Case Studies of RD&E Performance in Electronics

Final Report

CASE STUDIES OF RD&E PERFORMANCE IN ELECTRONICS

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RESEARCH TEAM

Dr. Chatri Sripaipan Thailand Development Research Institute	Project Director
Dr. Anupap Tiralap Thailand Development Research Institute	Project Leader
Dr. Sumeth Vongpanitlerd Thailand Development Research Institute	Researcher
Dr. Wittaya Watcharawittayakul National Institute of Development Administration (NIDA)	Researcher
Asst. Prof. Prayoon Shiowattana Technological Promotion Association (Thai-Japan)	Researcher
Dr. Pichet Durongkaveroj Thailand Development Research Institute	Researcher
Ms. Yada Mukdapitak Ministry of Science, Technology and Environment	Research Associate
Ms. Prathinporn Chantaworaluk Thailand Development Research Institute	Research Assistant

EDITOR

Mr. Marc Atkins

NATIONAL ACADEMY OF SCIENCES PROJECT ADVISER

Dr. William L. Hughes
6118 Greenleaf Court, Rapid City, South Dakota, U.S.A.

WORKSHOP FACILITATOR

Dr. Orapin Sopchokchai
Thailand Development Research Institute

Ms. Somjit Tipprapa
Population and Community Development Association (PDA)

SUPPORT STAFF

Ms. Atchalita Phutchawat
Ms. Amornrat Apinunmahakul
Ms. Chanpen Lawsiripaiboon
Ms. Sureeporn Hiruncharoensuk
Ms. Suwalee Somlap
Ms. Usa Panyawadee
Ms. Wangsupha Penratana

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Last, the research team accepts full responsibility for the research content and any errors thereof.

The Research Team

THE LIST OF PARTICIPANTS IN THE BRAINSTORMING EXCERCISE FOR CRITERIA SELECTION

National Science and Technology Development Agency

Dr. Aroon Auansakul
National Science and Technology Development Agency

Dr. Harit Sutabutr
National Metal and Materials Technology Center

Dr. Kamolrut Boonnour
National Science and Technology Development Agency

Dr. Krissanapong Kirtikara
National Electronics and Computer Technology Center

Dr. Montri Chulavatanatol
National Science and Technology Development Agency

Dr. Nit Chantramanklasri
National Science and Technology Development Agency

Dr. Pairash Thajchayapong
National Electronics and Computer Technology Center

Dr. Panya Srichandr
National Metal and Materials
Technology Center

Dr. Sakarindr Bhumiratana
National Center for Genetic Engineering and Biotechnology

Dr. Sutat Sriwatanapongse
National Center for Genetic Engineering and Biotechnology

Dr. Wantanee Chongkum
National Science and Technology Development Agency

Dr. Waykin Nopanitaya
National Science and Technology Development Agency

Dr. Yongyuth Yuthavong
National Science and Technology Development Agency

Industrialists

Mr. Gowit Jira
Elcom Research Co., Ltd.

Mr. Sitthichai Srikangwan
Century Electronics and Systems Co., Ltd.

Mr. Siwa Pongpipat
Siwa Testing Inspection and Consulting Co., Ltd.

Research Team in Biotechnology

Dr. Amaret Bhumiratana
Mahidol University

Dr. Bhinyo Panijpan
Mahidol University

Mr. Johann C. Stuyt
SEAMICO Business Information and Research Co., Ltd.

Dr. Pintip Ruenwongsa
Mahidol University

Dr. Supat Attathom
Kasetsart University

Research Team in Materials

Dr. Chatchai Somsiri
Chulalongkorn University

Dr. Joyce Thompson
Mahanakorn College

Dr. Krisda Suchiva
Mahidol University

Dr. Lek Uttamasil
Chulalongkorn University

Dr. Paritud Bhandhubanyong
Chulalongkorn University

Dr. Wikrom Vajragupta
Chulalongkorn University

Dr. Woraphat Phucharoen
Chulalongkorn University

Research Team in Electronics

Dr. Anupap Tiralap
Thailand Development Research Institute

Dr. Pichet Durongkaveroj
Thailand Development Research Institute

Asst. Prof. Prayoon Shiowattana
Technological Promotion Association (Thai-Japan)

