companies. These types of institutions all have different roles in the TRTS project and are expected to have differing expectations, incentives, and capabilities with respect to construction automation technologies.

4.5.1 Automation Technologies Currently Used in the TRTS

Four different areas of application of automation technologies were identified. These are analysis and design, project management and control, monitoring, and construction equipment. The firms involved in activities that could employ these technologies were asked explicitly about their use.

a. Analysis and design

AutoCAD release 12 (or 13), Stable 5, and Rido are the most commonly used analysis and design software packages among the architectural and engineering firms in Taiwan according to the survey, as shown in Tables 4.2 and 4.3. In particular, AutoCAD R12 (or 13) is available to all the design companies. Besides this, most of the companies have developed special programs for their own use, which are macros in Microsoft Excel. Generally speaking, the degree of automation in analysis and design for Taiwan's design companies is somewhat between partial automation and operation automation. The demand for these technologies is urgent and the companies can develop the needed technologies themselves.

The high percentage of use of AutoCAD can be attributed mainly to the universal use of computers and the courses provided in high-level education in Taiwan. Most universities or colleges in Taiwan have AutoCAD courses. For civil engineering students, AutoCAD is a core course. Civil engineering graduate students tend to enter architectural and engineering firms rather than construction companies because of the hardships encountered in construction field work. Therefore, AutoCAD has become a popular software package in architectural and engineering firms, while not being widely used in construction companies.

Table 4.2 The Design Automation Technologies in the TRTS

Design	Architectural firms using (% of total firms)	Engineering firms using (% of total firms)	Level of Automation	Degree of Demand
AutoCAD12,13	100	100	P,O	5,4
AutoDESK	63	38	P,O	5,4
MicroStation	63	75	P,O	5,4
GIS	13	25	P,O	3
Other				
None	0	0	NA	NA

P: partial automation, O: operation automation
S: system automation, C: complete automation
5: needed urgently, 4: needed and developed by the company itself,
3: needed but no economical justification, 2: cooperation with other companies
1: no need at all

Table 4.3 The Analysis Automation Technologies in the TRTS

Analysis	Architectural firms using (% of total firms)	Engineering firms using (% of total firms)	Level of Automation	Degree of Demand
Stable 5	13	100	P	5,4
Rido	13	88	P	5,4
Excel Macro	75	100	P	5,4
Other				
None	0	0	NA	NA

P: partial automation, O: operation automation
S: system automation, C: complete automation
5: needed urgently, 4: needed and developed by the company itself,
3: needed but no economical justification, 2: cooperation with other companies
1: no need at all

b. Project control and management

For Taiwan's construction industry, the project management work could be done by contractors themselves instead of the designing firms, but sometimes it still can be done by engineering or architectural companies.

Primavera Project Planner (P3) is the most popular construction management software available in architectural and engineering firms in Taiwan, as shown in Table 4.4. However, according to the survey, the version they use is still a DOS version (5.0) rather than the Windows version which is used in America. It is obvious there would be a time-lag between Taiwan's construction industry and America's because they had to translate the whole system into Chinese.

Most of the contractors use only the simple bar chart and CPM method to control their projects, which means this kind of automation is still not rooted in the contractors' companies. Fortunately, based on P3, some Taiwanese construction companies have developed their own project control software, such as Project Accounting Control System (PACS) for the Retired Serviceman Engineering Agency (R.S.E.A.), and Construction Management Information System (CMIS) for the Chinese Engineering Corporation.

Because the four public offices are all under the command of DORTS, they all use the same management system, which is Project Management Information System (PMIS), a management software developed by DORTS. The concept of this system is outlined in Figure 4.1.

Generally speaking, the level of automation in project control and management for Taiwan's construction industry is somewhat between partial automation and operation automation. The demand is urgent and the technologies can be developed by the companies themselves.

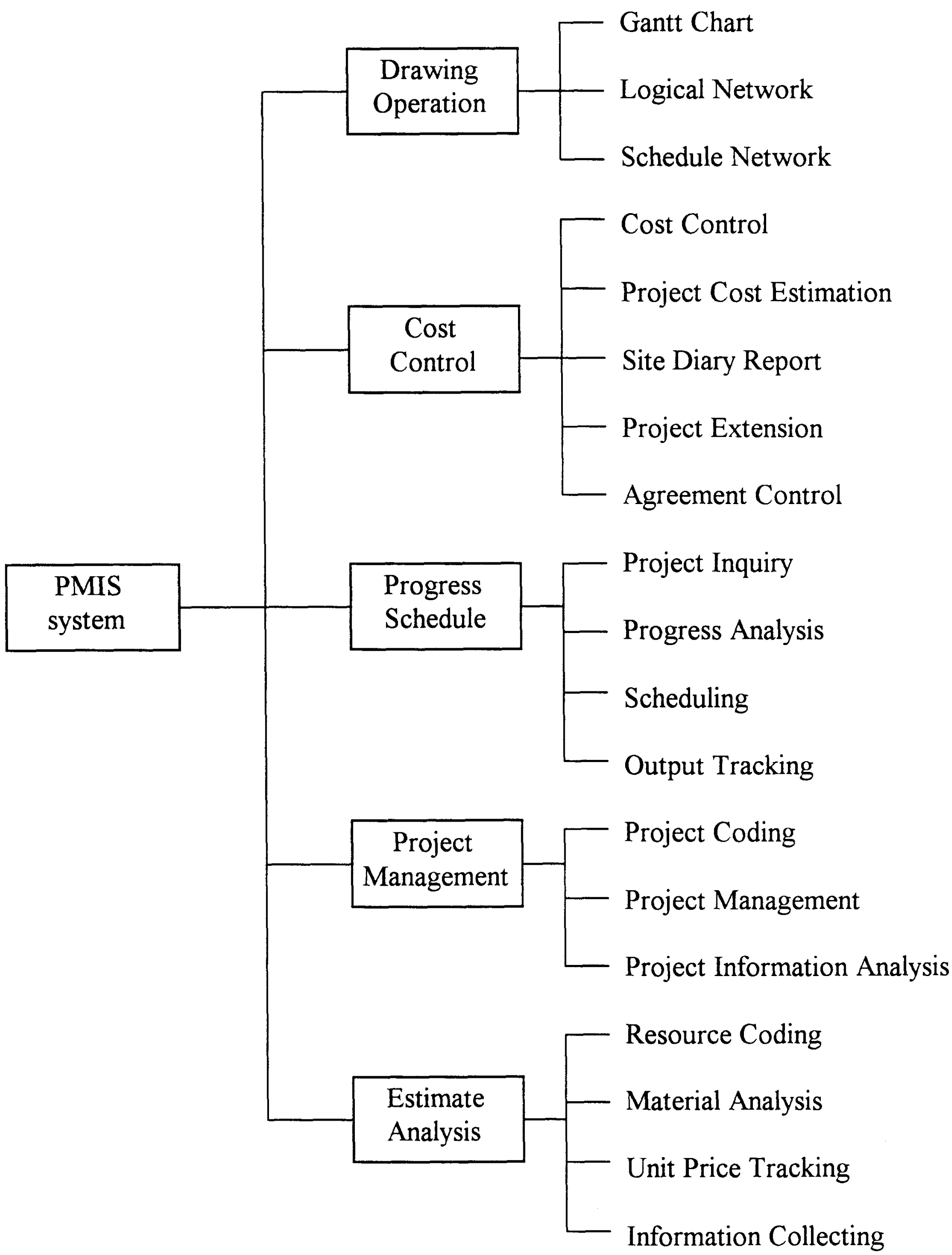


Figure 4.1 The Concept of PMIS

Table 4.4 The Management Automation Technologies in the TRTS

Project Management	Architectural firms using (% of 8 firms)	Engineering firms using (% of 8 firms)	Contractor firms using (% of 14 firms)	Public Sectors (% of 4 offices)	Level of Auto	Degree of Demand
Barchart	100	100	100	100	P	4
CPM(network)	100	100	100	100	P	4
P3(DOS)	75	75	21	0	P,O	4
P3(WIN)	0	0	0	0	O	5
Other	13	0	29	100	O	4
None	0	0	0	0	NA	NA

P: partial automation, O: operation automation
S: system automation, C: complete automation
5: needed urgently, 4: needed and developed by the company itself,
3: needed but no economical justification, 2: cooperation with other companies
1: no need at all

c. Monitoring

The overall purpose of instrumentation and monitoring is to protect structures from damage arising from the construction of TRTS structures. Monitoring is proposed because of the difficulty in predicting the behavior of areas adjacent to construction activities. In general, the instrumentation programs for TRTS are generally similar with differences in detail only. Therefore, we take construction bid numbers CH218 to CH222 of the Hsintien Line as an example to examine the current monitoring system in TRTS. Tables 4.5, 4.6, and 4.7 show the descriptions of monitoring variables and instrumentation of CH218 to CH222. Table 4.8 shows the level of automation and the degree of demand for this instrumentation. It indicates that the level of automation in monitoring systems for Taiwan's construction industry is somewhat between partial automation and operation automation. The demand is urgent and the technologies can be developed by the companies themselves.

Table 4.5 Construction Abstracts of CH218 to CH222, Hsintien Line, TRTS

Construction Bid Number	Unit	CH218	CH219	CH220	CH221	CH222
Station Name		NTU Hospital	CKS Memorial	Kuting	Building of Taiwan Electricity	Gong-Goan
Main Slurry Wall Length	M	260	352	322	251	246
Main Slurry Wall Width	M	1.0-1.2	1.2	1.0-1.2	1.0-1.2	1.0-1.2
Main Slurry Wall Depth	M	30.5	31.5	40	32-34	31.5
Maximum Excavation	M	16	96	135	438	17.5
Cut and Cover Depth	M	NA	24	21	19	NA
Shield Tunnel Length	M	646	502	NA	639	1310

Table 4.6 The Monitoring System Observation Variables and Instrumentation of CH218 to CH222, Hsintien Line, TRTS

Consideration	Extent	Variables	Control	Instrumentation
Construction Safety	Underground Station	Deformation	Slurry Wall	Inclinometer
				Rebar Stress Transducer
				Piezometer
			Supporting System	Strutted Strain Gage
				Strutted Load Cell
			Outside	Surface Settlement Marks
		Water Level	Inside Excavation	Observation Well
				Piezometer
			Outside Excavation	Observation Well
				Piezometer
	Tunnel	Deformation	Tunnel Lining	Convergence Bolts
				Tape Extensometer
				Piezometer
				Pressure Cell
		Water Level	Above Tunnel	Observation Well
				Piezometer
		Settlement		Settlement Indicator
Building Safety	Underground Station	Settlement	Building	Tiltmeter
	Tunnel			Settlement Reference point
				Crack Gage
			Road	Settlement Reference point
				Subsurface Settlement Indicator

Table 4.7 Number of Monitoring Instruments of CH218 to CH222, Hsintien Line, TRTS

Construction Bid	Unit	CH218	CH219	CH220	CH221	CH222
Item & Description		Quantity	Quantity	Quantity	Quantity	Quantity
Instrumentation						
Bench Point	M	46	46	43	210	150
Convergence Bolts	Set	24	27	NA	132	112
Strutted Strain Gage	Set	142	510	402	92	44
Settlement Reference Point(Ground)	Set	70	147	36	180	142
Settlement Reference Point(Concrete)	Set	209	406	253	591	313
Settlement Reference Point(Utility)	Set	NA	NA	NA	24	35
Subsurface Settlement Indicator	Set	256	16	NA	5	1
Tape Extension Meter	Set	NA	NA	NA	NA	56
Inclinometer	M	232	460	575	759	293
Tiltmeter	Set	3	7	16	91	16
Crack Gage	Set	NA	NA	NA	89	20
Strutted Load Gage	Set	NA	NA	NA	37	NA
Rebar Stress Transducer	Set	24	60	85	40	20
Pressure Cell	Set	NA	NA	NA	48	NA
Concrete Strain Gage	Set	NA	NA	NA	80	NA
Piezometer(Slurry Wall)	Set	4	24	9	38	7
Piezometer(Tunnel)	Set	NA	NA	NA	20	NA
Observation Well	M	NA	NA	NA	185	18
Piezometer(subsurface)	M	417	416	519	398	75

Table 4.8 Classification of Instrumentation

Instrumentation	Level of Automation	Degree of Demand
Inclinometer	O	4
Rebar Stress Transducer	O	4
Piezometer	P	4
Strutted Strain Gage	O	4
Strutted Load Cell	O	4
Surface Settlement Marks	P	4
Observation Well	P	4
Convergence Bolts	O	4
Tape Extensometer	O	4
Pressure Cell	O	4
Settlement Indicator	P,O	4
Tiltmeter	O	4
Settlement Reference point	P	4
Crack Gage	O	4
Subsurface Settlement Indicator	P,O	4

P: partial automation, O: operation automation
S: system automation, C: complete automation
5: needed urgently, 4: needed and developed by the company itself,
3: needed but no economical justification, 2: cooperation with other companies
1: no need at all

d. Equipment

In the TRTS, the construction equipment can be selected solely by the contractors. While designers or public agencies may give suggestions on construction methods and equipment, the contractors yet have full freedom to choose the equipment appropriate for their firm that can still meet the contract requirements.

Generally, the two different construction methods for the geotechnical engineering work in the TRTS are the open-cut-and-cover method and the shield machine tunneling method. Sometimes a newly introduced method, the New Austrian Tunneling Method (NATM), is also used in the TRTS.

The shield machine is the most common tunnelling technology in the TRTS because of its lesser impact on Taipei's traffic, its lower pollution during construction process, and safety considerations. The TBM, which was also expected to be used in the TRTS, was not found during this survey. This may be due to the differences in soil conditions encountered in the Taipei basin. The majority of the TRTS tunnelling consists of soft soil where the shield machine works well, not hard rock where the TBM works well. Table 4.9 shows the types and manufacture firms of shield machines used in the TRTS. From that table, it is obvious that the earth pressure balance shield machines are the main type, and Japanese and German firms provide most of the shield machines in Taiwan.

Besides the main body of the shield machine, some auxiliary equipment in the shield machine tunneling method includes units such as the portal crane, locomotives for tunneling, the segment carriage device, the oil hydraulic jack, the shuttle train (trolley cars), and the screw conveyor. Because all shield machine systems are very much alike with only minor differences by manufacturer, this research focuses on a typical one for exhibition. Table 4.10 shows the detailed information of this auxiliary equipment in CH223, TRTS.

Because of the wide range of other geotechnical equipment, this research took one bid in the TRTS to display the typical equipment used in Taiwan's geotechnical engineering projects. Table 4.11 shows the equipment and manufacturer firms used in the typical geotechnical engineering work in CP261, TRTS.

According to this survey, it appears that almost every large geotechnical machine in the TRTS was imported from a foreign company, which means that such technologies in Taiwan are still dependent on developed countries. Therefore, skill transfer and purchasing (leasing) cost will be important issues for Taiwan's contractors. However, since these high-technology machines have all been developed or used for a certain time, it seems more economical and conservative for Taiwan's contractors to purchase or lease such equipment directly from other advanced foreign companies instead of developing these technologies by themselves.