Dr. Wittaya Watcharawittayakul
National Institute of Development Administration

Ms. Yada Mukdapitak
Office of Science Technology and Environment

TDRI Researchers

Dr. Chatri Sripaipan

Dr. Sumeth Vongpanitlerd

Dr. Orapin Sopchokchai

TDRI Support Staff

Ms. Amonrat Apinunmahakul

Ms. Atchalita Phutchawat

Ms. Chanpen Lausiripaiboon

Ms. Doungdao Piyanontalee

Mr. Pramote Chotikastit

Ms. Prathinporn Chantaworaluk

Ms. Sureeporn Hiruncharoensuk

Ms. Suwalee Somlap

Ms. Wangsupha Penratana

EXECUTIVE SUMMARY

The main purpose of this study is to draw some lessons from the case studies of R&D projects in Thailand and to outline the policy implications of those lessons. Of course, it is worth mentioning that although the lessons learned are drawn from only five case studies, which can by no means represent Thailand as a whole, they nevertheless indicate that there are a number of key factors which affect R&D performance in Thailand which need to be addressed.

The five case studies selected aim to cover all product ranges of the electronics spectrum including hardware (computers and telecommunications), software, and components. In addition, they have been selected to cover a wide range of research and development (R&D) goals, with some being clearly market oriented while others focused more on the accumulation of knowledge. Finally, all the case studies were chosen because they were able to provide good material for analyzing the positive and negative aspects of electronics R&D in Thailand.

The five case studies include the following: the development of personal computers, the development of a private automatic branch exchange, the design of application specific integrated circuits, the development of software for linear electronic circuit design, and the fabrication of medium scale integrated circuits.

Surprisingly, although the case studies cover a wide range of products and research goals, they do point to a number of common lessons which can be drawn from the experiences of electronics RD&E in Thailand. These lessons can be outlined as follows:

1. Thai researchers can complete their assigned R&D projects and produce concrete results in spite of having to work in unfavorable and constrained environments. The case studies show that topic selection is a very decisive factor in determining the efficiency of a research project, and hence the potential for the utilization of research. Modest research topics (such as reversing engineering of foreign products against originally designed products starting from scratch) seemed to yield better results in terms of the

level of technological knowledge acquired and in the potential for the commercialization of research, development and engineering (RD&E) results.

2. Industrial needs are not always clearly identified. Industrial firms tend to muddle through in setting up their directions and goals as the government has never provided specific targets and convincing plans which the industry can follow. Consequently, the research community can hardly anticipate industrial needs. Thus, research topics selected in close consultation with, and the participation of, private firms, tend to end up with higher utilization of research results. Projects carried out by university researchers alone tend to be commercially abortive despite having commercial objectives in mind.

3. Although commercialization of RD&E results is closely related to the relevancy of RD&E to industrial needs, for it to be successful requires more than simple topic selection and private sector participation. It also has to be well managed to keep up with moving windows of opportunity, particularly in a fast-changing technological field like electronics. This is because along with the process of product development (from the conception of research ideas to market introduction), the five tuning and adjustment of research prototypes to meet market demands is always needed.

4. Needless to say, inadequate technological infrastructure is the bane of R&D performance. The case studies show that projects which can secure the support of good and reliable manpower can be completed much faster and more efficiently than those which cannot secure such support. Technical services such as standards, testing, training, information, and consultancy are also raised again and again as non-supportive factors for RD&E, as is the absence of supporting industries such as printed circuit board (PCB) producers and suppliers of other parts and components. As a result, projects spend more time, effort, and resources than necessary.

In order to improve R&D performance in Thailand, lessons extracted from the case studies above indicate that a number of initiatives related to government policy and market mechanisms are required.

1. Topics selected for RD&E projects should be agreed to by all concerned parties; namely, academics, industrialists, and government agencies. This is to make use of each party's knowledge and experience and to make sure that each party has a stake in the project. This is a critical point in determining the success of RD&E projects. In the case of Thailand it is recommended that the government agency (the project funder), the private firm (the product manufacturer), and the university (the researcher) be involved.

2. Private sector participation in R&D projects right from the onset should be required. This is in order to inject commercial aspects into RD&E projects which are presently largely carried out by university researchers. Private firms are prepared to spend more money than expected if project shows positive signs and are also more willing to terminate bad projects which waste effort, time, and resources. In other words, they are flexible enough to use resources in a productive way if they are allowed to share risks and benefits of a project.

3. Management of RD&E projects should be strongly emphasized. This is not only to increase the possibility of commercializing RD&E results, but also to make better use of the time, effort, and resources involved. Project management is required right from topic selection through project execution and market introduction. This marks a sharp difference between successful and unsuccessful projects.