Table 4.9 Shield Machines used in the TRTS

Bid Number	Machine Type	Manufacturer	Country
CT201	Earth pressure balance	HerrenkNecht	Germany
CH218	Earth pressure balance	Mitsubishi	Japan
CH219	Earth pressure balance	IHI	Japan
CH221	Dredging	Komatsu	Japan
CH222	Earth pressure balance	LOVAT	Canada
CH223	Earth pressure balance	Hitachi	Japan
CH224	Earth pressure balance	Kawasaki	Japan
CN251	Earth pressure balance	Aumura	Japan
CN253A	Earth pressure balance	Hitachi	Japan
CN253B	Earth pressure balance	Hitachi	Japan
CN254	Earth pressure balance	Hitachi	Japan
CN256	Earth pressure balance	Mitsubishi	Japan
CN257	Earth pressure balance	Hitachi	Japan
CN258	Earth pressure balance	LOVAT	Canada
CP261	Earth pressure balance	Mitsubishi	Japan
CP262	Earth pressure balance	Kawasaki	Japan
CP263	Earth pressure balance	Komatsu	Japan
CP264	Earth pressure balance	HerrenkNecht	Germany
CC275	Earth pressure balance	HerrenkNecht	Germany
CC276	Earth pressure balance	HerrenkNecht	Germany
CC277	Earth pressure balance	HerrenkNecht	Germany

Table 4.10 Specifications of Mechanical Equipment for Shield Machine, CH223, TRTS

(1) Dimensions of Shield Body

Outside Diameter		6040mm
Inside Diameter		5950 mm
Tail Clearance		25 mm
Overall Length (Length of screw conveyor and center plate are not include)		7100 mm
Tail Plate	Thickness	45 mm
	Material	Mild steel JIS SS-440
Tail Sealing	Type	Wire brush
	Quantity of fitting steps	3
Dividing Quantity		6

(2) Propulsion Equipment

Shield Jack Elongation Speed (at whole number actuation)	5.0 cm/min
Equipped Thrust Force per Unit Area of Facing	115.2 tf/m^2
Total Thrust	300 tf

(3) Cutter Equipment

Support Type		Intermediate Support
Driving Type		Oil Hydraulic Motor Driving
Equipped Torque	Ordinary Torque	375 tf-m at 140 kgf/cm^2 (a=1.7)
	Maximum Torque	562 tf-m at 210 kgf/cm^2 (a=2.6)
Numbers of Revolutions	Ordinary Torque	0.95 r.p.m.
	Maximum Torque	0.63r.p.m.
Overcut Equipment	Type	Oil Hydraulic Jack Type Copy Cutter
	Equipped Quantity	1
	Overcut Amount	100 mm

Table 4.10 Continued

(4) Attitude Control Equipment

Wire Tractional Bracket	Type	Fixing
	Attaching Position	Tail
	Quantity	4
Resisting Plate	Type	NA
	Attaching Position	NA
	Quantity	NA
Sled	Type	NA
	Attaching Position	NA
	Quantity	NA

(5) Screw Conveyor

Type	Ribbon Screw
Capacity	0 ~ 135 m^3/h
Driving Type	Oil Hydraulic Motor Driving
Equipped Torque	8.6 tf-m
Rotational Speed	0 ~ 10 r.p.m.

(6) Rotary Discharger

Capacity	0 ~ 250 m^3/h
Driving Type	Oil Hydraulic Motor Driving
Equipped Torque	4.4 tf-m
Rotational Speed	0 ~ 5 r.p.m.

(7) Erector System

Type	Ring Type
Number of Revolutions	0 ~ 1.0 r.p.m.
Hanging - up Force	8.9 tf
Pushing Force	13.0 tf
Grip Slide Movement	+550, -100 mm
Rotary Angle	Clockwise and Counterclockwise 210^0

Table 4.10 Continued

(8) Segment Reforming Device

Type	Upper and Lower Expansion
Expansion Force	33 tf
Traveling Stroke	1100 mm

(9) Power Unit

(9a) Oil Hydraulic Pump

Application	Type	Discharge Amount (l/min)	Operating Pressure (kgf/cm2)	Quantity
Shield	Plunger Pump	48	350	1
Cutter	Plunger Pump	260 / 173	140 / 210	7
Screw	Plunger Pump	129	210	2
Rotary Discharger	Plunger Pump	66	210	1
Copy Cutter	Gear Pump	24	210	1

(9b) Electric Motor

Application	Output (kw)	Number of Poles	Voltage * Frequency (V*Hz)	Quantity
Shield	37	4	440,60	1
Cutter	75	4	440,60	7
Screw	55	4	440,60	2
Rotary Discharger	30	4	440,60	1
Copy Cutter	11	4	440,60	1

(10) Oil Hydraulic Motor

Application	Output Axle Torque (kgf-m)	Operating Pressure (kgf/cm^2)	Quantity
Cutter	4233 / 6350	140 / 210	10
Screw	624	210	2
Rotary Discharger	861	210	1
Erector	449	210	2

Table 4.10 Continued

(11) Oil Hydraulic Jack

Name	Thrust (tf)	Stroke (mm)	Operating Pressure (kgf/cm^2)	Quantity	Total Thrust (tf)
Shield Jack	150	1500	350	22	3300
Copy Cutter Jack	16.5	100	210	1	16.5
Gate Jack	7	550	140	1	7
Erector Lift Jack	6.5	600	210	2	13
Erector Slide Jack	6.5	650	210	1	6.5
Erector Expansion Jack	11	250	140	2	22
Erector Support Jack	3.5	150	70	2	7
Segment Travel Jack	7	1100	140	2	14
Segment Lift Jack	16.5	600	210	2	33

(12) Trolley Cars

Name	Dimension (mm) (Width/ Height/ Length)	Quantity	Setting Equipment
No.1 Trolley Car	4600 / 2850 / 5500	1	Operating Panel
			Power Unit
No.2 Trolley Car	4600 / 2850 / 6000	1	Power Unit
No.3 Trolley Car	4600 / 2850 / 4000	1	Control Panel
			Transformer (50+5kVA)
			Grease Pump
No.4 Trolley Car	4600 / 2850 / 4000	1	Transformer (900kVA)

(13) Segment Carriage Device

Length		15.25 m
Lifting Load		1.5 tf * 2 pc
Speed	Lifter	10.7 m/min
	Carrier	15.6 m/min
Electric Motor	Lifter	3kW * 4P * 220V * 2pc
	Carrier	3.7kW * 4P * 220V * 1pc

Table 4.10 Continued

(14) Segment Carriage Device for Temporary Excavation

Length		7.5 m
Lifting Load		1.5 tf * 2 pc
Speed	Lifter	10.7 m/min
Electric Motor	Lifter	3kW * 4P * 220V * 2pc

(15) Belt Conveyor

Length		24 m
Theoretical Capacity		135 m^3/h
Belt	Width	900 mm
	Speed	80 m/min
Electric Motor	Lifter	22kW * 4P * 220V * 1pc

Table 4.11 Geotechnical Equipment used in CP261, TRTS

Function	Equipment	Type or Firm
Pin Pile	80 ~ 100 HP Vibrating Pile Driver	Chido CT-20
	35 T Crane	Tadano
Ground Treatment	High Pressure Jet Pump	C.C.P. International T10-450
	High Pressure Pile Driller	ATLAS Copco
	Automatic Mixer	C.C.P. International MP-3800
Slurry Wall	M.H.L. Excavator	Masago 80120
	80 T Crawled Crane	Hitachi KH-300
Concrete Placing Boom	Concrete Pumps	Putzmelster BSF 2115
	Agitators	MVE-RM, MVE-RF, MVE-FS
Jet Grouting	Pumps	Klaus Obermann Gnbh MD100-2S
	Automatic Tracted Driller	IMI M30B
	Backhoe	Komatsu pc 120-400
	Swing	Swing Jet

4.5.2 Advantages

Table 4.12 shows the results of the survey related to perceived advantages of construction automation. The responses are separated by types of company. Figure 4.2 displays the proportion for the whole sample. Over three quarters of the companies (76%) selected category (c) increase project quality and (d) save work labor and time as important advantages of construction automation. In addition, 65% selected category (a) increase productivity. It shows that these three items are the major benefits for those companies exploiting construction automation. In fact, these items are on the top three list of each respondent type except for contractors, where a smaller proportion identifies it. Figure 4.3 displays the results of the survey question by type of company.

For contractors, the most significant benefits in using construction automation are to increase project quality, save work labor and time, and promote employee's knowledge. It is reasonable that the incentives for contractors to introduce construction automation are generally for saving work labor and time and increasing quality. It is surprising, however, that the categories of (b) reduce the project cost and (a) increase productivity are chosen by less than 50% of contractors. This lower response is probably due to the huge initial investment and complex learning process of construction automation.

For architectural and engineering firms, every category is chosen by more than 50% of firms except categories (f) increase site safety and (g) reduce environmental pollution. Since most employee of these companies only work in offices, these impacts of automation would not be expected to be strong. The respondents for architectural and engineering firms seem to have a large number of benefits in general, which would explain why they are viewed as the most effective agencies for exploiting construction automation in Taiwan.

The four public agencies have fairly consistent responses. At least 2 public agencies marked benefits in each category. It is unclear, however, whether these benefits are perceived with respect to their own use of automation technologies or with respect to their role in promoting construction automation on the TRTS and the industry as a whole.

Table 4.12 Results: Advantages

	C	%	A	%	E	%	P	%	total	%
a. increase productivity	6	43	6	75	6	75	4	100	22	65
b. reduce the project cost	5	36	4	50	6	75	3	75	18	53
c. increase project quality	8	57	7	88	7	88	4	100	26	76
d. save work labor and time	9	64	7	88	6	75	4	100	26	76
e. promote employee's knowledge	7	50	5	63	4	50	3	75	19	56
f. increase site safety	4	29	1	13	1	13	2	50	8	24
g. reduce environmental pollution	4	29	1	13	1	13	2	50	8	24
h. establish the company image	3	21	4	50	5	63	3	75	15	44
i. promote competitiveness	5	36	5	63	6	75	2	50	18	53
Total number of firms	14		8		8		4		34	

C: Contractor A: Architectural firm E: Engineering firm P: Public agencies
* Percentages calculated of number of responses from total relevant number of firms

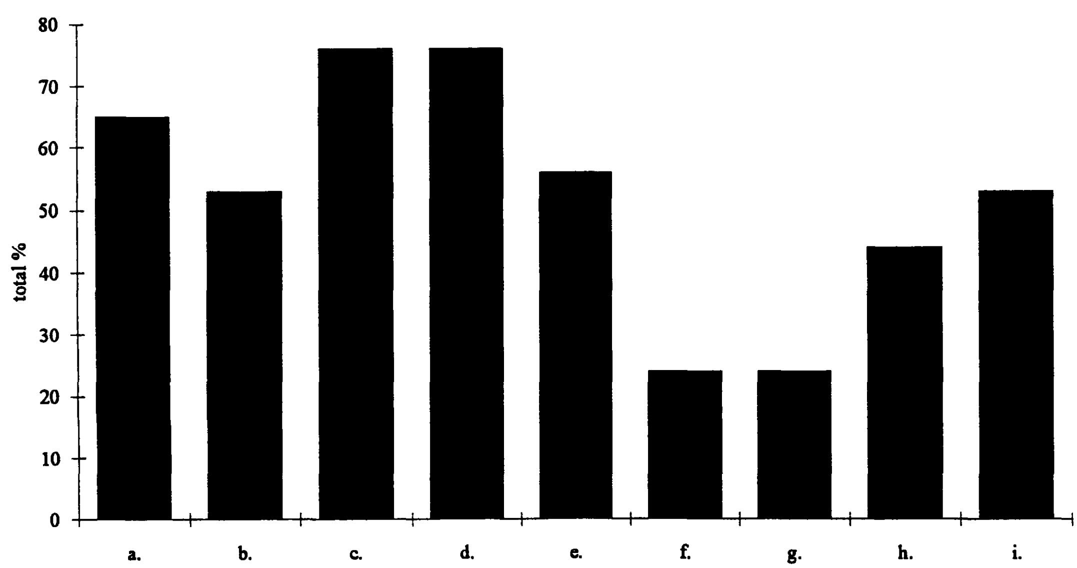


Figure 4.2 Results: Advantages -- All firms

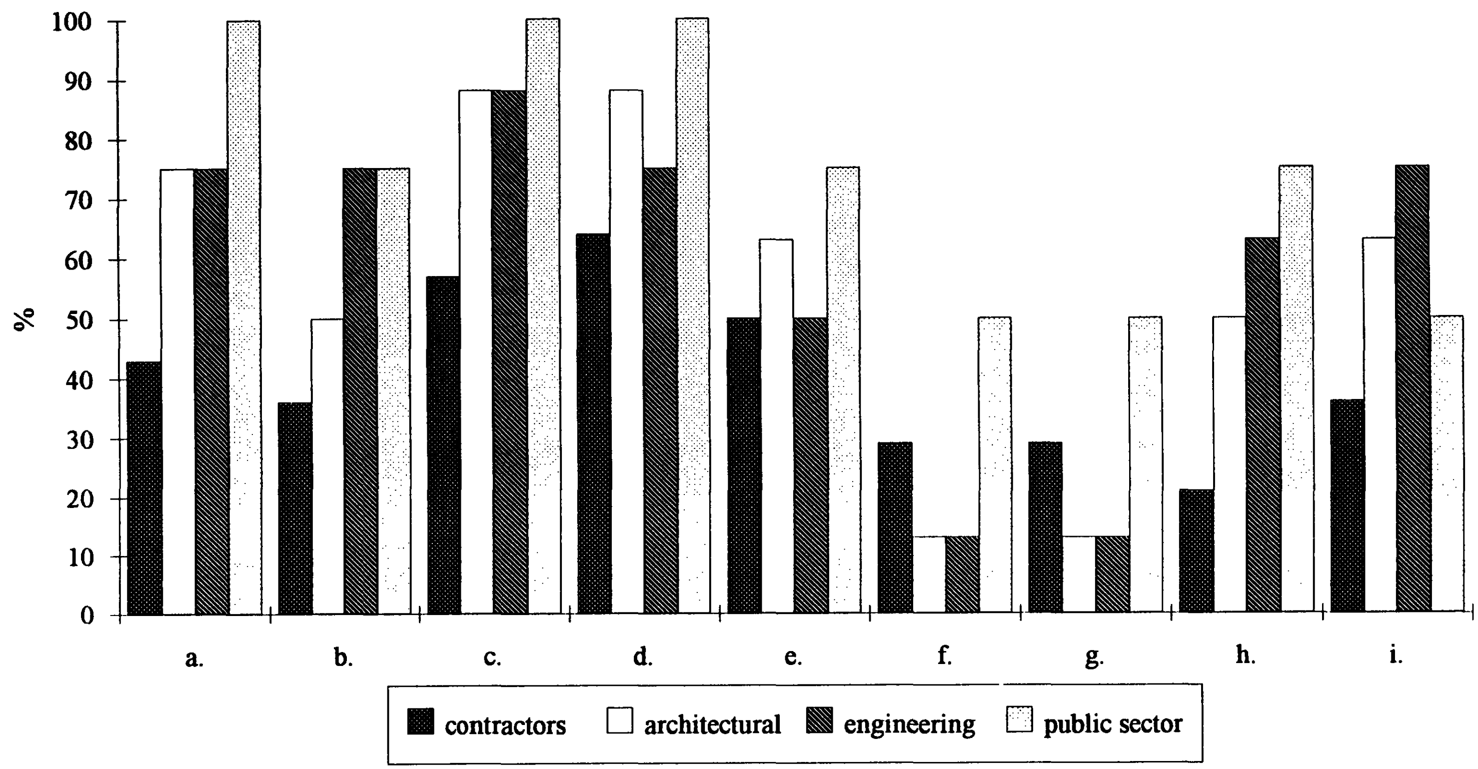


Figure 4.3   Results: Advantages -- By type of firm

4.5.3 Difficulties

This survey is divided into two parts: one is the difficulties inside the firm; the other is the difficulties outside the firm.

Table 4.13 shows the results of the survey related to perceived difficulties inside the firm due to automation technologies, separated by the type of company. Figure 4.4 displays the proportion of the whole sample which chose each category of difficulties. Among these responses, category (e) the instability of future work is the most significant factor considered by the most firms (56%), while the second one is (d) lack of skilled labor (50%). Both (c) insufficient capital and (g) no international cooperation experience and ability were identified by 47% of the companies. It shows that these four items are the major difficulties inside the firms when they introducing or exploiting construction automation.

The difficulties encountered within the firms differed markedly by type of company (Figure 4.5). For contractors, categories (e) the instability of future work (64%), (g) no international cooperation experience and ability (57%), and (d) lack of skilled labor (50%) are the most significant difficulties inside the firms for exploiting construction automation. It indicates that contractors are most concerned about the future work since the new automation technologies could be useless if there is no future work, and that would be a huge consideration for contractors. Also, lack of skilled labor and no international cooperation experience and ability are chose by over 50% contractors. This is probably because most of the construction automation technologies are directly purchased from overseas or through technology cooperation with foreign companies, therefore skilled labor and international cooperation experience are important for Taiwanese contractors. Only about 43% of contractors chose category (c) insufficient capital, so it appears that a majority of Taiwanese contractors interviewed are willing to put money into high initial investment construction automation technologies and most of them can afford it.

For architectural and engineering firms, it is expected that their experiences would be similar. However, only for (e) instability of future work do they both exceed 50%, which means they also fear the instability of the future market. More importantly, the

Table 4.13 Results: Difficulties in Introduction -- inside the firm

	C	%	A	%	E	%	P	%	total	%
a. design activities can not support the use of the automation technologies	6	43	0	0	0	0	2	50	8	24
b. regulation or laws	4	29	2	25	1	13	2	50	9	26
c. insufficient capital	6	43	6	75	3	38	1	25	16	47
d. lack of skilled labor	7	50	5	63	2	25	3	75	17	50
e. the instability of future work	9	64	4	50	5	63	1	25	19	56
f. no access to relevant information	3	21	2	25	3	38	1	25	9	26
g. no international cooperation experience and ability	8	57	3	38	2	25	3	75	16	47
h. no priority to negotiate the bid price	6	43	2	25	0	0	2	50	10	29
Total number of firms	14		8		8		4		34	

C: Contractor A: Architectural firm E: Engineering firm P: Public agencies
* Percentages calculated of number of responses from total relevant number of firms

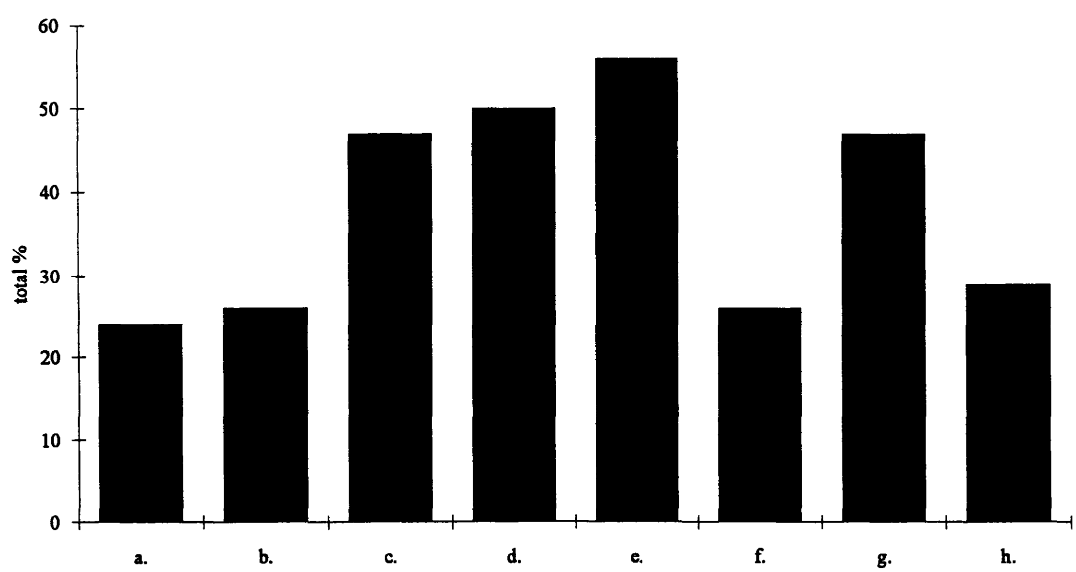


Figure 4.4 Results: Difficulties in Introduction inside the firm -- All firms

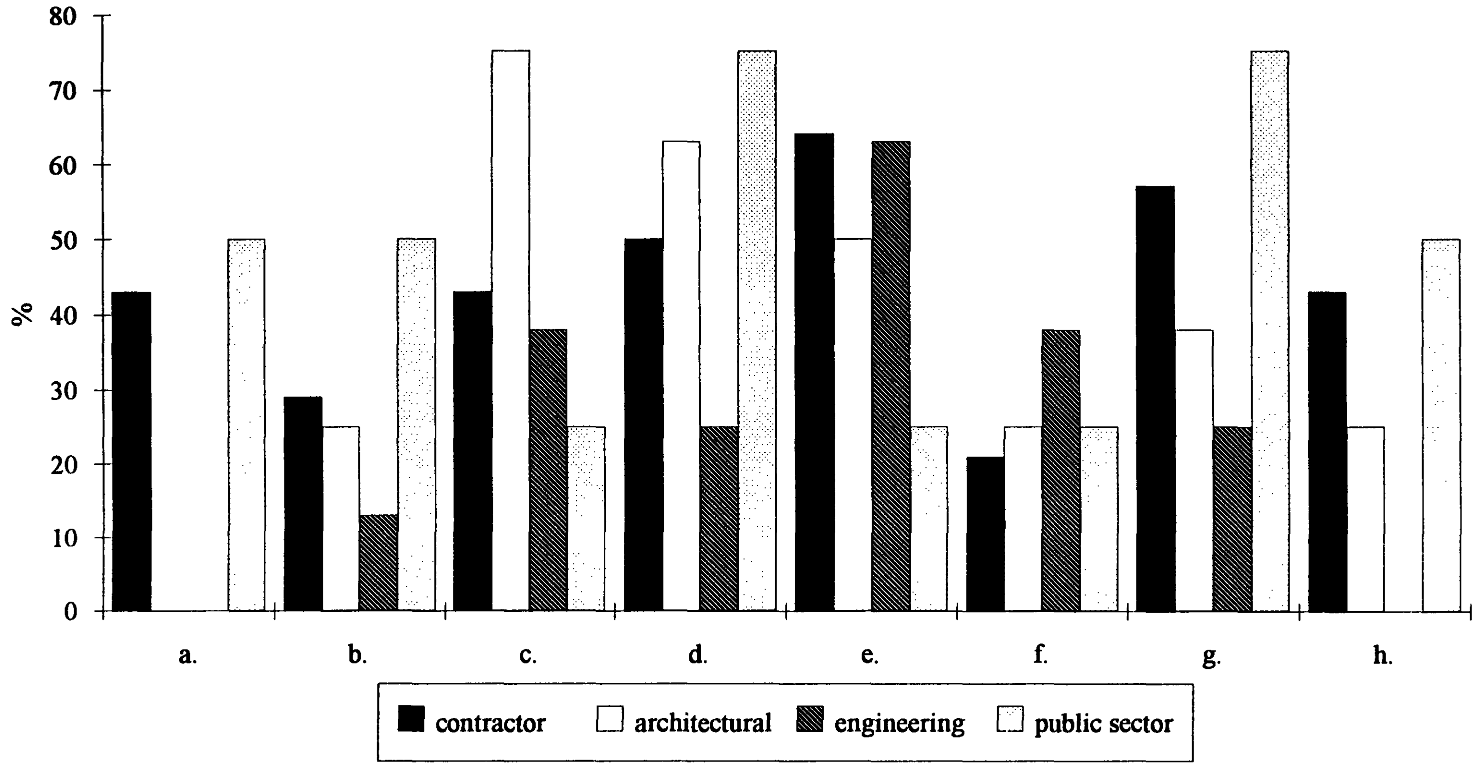


Figure 4.5 Results: Difficulties in Introduction inside the firm -- By type of firm

majority of architectural firms have difficulties with (c) insufficient capital (75%) and (d) lack of skilled labor(63%), which probably can be explained by little high-level architectural education in Taiwan compared to engineering education. With little skilled labor, architectural firms have to buy the new technologies which sometimes can be developed by themselves. Engineering firms seem not to have too much difficulty for exploiting construction automation since less than 40% of the interviewed firms experienced difficulties other than the instability of future work.

For public agencies, obviously, the instability of future work is not a significant factor. Instead, they care about international cooperation experience (75%) and skilled labor (75%), which are concerns for contractors, since they have a closer identity to field activities, which lead them to consider the exploitation of construction automation from the same point of view.

Table 4.14 shows the results of the survey related to the difficulties encountered outside the firm. Figure 4.6 displays the proportion of the survey which chose each category. Among these responses, category (e) no high-level construction automation research institution is cited by 53% of the companies, followed by (a) no reward system (50%). It shows that these two items are the major difficulties outside the firms when they introduce or exploit construction automation technologies.

Figure 4.7 displays the results of the percentage of companies for each type, which shows a fairly consistent result compared to the whole sample. For contractors, category (a) no reward system is chose by 71% of the contractors, which is far ahead of other categories of difficulties. It is perceived that Taiwanese contractors really need some incentive for exploiting construction automation. This result corresponds to the result in section 4.5.5 which shows that contractors expect the Taiwanese government to give them some incentives, such as a tax credit, capital loan, and reward systems for using construction automation technologies. Other categories seem not to have much influence, although category (b) no professional construction system was cited by 43% of the companies.

Table 4.14 Results: Difficulties in Introduction -- outside the firm

	C	%	A	%	E	%	P	%	total	%
a. no reward system	10	71	2	25	2	25	3	75	17	50
b. no professional construction system	6	43	1	13	2	25	2	50	11	32
c. big-contractor system hasn't been established	5	36	1	13	1	13	4	100	11	32
d. no construction automation service	3	21	3	38	4	50	1	25	11	32
e. no high-level construction automation research institutions	5	36	4	50	7	88	2	50	18	53
f. project scale is not big enough	5	36	0	0	1	13	1	25	7	21
g. difficulties in skill transfer	4	29	1	13	2	25	2	50	9	26
Total number of firms	14		8		8		4		34	

C: Contractor A: Architectural firm E: Engineering firm P: Public agencies
* Percentages calculated of number of responses from total relevant number of firms

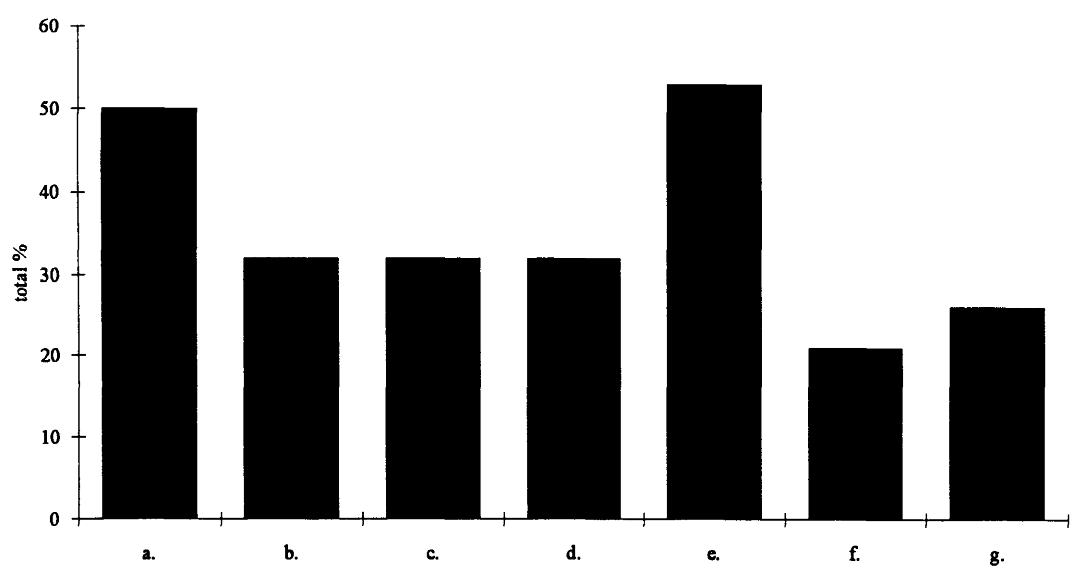


Figure 4.6 Results: Difficulties in Introduction outside the firm -- All firms

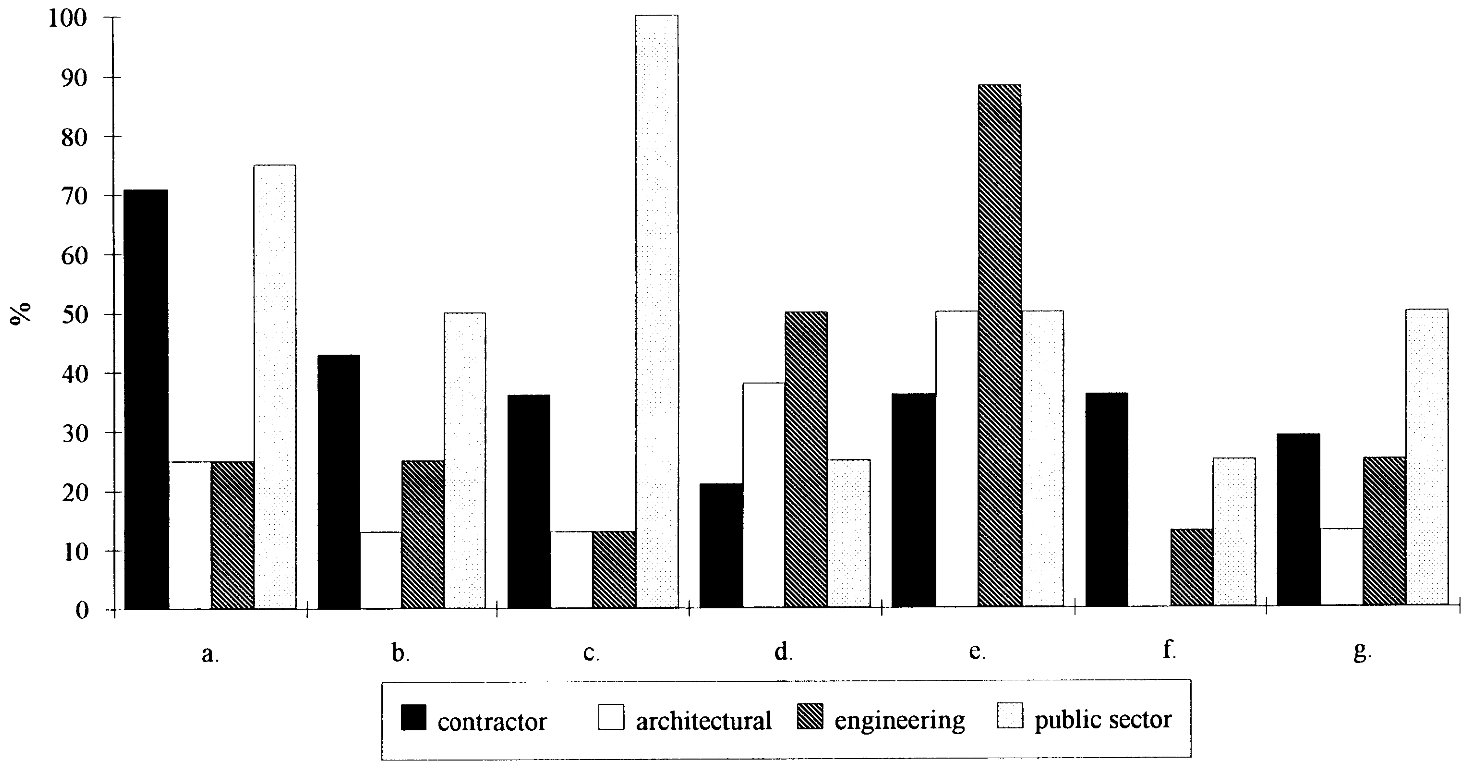


Figure 4.7 Results: Difficulties in Introduction outside the firm -- By type of firm

For architectural and engineering firms, what they are most concerned with are (e) no high-level construction automation research institution (50% and 88% respectively) and (d) no construction automation service (38% and 50% respectively). These aspects are already identified as problems in Taiwan. The Taiwan Industrial Technologies Research Institution, which is the largest automation research institution funded by the Taiwanese government, researches and develops many automation technologies every year, but the focus is primarily for the manufacturing industries. Construction design firms also show an urgency for such services.

For public agencies, categories (c) big-contractor system hasn't been established (100%) and (a) no reward systems (75%) are the two main difficulties faced when exploiting construction automation. From their point of view, a big contractor has large amounts of financing, high technology abilities, and a good reputation. If they can work with such contractors, construction automation is easily implemented. They are also concerned about the reward system, which is important for contractors.

4.5.4 Means of Introduction

Table 4.15 shows the results of the survey on how each company introduced construction automation. Figure 4.8 displays the proportion of the sample which chose each mode of introduction. The results indicates that categories (a) purchase directly and (c) development by international cooperation are chosen by the most companies (both 26% of the companies). It shows that these two items are the major ways for companies to introduce construction automation in general.

However, the individual data of four different construction team show very divergent results (Figure 4.9). For contractors, they want to purchase the automation technologies directly, which is the easiest way to introduce construction automation. Only about 21% of contractors introduce construction automation by international cooperation and technology transfer from other countries. These results are reasonable because they

Table 4.15 Results: Means of Introduction

	C	%	A	%	E	%	P	%	total	%
a. purchase directly	5	36	1	13	2	25	1	25	9	26
b. purchase & research	2	14	2	25	2	25	2	50	8	24
c. development by international cooperation	3	21	2	25	2	25	2	50	9	26
d. technology transfer from other countries	3	21	2	25	2	25	1	25	8	24
e. research by cooperating with domestic institutions	2	14	1	13	0	0	3	75	6	18
f. no demand	1	7	1	13	1	13	0	0	3	9
Total number of firms	14		8		8		4		34	

C: Contractor A: Architectural firm E: Engineering firm P: Public agencies
* Percentages calculated of number of responses from total relevant number of firms

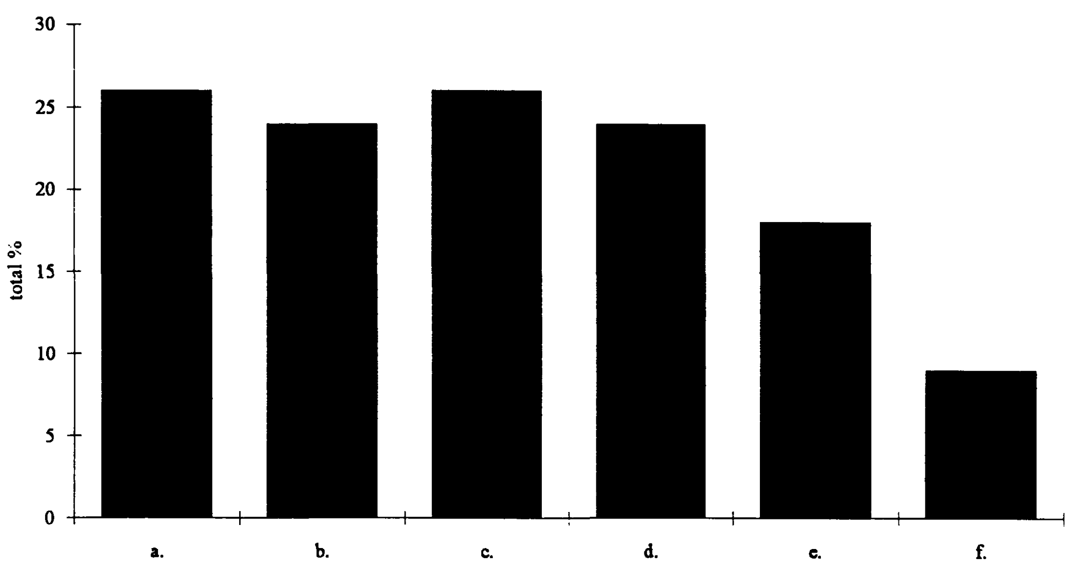


Figure 4.8 Results: Means of Introduction -- All firms

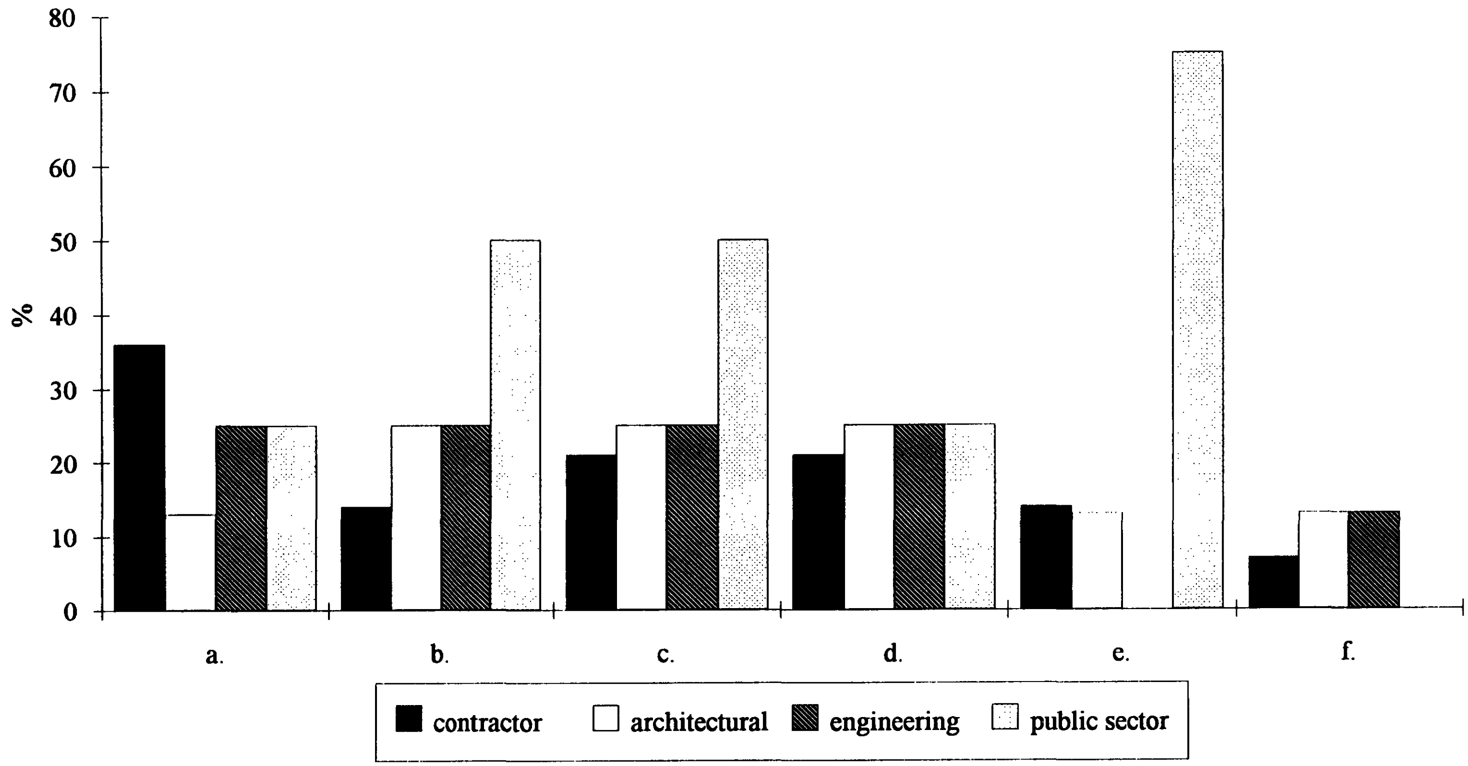


Figure 4.9 Results: Means of Introduction -- By type of firm

correspond to the results in section 4.5.3, which shows that the difficulties for introducing construction automation inside the firm for contractors are the lack of skilled labor and lack of experience in international cooperation. Therefore, directly purchasing is the effective way for Taiwanese contractors to introduce construction automation.

For architectural and engineering firms, the result doesn't have strong indications of how they introduce construction automation. Probably because of the prosperity of computer industry in Taiwan for recent years, the automation technologies related to computers can be developed by those firms.

For public agencies, they want the automation technologies can be researched and developed in Taiwan, therefore, (b) purchase and research (50%), (c) development by international cooperation (50%), and (e) research by cooperating with domestic institution (75%) are the most interesting categories for public agencies.

4.5.5 Expectations to Taiwanese Government

Table 4.16 shows the results of the survey with respect to the expectations of the Taiwanese government in encouraging construction automation. Figure 4.10 displays the proportion of the sample which chose each category. The results show that (a) reduce tax and set up investment reward system is the most significant expectation by the most companies (65%). Two other categories, (c) technology help (44%) and (f) establish construction automation information center (41%), are also chosen by many companies. The results show that these three items are the major expectations of companies for the Taiwanese government to perform to encourage exploitation of construction automation. Furthermore, category (a) was chosen by over 50% companies for each type of construction company, probably because reward and tax credit are the most welcomed steps in reducing the cost.

Figure 4.11 displays the results by type of company and reveals each type's favorite expectations. For contractors, the actions of reducing taxes and setting up investment reward systems (71%), capital loans from government (50%), and technology help (50%) are the expectations from the majority of companies. From section 4.5.3, the difficulties encountered outside the firms, we can anticipate that those three items would be the major expectations for contractors. Other categories such as revise the relevant laws and subsidy the R&D expenditures are also expected by contractors.

For architectural and engineering firms, they show different expectations of the Taiwanese government. Categories (f) establish construction automation information center (63%), (a) reduce tax and set up investment reward system (63%), and (d) education improvement (50%) are the architectural firms' major expectations. This corresponds to the difficulties inside and outside the firms for architects, which are insufficient capital, lack of skilled labor, and the need for research institution. Almost two thirds of the engineering firms (63%) hope that the Taiwanese government can provide technology help, which is a step to a highly automated industry. It also corresponds to their difficulties outside the firm, which are the needs of a research institution and a construction automation service.

For the public agencies, their expectations seem to correspond to those of private firms. They perceived a need for tax credit and reward systems, the construction information center, technology help, and education improvement.

4.6 Summary

Based on this research, the advanced construction technologies and equipment in Taiwan are mostly imported from abroad to meet urgent requirements. Although the general level of construction automation is regarded as high and the perceived advantages are tremendous, there are still many problems which construction companies face during the process of exploiting construction automation technologies. The instability of future work and the lack of reward systems are the most serious constraints that Taiwan's construction industry currently perceives. It appears that available financing is another important issue. The lack of a high-level construction automation research institution is also identified as a serious problem for Taiwan's construction industry, which can lead to a lowered willingness to invest in research and development, and may induce the purchase of automation technologies from abroad. Therefore, the expectations of Taiwan's construction industry towards the Taiwanese government focus on several incentives, such as a tax credit, reward system, and technology help, which can assist them immediately.

Table 4.16 Results: Expectations to the Taiwanese Government)

	C	%	A	%	E	%	P	%	total	%
a. reduce tax & set up investment reward system	10	71	5	63	4	50	3	75	22	65
b. capital loan from government	7	50	3	38	1	13	1	25	12	35
c. technology help	7	50	1	13	5	63	2	50	15	44
d. education improvement	3	21	4	50	3	38	2	50	12	35
e. revise the relevant laws	6	43	2	25	2	25	1	25	11	32
f. establish CA information center	3	21	5	63	3	38	3	75	14	41
g. subsidy R&D expenditures	6	43	2	25	1	13	1	25	10	29
h. market protection against foreign companies	3	21	2	25	2	25	1	25	8	24
Total number of firms	14		8		8		4		34	

C: Contractor A: Architectural firm E: Engineering firm P: Public agencies
* Percentages calculated of number of responses from total relevant number of firms

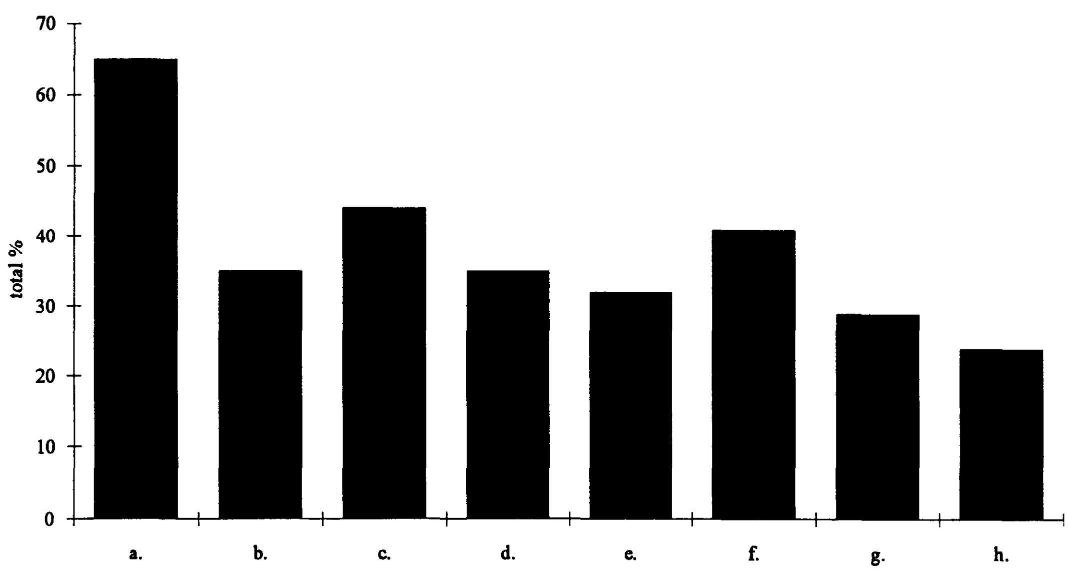


Figure 4.10 Results: Expectations to the Taiwanese Government -- All firms

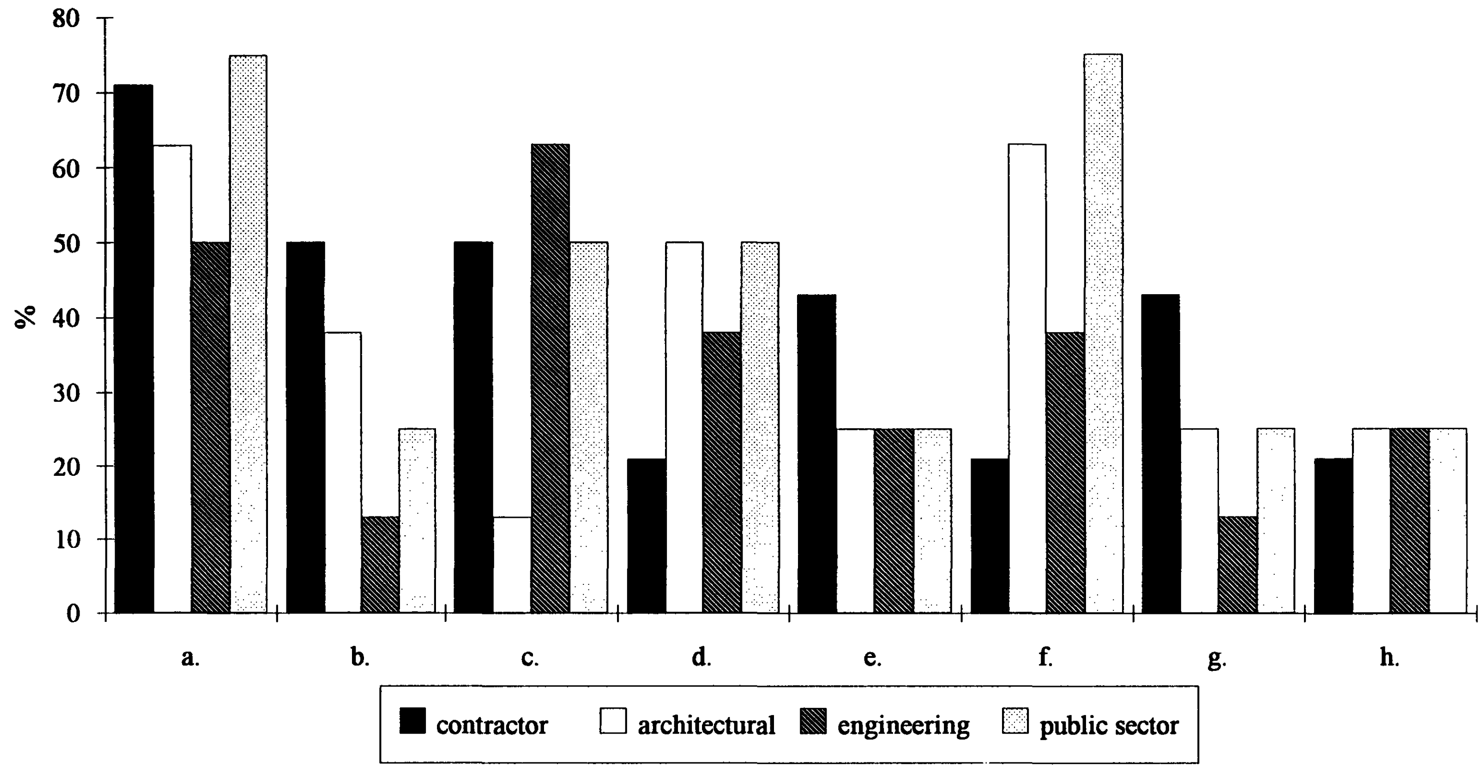


Figure 4.11 Results: Expectations to Taiwanese Government -- By type of firm

CHAPTER 5

ANALYSIS OF CONSTRUCTION AUTOMATION BENEFITS

5.1 Introduction

In order to understand whether construction automation makes sense in Taiwan's construction industry, this research uses a degree survey method which focuses on the perceived benefits for respondents after exploiting construction automation technologies. The public agencies were asked about impacts of automation on their own activities rather than on the whole construction industry. In the designed questionnaire, the respondents answer not only what benefits they got but also the degree of benefit compared to the base year (1992) after exploiting construction automation. Because it is hard for respondents to state the real degree of construction benefits, this research use 5 numbers to represent the perceived degree of benefit (except for perceived productivity increase).

For productivity increase survey, the respondents answer the degree question based on the real percentage of productivity increase observed. For the eight other benefit categories, 0 ~ 4 are the degree index: 0 represents the lowest degree, 2 represent the medium degree, and 4 represent the highest degree.

The survey examines the degree of every benefit category for the past three years and predictions for 1996. The results for the survey indicate progress for Taiwan's construction industry. They all show a continuous increase for the past three years and a brilliant expectation, which falls between level "2" (medium) and level "3" (improve a lot). This indicates that construction automation is making sense in Taiwan's construction industry during these years and in the future.

5.2 Productivity Increase Analysis

This analysis measures the increase in average productivity per year compared to the base year (1992) after exploiting construction automation. The definition of productivity is the total construction output (total construction award money) of the year divided by the total input of people and time for contractors. For design teams, the productivity is the total volume of business (design fee) of the year divided by the total input of people and time.

The results of this survey are shown as Tables 5.1, 5.1a, and Figure 5.1. The productivity for engineering and architectural firms has an apparent increase after exploiting construction automation. Moreover, the architectural firms even predict the productivity to increase to almost 40% for 1996. Both contractors and public sectors exhibit a consistent trend before 1995, and display that productivity increases in 1995 are worse than in 1994. However, they both predict an optimistic growth for 1996. Generally speaking, the achievement of productivity increases through using construction automation is good for organizations involved in the TRTS.

The results for individual companies are somewhat different. Contractors show a wide spread of productivity increases which is between 3% to 12% in 1993 and increases to 9% to 20% in 1995. It can be detected that good productivity performance contractors in the previous year keep on doing well in the future, although there is a downward trend on average in 1995. Whether doing well or badly, contractors all predict a brilliant future, which indicates that they all hope for the effectiveness of construction automation.

Architectural firms show fantastic numbers on this question, with a very consistent upward trend displayed for every company. The sixth firm even predicts an incredible high number (50%) growth for 1996.

Engineering firms also show a fantastic result. However, the productivity seems to stop from 1994 to 1995, and the prediction for 1996 even is unchanged for every firm. This result may be that the productivity increases due to construction automation technologies have achieved a high level before 1994. Since 1994, not much new

Table 5.1 Average Productivity Increase Percentage

(%)

	1992	1993	1994	1995	1996
Contractor	0.00	7.50	12.83	12.50	24.71
Architectural	0.00	10.83	17.50	27.50	38.88
Engineering	0.00	15.39	21.39	24.64	25.00
Public Sector	0.00	9.18	14.18	13.50	19.50

Base Year: 1992

Prediction: 1996

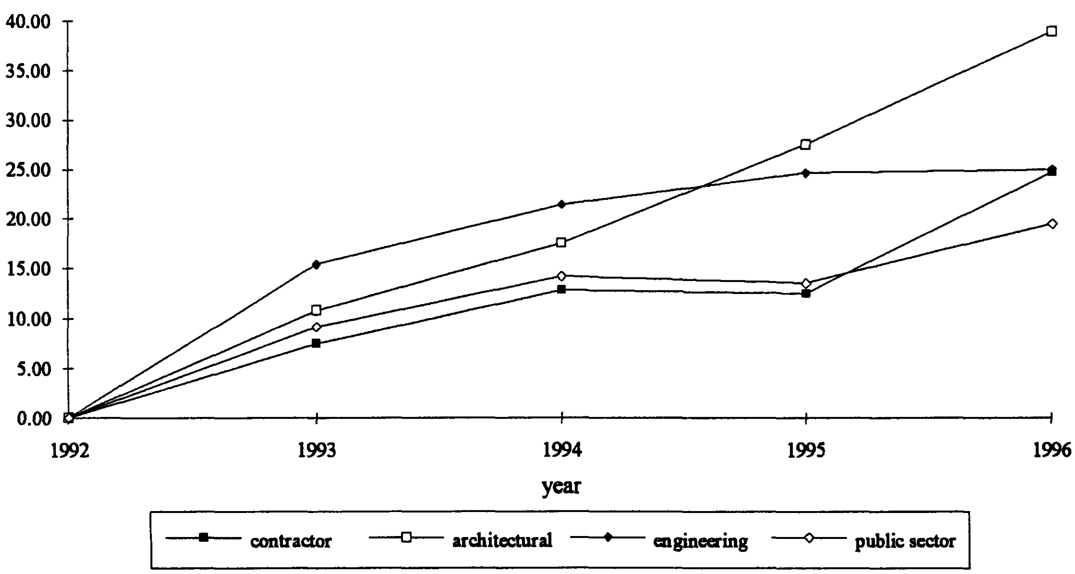


Figure 5.1 Average Productivity Increase Analysis

Table 5.1a The Results of Productivity Increase for Individual Companies

	1993	1994	1995	1996
Contractor 1	5.5	8.2	7.9	18.0
2	7.3	11.5	10.5	23.0
3	6.4	9.1	8.4	17.0
4	12.0	18.3	18.4	35.0
5	3.0	5.0	7.6	15.0
6	6.5	12.6	10.5	26.0
7	4.0	8.9	9.0	20.0
8	8.0	15.4	15.0	30.0
9	8.5	15.5	17.2	28.0
10	10.4	16.6	14.4	28.0
11	11.0	18.4	20.0	36.0
12	8.4	13.0	12.3	24.0
13	6.2	11.4	12.6	24.0
14	7.8	15.7	11.4	22.0
Architectural 1	9.2	15.4	22.8	30.0
2	10.5	17.2	30.0	40.0
3	9.3	15.0	21.2	35.0
4	14.2	19.0	32.5	38.0
5	8.4	17.2	28.4	42.0
6	11.0	18.4	35.0	50.0
7	12.8	20.8	26.1	36.0
8	11.2	17.0	24.0	40.0
Engineering 1	14.9	22.4	24.3	24.0
2	17.0	20.8	20.7	18.0
3	17.1	23.2	26.1	26.0
4	12.8	18.4	23.4	26.0
5	13.7	19.6	22.6	20.0
6	16.0	22.8	27.8	30.0
7	19.4	26.3	29.5	33.0
8	12.2	17.6	22.7	23.0
Public Office 1	7.5	13.6	12.4	20.0
2	11.3	15.9	16.2	22.0
3	9.7	15.0	14.0	18.0
4	8.2	12.2	11.4	18.0

technologies for engineering firms were developed, and therefore, they predict an unchanged future for 1996.

Like contractors, public agencies also have a downward trend in 1995, but expect a big jump for 1996. The data of the four agencies are pretty close, and in general are below those reported by many of the companies.

5.3 Cost Reduction Analysis

This analysis is to understand the degree of cost reduction of similar construction tasks compared to the base year after using construction automation. The definition of cost for construction teams is the unit cost of construction tasks such as the concrete floor per square meter and the sewage per meter. For design teams, the cost is defined as the unit cost of products, such as shop drawings.

The results of this survey are shown as Tables 5.2, 5.2a, and Figure 5.2. The respondents all think that using construction automation doesn't help much in the short term. These results are probably influenced by the high initial investment costs for construction automation. Contractors and public sectors exhibit worse achievement in cost reduction, and the public agencies even think there is no growth during the past three years.

The data of individual architectural and engineering firms show a obvious upward trend for cost reduction degree. The second firm of engineering companies and the sixth firm of architectural companies predict a "4" level growth for 1996. The sixth firm of architectural companies even has a continuous increase for four years.

Table 5.2 Average Cost Reduction Degree

	1992	1993	1994	1995	1996
Contractor	0.00	0.93	1.14	1.43	1.57
Architectural	0.00	1.13	1.50	2.00	2.75
Engineering	0.00	1.63	1.75	2.00	2.63
Public Sector	0.00	1.00	1.00	1.00	1.75

0: no reduction

1: reduce a little

2: medium

3: reduce a lot

4: reduce very much

Base Year: 1992

Prediction: 1996

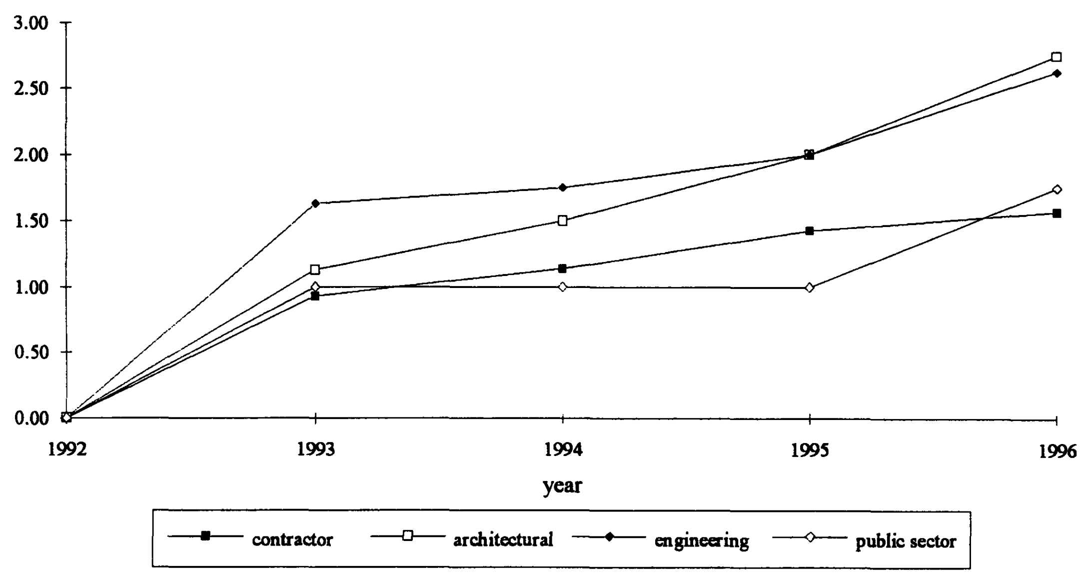


Figure 5.2 Average Cost Reduction Degree Analysis

Table 5.2a The Results of Cost Reduction Degree for Individual Companies

	1993	1994	1995	1996
Contractor 1	0	0	1	1
2	1	1	1	1
3	1	2	2	2
4	2	2	2	2
5	0	1	1	1
6	0	0	1	1
7	0	0	1	1
8	1	1	1	2
9	1	2	2	2
10	2	2	2	2
11	2	2	2	2
12	1	1	1	1
13	1	1	2	2
14	1	1	1	2
Architectural 1	1	1	1	2
2	1	1	2	3
3	0	1	1	2
4	2	2	3	3
5	0	1	2	3
6	1	2	3	4
7	2	2	2	2
8	2	2	2	3
Engineering 1	1	2	2	2
2	2	2	2	4
3	2	2	2	3
4	1	1	2	2
5	1	1	2	2
6	2	2	2	3
7	3	3	2	3
8	1	1	2	2
Public Office 1	0	1	1	2
2	2	1	1	1
3	1	1	1	2
4	1	1	1	2

5.4 Quality Increase Analysis

This analysis measures the increase of the quality for the whole project, such as precision, error extent, and stability compared to the base year after exploiting construction automation. It is judged by the respondents' experience and graded by 0~4 points.

The results of this survey are shown as Tables 5.3, 5.3a, and Figure 5.3. Among the respondents, the engineering and architectural firms show the achievements in quality improvement, and both expect a continued high growth for 1996. Furthermore, the fourth, sixth, and seventh firms of architectural and the seventh of engineering firms display a fantastic improvement in quality. They are all above the level of "3", which increases the project quality a lot, and the seventh firm of engineering companies even shows they have achieved level "4" for the four years.

The achievement for contractors is below medium level, which means that the respondents believe that construction automation has not helped much in quality improvement in construction for past three years in Taiwan. One reason maybe that the learning process for new technologies often needs a certain amount of accumulated time, and Taiwan's contractors are eager to see the outcome and may overlook the time needed to complete the process. However, contractors 9 and 11 still give this question positive answers, revealing not only an upward trend but also achieving the level "3" in 1995, with contractor 9 even predicting level "4" for 1996.

Most public agencies show consistent positive results for four years. Strangely, the first agency perceives that it gets little benefit; the level of quality improvement is still "1", which means the projects in this agency don't improve in quality improvements due to automation technologies for the past three years.

Table 5.3 Average Quality Increase Degree

	1992	1993	1994	1995	1996
Contractor	0.00	1.21	1.57	1.79	2.21
Architectural	0.00	2.00	2.38	2.50	3.00
Engineering	0.00	2.13	2.63	2.88	3.00
Public Sector	0.00	1.75	1.75	2.25	2.25

0: no increase

Base Year: 1992

Prediction: 1996

1: increase a little

2: medium

3: increase a lot

4: increase very much

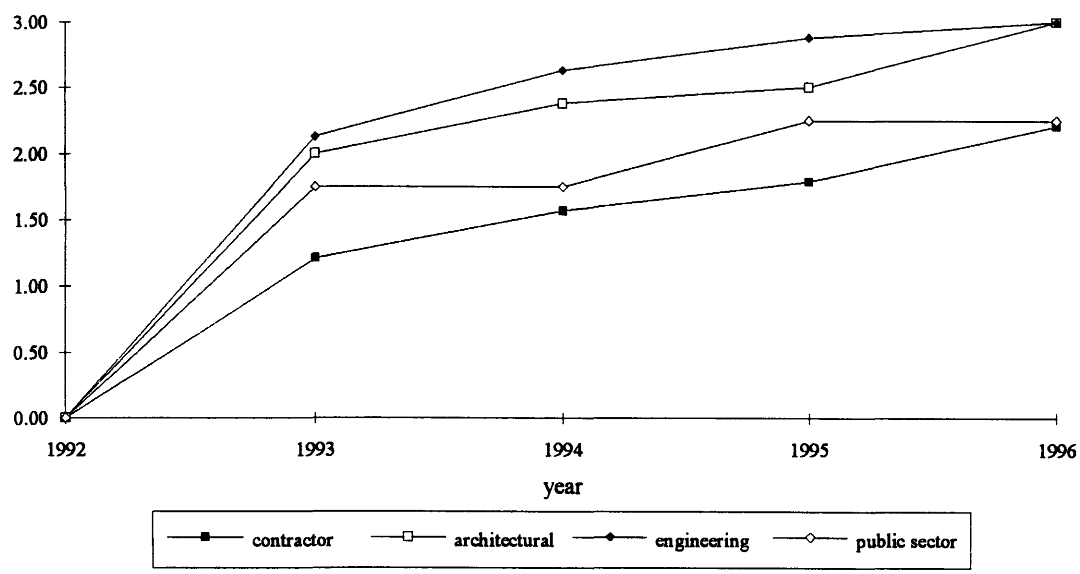


Figure 5.3 Average Quality Increase Degree Analysis

Table 5.3a The Results of Quality Increase Degree for Individual Companies

	1993	1994	1995	1996
Contractor 1	1	1	1	2
2	1	1	1	1
3	1	2	2	3
4	2	2	2	2
5	1	1	1	2
6	0	1	1	1
7	0	0	1	1
8	1	1	2	2
9	2	3	3	4
10	2	2	2	3
11	2	3	3	3
12	1	1	1	2
13	1	2	3	3
14	2	2	2	2
Architectural 1	2	2	2	3
2	2	3	3	3
3	1	1	2	2
4	3	3	3	4
5	1	2	2	2
6	2	3	3	4
7	3	3	3	4
8	2	2	2	2
Engineering 1	2	2	3	3
2	3	3	3	3
3	2	3	3	3
4	1	2	2	2
5	1	2	2	3
6	2	3	3	3
7	4	4	4	4
8	2	2	3	3
Public Office 1	0	1	1	1
2	3	2	3	3
3	2	2	3	3
4	2	2	2	2

5.5 Work Labor and Time Savings Analysis

This analysis measures the savings in labor and time for similar tasks compared to the base year after using construction automation. The aim here is to understand the time and manpower benefits of construction automation.

The results of this survey are shown as Tables 5.4, 5.4a, and Figure 5.4. Although most of the contractors saw no benefits for the first year, and low labor time savings in subsequent years, the other respondents have received savings during past three years after exploiting construction automation. Generally speaking, the degree for this analysis is average on level "2.5", which means the most apparent benefit for construction in Taiwan has a pretty good result between "medium" and "save a lot".

For individual data of contractors, there are still three contractors who saw benefits in time and labor savings. Contractor 4, 10, and 11 all have a level "2" degree savings for the past three years, and predict a level "3" growth for 1996. But for contractor 6, there is even no growth in 1993 and 1994, and only level "1" prediction for 1996.

For architectural and engineering firms, almost every firm has at least achieved level "2" before 1995. Most of the architectural firms have an increased curve and predict a brilliant future for 1996. The first firm of engineering companies has a great jump from 1993 to 1994 (0 to 2), and shows a continuous increase for the rest of the years. This firm and firm 7 also expect the highest level of labor and time savings in 1996.

Public agencies show steady increase for all four agencies. They all predict the degree of labor and time savings is at least "2" for 1996.

Table 5.4 Average Work Labor and Time Saving Degree

	1992	1993	1994	1995	1996
Contractor	0.00	0.93	1.21	1.57	1.93
Architectural	0.00	1.38	1.75	2.13	2.63
Engineering	0.00	1.50	2.00	2.25	2.88
Public Sector	0.00	1.50	1.75	2.00	2.25

0: no saving

Base Year: 1992

1: save a little

Prediction: 1996

2: medium

3: save a lot

4: save very much

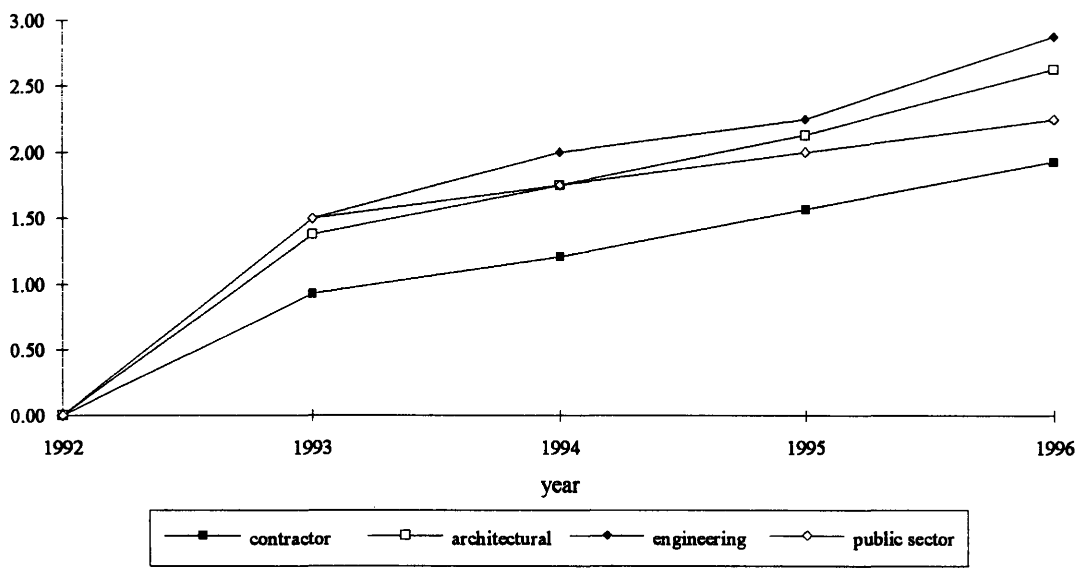


Figure 5.4 Average Work Labor and Time Saving Degree Analysis

Table 5.4a The Results of Labor and Time Saving Degree for Individual Companies

	1993	1994	1995	1996
Contractor 1	1	1	2	2
2	1	1	1	2
3	1	1	1	1
4	2	2	2	3
5	0	1	1	2
6	0	0	1	1
7	1	1	2	2
8	0	1	1	1
9	1	1	1	2
10	1	2	3	3
11	2	2	2	3
12	1	2	2	2
13	1	1	1	1
14	1	1	2	2
Architectural 1	1	1	2	3
2	2	2	2	3
3	0	1	1	2
4	3	3	3	3
5	1	2	3	3
6	1	1	2	2
7	2	2	2	3
8	1	2	2	2
Engineering 1	0	2	3	4
2	2	2	2	3
3	2	2	2	2
4	1	1	2	2
5	1	2	2	3
6	2	2	2	3
7	2	3	3	4
8	2	2	2	2
Public Office 1	1	2	3	3
2	2	2	2	2
3	2	2	2	2
4	1	1	1	2

5.6 Employee's Knowledge Promotion Analysis

This analysis measures the promotion of an employee's knowledge after exploiting construction automation.

The results of this survey are shown as Tables 5.5, 5.5a, and Figure 5.5. These results are similar to those observed in time and labor savings. Again, the contractors perceive less benefits while other respondents perceive more improvement in their employees' knowledge during past three years after using construction automation. Since work in construction companies is very laborious, it is hard to retain employees, which may explain the low perceived impact on employees knowledge by contractors. However, there are still some anomalies for individual contractors: contractors 3, 8, and 9 all achieve level "2" before 1993, display a steady growth, and predict level "3" for 1996.

Architectural and engineering firms seem to have gotten great benefits in advancing employee's knowledge: in 1995, all but 1 firm are above level "2" (medium), with four of them expecting to achieve the highest level "4" (increase very much) in 1996. Architectural firm 3 is different from others. Although it also expects to grow to level "2", the performance of the past three years was fairly low.

Public agencies show a steady growth and average level during the four years, which means the employees' knowledge have been promoted to a moderate degree.

5.7 Safety Increase Analysis

This analysis measures the safety improvement of construction compared to the base year after exploiting construction automation. Because the design teams (architectural and engineering companies) are not exposed to safety consideration, the two categories are not included in this analysis.

The results of this survey are shown as Tables 5.6, 5.6a, and Figure 5.6. They show that these two types of organizations feel pessimistic about safety improvement after

Table 5.5 Average Employee's Knowledge Promotion Degree

	1992	1993	1994	1995	1996
Contractor	0.00	1.14	1.29	1.64	1.93
Architectural	0.00	1.88	2.13	2.38	2.88
Engineering	0.00	1.88	2.25	2.63	3.00
Public Sector	0.00	1.75	2.00	2.25	2.50

0: no promotion

1: promote a little

2: medium

3: promote a lot

4: promote very much

Base Year: 1992

Prediction: 1996

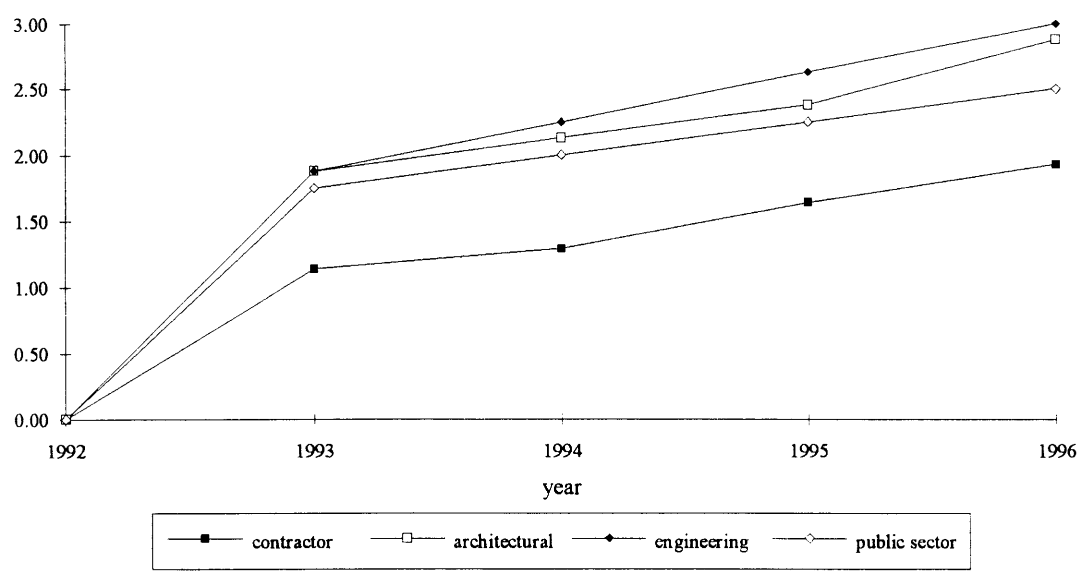


Figure 5.5 Average Employee's Knowledge Promotion Degree Analysis

Table 5.5a The Results of Employee's Knowledge Promotion Degree for Individual Companies

	1993	1994	1995	1996
Contractor 1	1	1	1	2
2	1	1	2	2
3	2	2	3	3
4	1	1	1	2
5	0	0	1	1
6	1	1	2	2
7	0	1	1	2
8	2	2	3	3
9	2	2	2	3
10	1	2	2	2
11	1	1	2	2
12	2	2	2	2
13	1	1	1	1
14	1	1	1	1
Architectural 1	2	2	2	3
2	2	3	3	3
3	1	1	1	2
4	3	3	3	4
5	1	1	2	2
6	3	3	3	4
7	1	2	2	2
8	2	2	3	3
Engineering 1	1	2	2	3
2	2	3	3	4
3	2	2	2	3
4	2	2	3	3
5	1	1	2	2
6	2	2	2	2
7	3	4	4	4
8	2	2	3	3
Public Office 1	1	2	2	2
2	2	2	2	2
3	2	2	3	3
4	2	2	2	3

Table 5.6 Average Safety Increase Degree

	1992	1993	1994	1995	1996
Contractor	0.00	0.86	1.21	1.43	1.57
Architectural	NA	NA	NA	NA	NA
Engineering	NA	NA	NA	NA	NA
Public Sector	0.00	1.25	1.50	1.50	1.50

0: no increase

1: increase a little

2: medium

3: increase a lot

4: increase very much

Base Year: 1992

Prediction: 1996

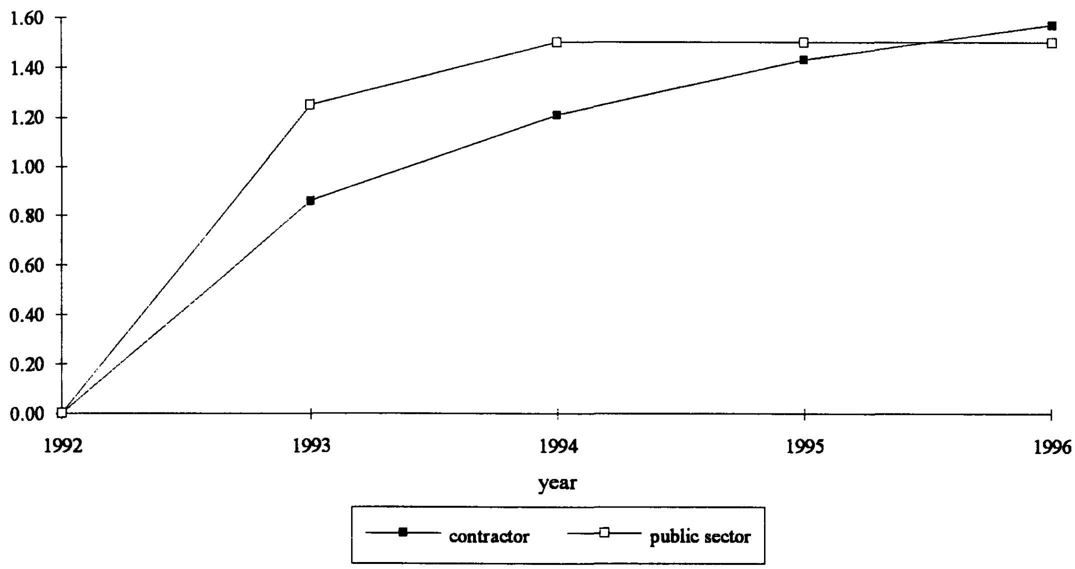


Figure 5.6 Average Safety Increase Degree Analysis

Table 5.6a The Results of Safety Increase Degree for Individual Companies

	1993	1994	1995	21996
Contractor 1	1	1	2	2
2	0	1	1	1
3	1	1	1	1
4	1	2	2	2
5	0	0	1	1
6	1	1	1	2
7	1	1	1	1
8	2	2	2	2
9	1	2	2	2
10	1	1	1	1
11	1	1	1	2
12	1	2	2	2
13	1	1	2	2
14	0	1	1	1
Public Office 1	1	1	1	1
2	1	2	2	2
3	1	1	1	1
4	2	2	2	2

using construction automation. The result of contractors shows an increasing momentum from 1993 to 1996, but the rate of rise is not so obvious. The result of public sectors even displays no progress from 1994 to 1996. From this information, the issue of how to improve the site safety and reduce the high-level labor-hurting rate still requires attention in Taiwan's construction industry.

5.8 Pollution Reduction Analysis

This analysis measures the degree of pollution reduction at the construction site compared to the base year after exploiting construction automation. Similar to section 5.7, the design teams are out of this survey since they mainly use the automation technologies in offices where pollution is less of a concern (here the research excludes the pollution of paper, computer, and radiation). The pollution contains air, water, soil, noise, and vibration waste due to construction works.

The results of this survey are shown as Tables 5.7, 5.7a, and Figure 5.7. Public agencies feel more positive than contractors in pollution reduction. The average result of public agencies is on level "1.5" to level "2" before 1995; agencies 2 and 3 even have a level "3" prediction for 1996. For contractors, the average result is under level "1.5", but contractors 4, 9, and 11 perform with steady improvement and both firm 4 and 11 expect to achieve level "3" for 1996. Generally speaking, construction automation is not perceived to have significant benefits for pollution reduction in Taiwan's construction industry.

Table 5.7 Average Pollution Reduction Degree

	1992	1993	1994	1995	1996
Contractor	0.00	0.93	1.29	1.50	1.79
Architectural	NA	NA	NA	NA	NA
Engineering	NA	NA	NA	NA	NA
Public Sector	0.00	1.50	1.75	2.00	2.50

0: no reduction

Base Year: 1992

1: reduce a little

Prediction: 1996

2: medium

3: reduce a lot

4: reduce very much

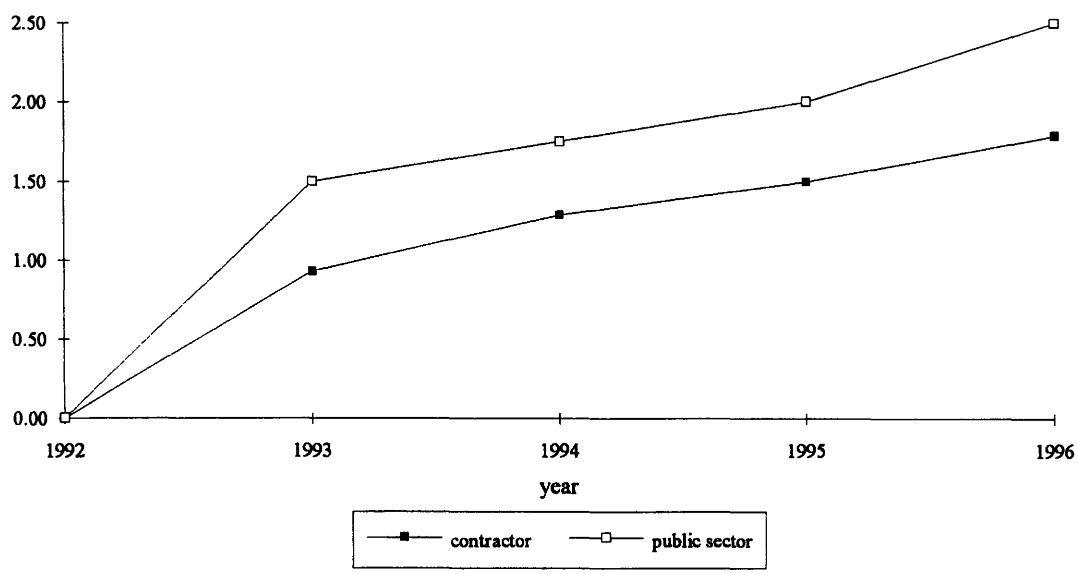


Figure 5.7 Average Pollution Reduction Degree Analysis

Table 5.7a The Results of Pollution Reduction Degree for Individual Companies

	1993	1994	1995	1996
Contractor 1	1	1	1	2
2	0	1	1	1
3	1	2	2	2
4	2	2	2	3
5	1	1	2	2
6	0	1	1	1
7	1	2	2	2
8	0	1	2	2
9	2	2	2	2
10	1	1	1	1
11	2	2	2	3
12	0	0	1	1
13	1	1	1	2
14	1	2	2	1
Public Office 1	1	2	2	2
2	2	2	3	3
3	2	2	2	3
4	1	1	1	2

5.9 Company Image Increase Analysis

This analysis measures the degree to which construction automation helps the respondents improve their company image compared to the base year.

The results of this survey are shown as Tables 5.8, 5.8a, and Figure 5.8. In general, all the firms saw the construction automation technologies as improving their company's reputations a medium amount, except for construction companies who saw little impact. The results for engineering and architectural firms fall on level "2" and predict a growth to level "2.5", which is between "medium" and "increase a lot".

However, the individual data for each architectural company diverge. The architectural firms 1, 5, 6, and 8, seem to have medium benefit in company image for the past years and expect a "3" or "4" level growth for 1996. On the contrary, firm 3 and 7 show a pretty low company image increase during those years.

The individual data of the other three types of organizations are consistent with their average performance. For contractors, every contractor shows a "1" to "2" level performance for the past three years except for contractor 10, which improved its company image very much by using construction automation. For engineering firms and public agencies, the results range from "0" to "3" in the first year, and increase to "2" to "3" in subsequent years. For engineering firm 7, it reached level "3" in 1993 and expects level "4" (increase very much) for 1996, which consistent with its perceived benefits in all other areas, indicates a high perceived benefit from using automation technologies.

5.10 Competitiveness Increase Analysis

The analysis measures the increase in competitiveness (both international and domestic) of the respondents compared to the base year after exploiting construction automation.

The results of this survey are shown as Tables 5.9, 5.9a, and Figure 5.9. All four types of organizations give construction automation affirmative answers; the results have a upward trend and they all predict for a better future which is between level "2" and "2.5".

For contractors, the individual data scatter. In 1994, some contractors think their competitiveness has increased to a medium level "2", however, there are still two contractors (2 and 14) feel no growth in their competitiveness. Even the predictions for 1996, four contractors (1, 3, 6, and 14) only feel level "1" (increase a little) for their competitiveness.

For the other three types of organizations, it seems to be more consistent with the average performance. Almost every company shows an upward trend during the past years; engineering firm 2 and architectural firm 7 even expect the highest level of their performance for 1996. Architectural firm 3 is the only company which doesn't predict a growth for 1996, it achieves level "1" (increase a little) only.

5.11 Summary

The productivity of Taiwan's manufacturing industry has increased significantly over the last 20 years because of automation technologies, which can encourage growth and development in other relevant industries. The construction industry, which is known as the locomotive of the economy, has been slowed by increasing wages and decreasing working time; the productivity increases in construction have been slower than those observed in the manufacturing industry. Although the money spent for construction has significantly increased in the recent years, indicating increasing project complexity, corresponding construction technologies appear to be difficult to promote to the same level as in manufacturing. In addition, these technologies may increase the cost burdens for contractors and therefore reduce the demand for construction automation.

According to this survey, construction automation has already shown a certain degree of advantages for Taiwan's construction industry. In fact, it appears that construction automation provides the same benefits for Taiwan as for other advanced countries, and may be an effective means to improve the whole industry. However, aimless automation may create higher costs than no automation at all. Before mandating higher degrees of automation, a prudent strategy would be to consult and examine the experience of other countries, analyze the whole environment, identify the barriers, and then draw up the appropriate implementation strategies.

Table 5.8 Average Company Image Increase Degree

	1992	1993	1994	1995	1996
Contractor	0.00	0.79	1.21	1.50	1.86
Architectural	0.00	1.38	1.63	1.88	2.50
Engineering	0.00	1.50	1.88	2.00	2.50
Public Sector	0.00	1.50	1.50	1.75	2.25

0: no increase

1: increase a little

2: medium

3: increase a lot

4: increase very much

Base Year: 1992

Prediction: 1996

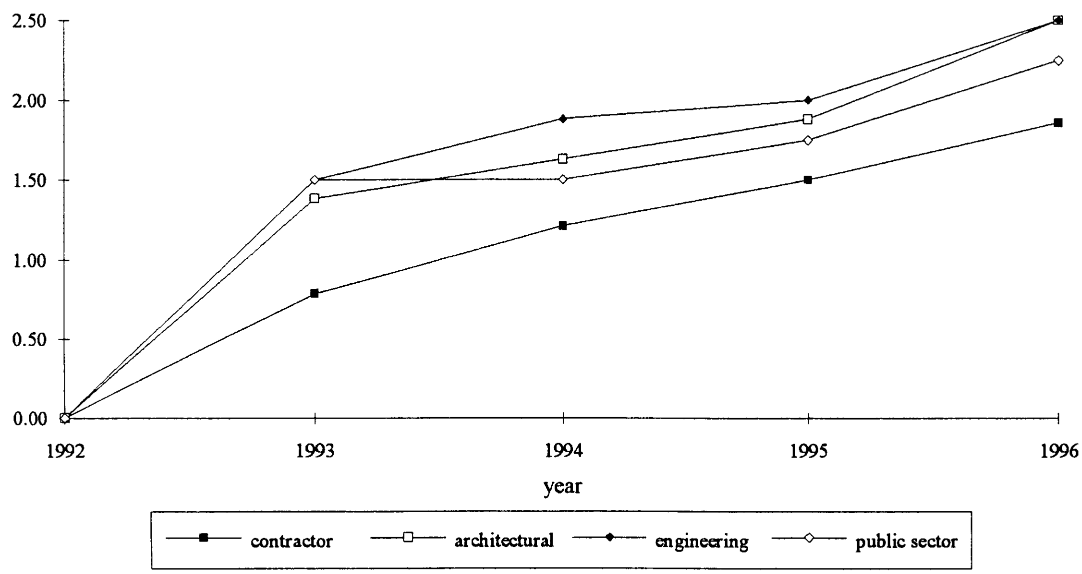


Figure 5.8 Average Company Image Increase Degree Analysis

Table 5.8a The Results of Company Image Increase Degree for Individual Companies

	1993	1994	1995	1996
Contractor 1	0	1	1	2
2	1	1	1	2
3	1	2	2	2
4	1	1	1	1
5	0	1	1	2
6	1	1	2	2
7	0	1	1	2
8	1	2	2	2
9	1	1	1	1
10	2	2	3	3
11	1	1	1	2
12	1	1	2	2
13	1	2	2	2
14	0	0	1	1
Architectural 1	2	2	2	3
2	1	1	2	2
3	0	1	1	1
4	1	2	2	2
5	2	2	2	4
6	2	2	2	3
7	1	1	1	2
8	2	2	3	3
Engineering 1	0	1	1	2
2	2	2	2	2
3	2	2	2	3
4	1	1	2	2
5	1	2	2	2
6	2	2	2	3
7	3	3	3	4
8	1	2	2	2
Public Office 1	1	1	1	2
2	1	2	2	2
3	2	2	2	3
4	2	1	2	2

Table 5.9 Average Competitiveness Increase Degree

	1992	1993	1994	1995	1996
Contractor	0.00	0.86	1.29	1.64	2.00
Architectural	0.00	1.13	1.38	1.88	2.25
Engineering	0.00	1.63	1.88	2.00	2.50
Public Sector	0.00	1.00	1.25	1.50	2.00

0: no increase

Base Year: 1992

1: increase a little

Prediction: 1996

2: medium

3: increase a lot

4: increase very much

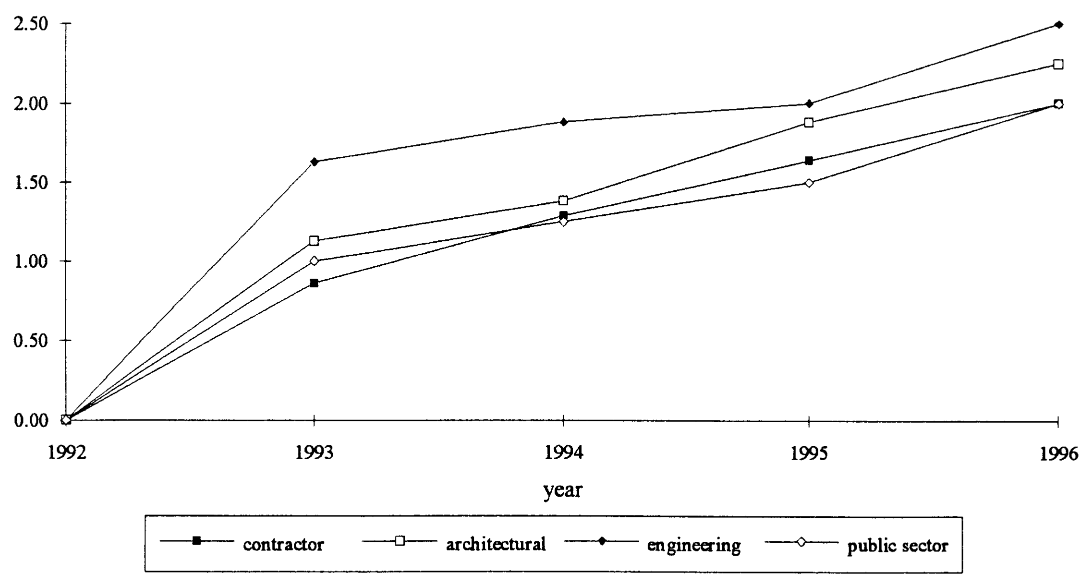


Figure 5.9 Average Competitiveness Increase Degree Analysis

Table 5.9a The Results of Competitiveness Increase Degree for Individual Companies

	1993	1994	1995	1996
Contractor 1	0	1	1	1
2	0	0	2	2
3	1	1	1	1
4	1	2	2	2
5	1	2	2	3
6	1	1	1	1
7	1	1	1	2
8	2	2	3	3
9	1	2	2	2
10	2	2	2	3
11	1	1	1	2
12	0	1	1	2
13	1	2	3	3
14	0	0	1	1
Architectural 1	1	1	2	2
2	1	2	2	2
3	1	1	1	1
4	2	2	2	3
5	0	1	1	2
6	1	1	2	2
7	2	2	3	4
8	1	1	2	2
Engineering 1	1	1	2	2
2	2	2	2	4
3	2	2	2	3
4	1	2	2	2
5	1	1	1	2
6	2	2	2	2
7	3	3	3	3
8	1	2	2	2
Public Office 1	1	1	1	2
2	1	2	2	2
3	1	1	2	2
4	1	1	1	2

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Today's construction industry in Taiwan is confronted with serious problems of labor shortages, wage increases, and international competition. Meanwhile, the Taiwanese government has initiated several large-scale public construction projects, which creates new demands on the industry. It is urgent to implement new construction technologies for Taiwan's construction industry.

This survey is an investigation of construction automation for the geotechnical engineering in the TRTS. The research tries to reflect the whole situation of construction automation in Taiwan and to be a reference for the following research. The research has gotten some major results:

1. The automation technologies currently used in the TRTS

Architectural and engineering firms generally have some degree of automation in analysis and design, and project control and management. They all used some advanced software applications to improve their work, with AutoCAD and CPM are used by all of the companies. Public agencies have their own management system, which is PMIS. Contractors, however, do not seem to use management automation technologies very often; only 21% of them use P3 for project control. Most of the automation technologies are needed urgently or needed and can be developed by the companies.

Almost all of the contractors use monitoring systems to monitor their works. In addition, every contractor has automated equipment to some degree. While the automation of monitoring is seen to be urgently needed or needed and can be developed by the company more or less, automated equipment is needed but lacks economical justification. Most of these companies want to cooperate with other foreign companies to obtain the equipment rather than developing it themselves. It seems that because of the prosperity of Taiwan's information industry, the automation technologies which related to the computer are easily developed, but the advanced construction equipment still has a ways to go for development by local companies.

2. The benefits of construction automation for contractors in the TRTS

From this survey, the benefits of increasing project quality and saving work labor and time was cited by high proportion of companies for all four types. Almost three quarters (76%) of the firms feel these two items are the major benefits they got after exploiting construction automation. Also, this research probes the degree of advantages of these items (with 1992 as the base year for the survey, and 5 different degrees for respondents to reply, where 0 is no improvement and 4 is improve the most). Based on this survey, we get the following results for the sample as a whole (Table 6.1):

Table 6.1 Average Benefits Perceived Degree in 1995,1996

	1995	1996 Expected
Productivity Increase	19.5%	27.0%
Cost Reduction	1.6	2.2
Quality Increase	2.4	2.6
Work Labor and Time Savings	2.0	2.4
Employee's Knowledge Promotion	2.2	2.6
Safety Increase	1.5	1.5
Pollution Reduction	1.8	2.2
Company Image Increase	1.3	2.3
Competitiveness Increase	1.8	2.2

Base Year: 1992

From the above table, the most significant advantages from construction automation perceived by the interviewed Taiwanese companies are project quality, employee's knowledge promotion, and reduction of labor, especially as measured in productivity gains. Company image is expected to improve the most from 1995 to 1996 along with productivity improvements, but safety is expected to remain at only low levels of improvement.

Because of the different characteristics of companies involved in the TRTS, the survey was separated according to four different types of companies, which are contractors, architectural firms, engineering firms, and public agencies. These four types of companies show different degrees of perceiving each benefit item. It indicates that the contributions of automation vary by different types of companies and thus induce different promotions and expectations in automation. It is interesting that even in the same type of company, there are divergent data shown in the survey. Some companies continued to perceive benefits from automation, and some companies did not; some companies perceived benefits in every question item, some companies only in several of them. This would be a good study for future research to see why companies perceived different degrees of benefits from automation.

The expectation for 1996 by most companies seem to be moderate, with only a few companies ever selecting "3" or "4". Because they are still in the beginning stage of construction automation and with the huge initial cost of automation investment, they may not anticipate significant progress. However, if the benefits perceived were less than costs in exploiting automation, the implementation of construction automation would stop or slow down, which was not found in this research. Therefore, we could say that the exploitation of construction automation in Taiwan still has positive value.

3. The difficulties of construction automation in the TRTS

The lack of reward systems, the instability of future works, the lack of skilled labor, and international cooperation experience seem to be the biggest problems for construction companies in using automation technologies. The architectural and engineering firms, on the other hand, see the lack of high-level construction automation research institutions and services, the instability of future works, and insufficient capital as the most difficult problems. For public agencies, the lack of big-contractors is of the greatest concern.

4. Preferences on how to introduce

The respondents show a strong demand in automation, but the biggest desires are to purchase technologies directly or to develop them through international cooperation. It indicates that companies still need the technology help from the research institution or foreign firms. This might be good for Taiwan's construction industry, because those technologies imported into Taiwan would be the mature software or equipment rather than the technologies in the trial stage.

5. The expectations to the Taiwanese government

The incentives of tax reduction and reward systems were cited by the majority of companies in each type of organization and especially by contractors, where 71% firms expect the government to increase these activities. In addition, providing technology help, and the establishment of a construction automation information center are also cited by construction, architectural, and engineering companies.

6.2 Conclusions

According to this survey, among the four application areas of construction automation technologies of analysis and design, control and management, monitoring, and construction equipment, the achievements for the first two categories in the TRTS is significant. The level of automation technologies employed by Taiwanese firms in analysis and design are equivalent to those used in most developed countries. The spread of control and management technologies has also been significant in architectural and engineering firms, although slowed somewhat by translation issues. For monitoring, the accomplishments are adequate, reflecting standard components and systems used throughout the world, but without the most advanced integrated or automated systems. For the construction equipment, however, although the opportunity for the introduction and use of automation technologies is huge, few contractors have the willingness to develop those automation technologies by themselves and do not appear to be able to obtain them in other ways. One reason could be that the huge amount of initial investment hampers their progress; another reason might be that the technology is not made available by the foreign companies.

From this research, construction automation makes some sense in Taiwan's construction industry. Productivity increases, which is a strong indicator of benefits from technology improvements (Pan, 1985), can be an important index for construction automation. From Chapter 5, we can see a stable increase of productivity of almost 20% in 1995, and a prediction of 27% for 1996, especially for architectural companies (39%). This represents a huge jump in 5 years, which could indicate that Taiwan's construction industry has significantly benefited from construction automation. Other benefits, such as saving labor and time, quality improvement, and employee's knowledge promotion, also indicate positive assessments of construction automation in Taiwan, although to a lesser extent. These benefits all show a stable upward trend for respondents, and strong expectations for 1996.

Many difficulties continue to exist for companies trying to introduce or exploit construction automation technologies, such as the instability of future work, lack of skilled labor, lack of high level construction automation research institutions, the small scale of most projects, and no reward systems. To conquer these difficulties, not only the Taiwanese government but also contractors, architectural, and engineering firms have to work together for the future.

6.3 Recommendations

This research focuses on the benefits and difficulties that Taiwanese construction companies perceived, which will bring out the need for automation in Taiwan's construction industry. Based on the survey results, this research provides some recommendations to both construction companies and the Taiwanese government. It hopes that construction automation technologies can be rooted in Taiwan's construction industry and bring immediate benefits for companies with eventually development of their own automation technologies in the long run. This pathway depends upon the cooperation between all construction organizations; only by cooperation among contractors, architectural firms, engineering firms, and the Taiwanese government can construction automation achieve to a better future in Taiwan.

Because construction automation is involved in the integration of many complex technologies and information, it is hard to get away from the restrictions of traditional technologies of the construction industry which was influenced by traditional skill areas for a long time, and to step towards complete automation. Therefore, we recommend implementation of construction automation technologies by phases. In the initial stages, these automation technologies which can easily be accepted and have immediate advantages can be provided and encouraged first (such as for analysis and design, and project control and management).

According to this research, the primary difficulties for using construction automation technologies for Taiwanese contractors are the instability of future work, lack of skilled labors, and lack of reward systems. Therefore, it is recommended that the Taiwanese government should foster a better construction automation environment by helping the contractors introduce automation technologies or equipment, and offering some reward systems such as financial loans and guarantees of the future works. In addition, in the near term, the Taiwanese government can help develop and commercialize construction automation technologies with the understanding that when the automation environment becomes mature enough, it can hand these technical works to the contractors and let them develop those technologies by themselves. In the long term, the Taiwanese government will only be concerned with the general activities such as training of technicians and basic R & D.

Any plan of construction automation has to cover all stages of analysis and design, control and management, and construction stages. If the automation technology is developed by each individual stage, it is possible that the competing technologies deviate from practice and cannot be implemented or are more expensive to integrate at every stage. From this research, although only a few companies (24%) cited that design cannot support the use of automation technologies, this is a potential problem in construction industry. For example, the traditional construction of utility pipes is performed after setting the steel bars. If a contractor develops a robot which can install the utility pipes but the robot can not work among the steel bars easily, the original construction sequence has to be reversed. Construction automation has to be considered in an integration of design and construction.

Contractors should hire more engineers not only doing the field work but also performing the management activities in the company. In Taiwan, because of the hardship of site work, many university graduates don't want to enter construction companies but instead prefer architectural or engineering firms where they can do most work in the office. Because they employ highly-educated people who learned a lot of automated technologies in universities, it is easy for architectural and engineering companies to promote automation, as revealed in the results of this research. In contrast, the results indicate a low acceptability of automation technologies by contractors. Therefore, attracting highly-educated people into construction companies would be one way to promote automation.

According to this research, the expectation of setting up a construction automation information center is significant (only less than tax credit and reward system) by all types of firms. It would be possible to combine the construction automation resources data base and information service center to integrate all the information needed for construction. For architectural and engineering firms, the investigation work could be reduced or even eliminated if the site information exists in the center; for contractors, they can access the center to get the latest information about automation technologies available in the field and make the decision whether to use them to obtain the greatest benefits. If the equipment and other automation suppliers can share this database with the design and construction firms, the data can be more rapidly available, more accurate, and more accessible, thus achieving the integration of interfaces.

Establishing a high-level construction automation research institution is also a good way to promote the automation technologies in Taiwan. The institution could help solve field problems and develop advanced automation technologies. The Taiwan Industrial Technologies Research Institution, which has made significant contributions to the manufacturing industry in automation, is a good example.

Taiwan's construction industry has experienced strong progress over last 10 to 20 years. Right now the industry is exploring construction automation as a means to get as many benefits as possible and to catch up with the advanced countries. Of the four application areas, design and analysis is influenced by education the most. The area could see even greater expansion if the international sale of technologies is more rapid. Control and management is also influenced by education to some degree, but is primarily driven by the need, as evidenced by the proliferation of company-developed project management programs in Taiwan. Monitoring is adequate at this stage, although not state-of-the-art. We still can expect further significant progress in developing the interface between the site and office since the computer industry in Taiwan is so prosperous. Equipment is on the level of moderate, but could make the greatest impact if the contractors could train their employees more and if international sales were more rapid.

Hopefully, this research could help promote Taiwan's construction industry in automation technologies, and thus help Taiwan become a developed country in the near future.

APPENDIX A Questionnaire

Survey for major benefits and constraints in geotechnical engineering for the TRTS

Directions: Please indicate your answers by marking the appropriate item(s) after each question or specify other. Thank you for your cooperation.

A. Current Accomplishment of Construction Automation

B. Demand for Automation Technologies

For Design and Analysis

a. What AUTOMATION TECHNOLOGIES do you use in your firm (Please specify the name and type in the following table)?

b. What does your firm think is the DEGREE of Automation of such Technology?

Complete Automation　　Operation Automation

System Automation　　Partial Automation　　No Automation

c. What is your firm's DEMAND for such Technology?

Needed Urgently　　Needed and Developed by your firm

Needed but no Economical Justification　　Cooperation with other firms

No Need at all

Design and Analysis Automation Technologies			
Name	Type	Degree	Demand

For Project Control and Management

a. What AUTOMATION TECHNOLOGIES do you use in your firm (Please specify the name and type in the following table)?

b. What does your firm think is the DEGREE of Automation of such Technology?

Complete Automation Operation Automation

System Automation Partial Automation No Automation

c. What is your firm's DEMAND for such Technology?

Needed Urgently Needed and Developed by your firm

Needed but no Economical Justification Cooperation with other firms

No Need at all

Project Control and Management Automation Technologies			
Name	Type	Degree	Demand

For Monitoring

a. What AUTOMATION TECHNOLOGIES do you use in your firm (Please specify the name and type in the following table)?

b. What does your firm think is the DEGREE of Automation of such Technology?

Complete Automation Operation Automation

System Automation Partial Automation No Automation

c. What is your firm's DEMAND for such Technology?

Needed Urgently Needed and Developed by your firm

Needed but no Economical Justification   Cooperation with other firms

No Need at all

Monitoring Automation Technologies			
Name	Type	Degree	Demand

For Construction Equipment

a. What AUTOMATION TECHNOLOGIES do you use in your firm (Please specify the name and type in the following table)?

b. What does your firm think is the DEGREE of Automation of such Technology?

Complete Automation   Operation Automation

System Automation   Partial Automation   No Automation

c. What is your firm's DEMAND for such Technology?

Needed Urgently   Needed and Developed by your firm

Needed but no Economical Justification   Cooperation with other firms

No Need at all

Construction Equipment Automation Technologies			
Name	Type	Degree	Demand

C1. What are the BENEFITS your firm gets from Construction Automation (Multiple choices)?

______a. increase productivity;
______ b. reduce the project cost;
______ c. increase project quality;
______ d. save work labor and time;
______ e. promote employee's knowledge;
______ f. increase site safety;
______ g. reduce environmental pollution;
______ h. establish the company image;
______ i. promote competitiveness.

C2: Please assign a rating of **0 ~ 4** to each advantage below for each year **(1993 ~ 1996)** your firm **has perceived, is perceiving, and will perceive** when using Construction Automation. (Base Year: 1992). A Larger Number correlated to a More serious benefit.

(0: No Benefit, 1: Little Benefit, 2: Medium, 3: Benefit a lot, 4: Benefit very much.)

	1993	1994	1995	1996	
a. increase productivity;	____	____	____	____	(0 ~ 4)
b. reduce the project cost;	____	____	____	____	(0 ~ 4)
c. increase project quality;	____	____	____	____	(0 ~ 4)
d. save work labor and time;	____	____	____	____	(0 ~ 4)
e. promote employee's knowledge;	____	____	____	____	(0 ~ 4)
f. increase site safety;	____	____	____	____	(0 ~ 4)
g. reduce environmental pollution;	____	____	____	____	(0 ~ 4)
h. establish the company image;	____	____	____	____	(0 ~ 4)
i. promote competitiveness.	____	____	____	____	(0 ~ 4)

D1: Please indicate the DIFFICULTIES your firm faced when Introducing Construction Automation INSIDE your firm (Multiple choices).

______ a. design activities cannot support the use of automation technologies;

______ b. regulations or laws;

______ c. insufficient capital;

______ d. lack of skilled labor;

______ e. the instability of future work;

______ f. no access to relevant information;

______ g. no international cooperation experience and ability;

______ h. no priority to negotiate the bid price.

D2: Please indicate the DIFFICULTIES your firm faced when Introducing Construction Automation OUTSIDE your firm (Multiple choices).

______ a. no reward system;

______ b. no professional construction system;

______ c. big-contractor system hasn't been established;

______ d. no construction automation service;

______ e. no high-level construction automation research institution;

______ f. project scale is not big enough;

______ g. difficulties in technologies transfer.

E: Please indicate HOW will your firm Develop or Introduce Construction Automation (Multiple choices)?

______ a. purchase directly;

______ b. purchase and research;

______ c. development by international cooperation;

______ d. technology transfer from other countries;

______ e. research by cooperating with domestic institution;

______ f. no demand.

F: Please indicate what are your firm's EXPECTATIONS to Taiwanese Government (Multiple choices)?

______ a. reduce tax and set up investment reward system;

______ b. capital loan from government;

______ c. technology help;

______ d. education improvement;

______ e. revise the relevant laws;

______ f. establish construction automation information center;

______ g. subsidize R&D expenditures;

______ h. market protection from foreign companies.

APPENDIX B List of Some Companies Who Responded to Questionnaire

Due to certain reasons, some respondents wished to remain anonymous. Following are the list of some companies which participated in the survey:

Contractors

Continental Construction Co. Ltd., Taipei, Republic of China.

Eastern Construction Co. Ltd., Taipei, Republic of China.

FTC Construction Co. Ltd., Taipei, Republic of China.

Ju-Jiang Construction Co. Ltd., Taipei, Republic of China.

Pacific Construction Co. Ltd., Taipei, Republic of China.

Pan Asia Construction Co. Ltd., Taipei, Republic of China.

Architectural firms

Li and Associates, Taipei, Republic of China.

Engineering firms

Fukken Engineering Co. Ltd., Taipei, Republic of China.

Great Asia Engineering Consultants inc., Taipei, Republic of China.

Moh and Associates Co. Ltd., Taipei, Republic of China.

Sino Geotechnology, inc., Taipei, Republic of China.

Sinotech Engineering Consultants, inc., Taipei, Republic of China.

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