4. Basic technological infrastructure such as technical manpower and services should be secured and invested before spending money on R&D projects. This is to provide a knowledge base and indispensable services to research activity, and hence improve its technical and/or economic success.

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ACRONYMS

AHP	Analytical hierarchy process
ASEAN	Association of South-East Asian Nations
ASIC	Application specific integrated circuit
B	Bachelor
BC	Budget committee
CAD	Computer-aided design
CAE	Computer-aided engineering
CMOS	Complementary metal oxide silicon
CMU	Chiang Mai University
CPI	Consumer price index
CPU	Central processing unit
CU	Chulalongkorn University
D/RDS	Diagnostic/Research Design Service
DISA	Direct invert station access
EC	Executive Committee
ECAP	Electronic circuit analysis program
EE	Electrical engineering
EMI	Electro-magnetic interference
EWS	Engineering workstations
GDP	Gross domestic products
GNP	Gross national products
IC	Integrated circuit
IDS	Industrial Development Support
IRC	International Research Coporation
ITRI	Industrial Technology Research Institute, Taiwan
KKU	Khon Kaen university
KMITL	King Mongkut's Institute of Technology Lat Krabang
KMITT	King Mongkut's Institute of Technology Thonburi
KU	Kasetsart University
KMITNB	King Mongkut's Institute of Technology North Bangkok
LAN	Local area network
LEK 6.0	Linear electronic circuit analysis project
LSI	Large scale integration
MIS/OR	Management information system/Operation research
MNC	Multi-national corporation
MOAC	Ministry of Agriculture and Cooperatives
MOST	Ministry of Science and Technology, Korea
MOSTE	Ministry of Science, Technology and Environment
MRP	Management review panel

ACRONYMS

M.S.	Master of Science
MTEC	National Metal and Materials Technology Center
MU	Mahidol University
NAS	National Academy of Sciences, U.S.A.
NCGEB	National Center for Genetic Engineering and Biotechnology
NECTEC	National Electronics and Computer Technology Center
NIDA	National Institute of Development Administration
NIEs	Newly industrialized economies
NSF	National Science Foundation, U.S.A.
NSTDA	National Science and Technology Development Agency
OA	Office automation
PABXs	Private automatic branch exchanges
PC	Personal computer
PCB	Printed circuit board
Ph.D.	Doctor of philosophy
PIF	Project initiation fund
PLCC	Plastic-leaded chip carrier
PSU	Prince of Songkla University
R&D	Research and development
RD&E	Research, development and engineering
RD&S	Research, development and survey
RIT	Rajamangala Institute of Technology
SMT	Surface mounted technology
SSIC	Small scale integrated circuit
S&T	Science and Technology
STAMP	Support for Technology Assessment and Mastery Program
STDB	Science and Technology Development Board
STOU	Sukhothai Thamathirat Open University
STP	Science and Technology Policy
STQC	Standards, Testing and Quality Control
SU	Silpakorn University
SWU	Srinakharinwirot University
TAC	Technical Advisory Committee
TDRI	Thailand Development Research Insitute
TIAC	Technical Information Access Center
TISI	Thai Industrial Standards Institute
TISTR	Thailand Institute of Scientific and Technological Research
TPA	Technological Promotion Association (Thai-Japan)
TRP	Technical Review Panel

ACRONYMS

USAID	United States Agency for International Development
UST/COST	United States-Thailand Commercialization of Science and Technology Program
VGA	Video graphic adaptor
VLSI	Very large scale integration
VS	Versus

CHAPTER 1 OBJECTIVES, SCOPE AND METHODOLOGY

1.1 RATIONALE AND OBJECTIVES OF THE STUDY

1.1.1 Rationale

In 1985, the Science and Technology Development Board (STDB) was established with the assistance of USAID's Science and Technology Development Project as a project under the Thailand Institute of Scientific and Technological Research (TISTR) of the Ministry of Science, Technology and Environment (MOSTE).* Originally scheduled to end in the latter half of 1992, this cooperative initiative between the Governments of Thailand and the United States of America was extended by USAID to September 1994 after taking into account a recommendation by a mid-term evaluation team.

According to its initial conceptualization, the STDB was to assist Thailand in its endeavors to achieve greater self-reliance in science and technology by enhancing the extent and effectiveness of S&T applications in support of social and economic development in the country. In line with the government's policy of developing three priority technology areas, which it had identified in the Sixth Five-year National Economic and Social Development Plan (1987-1991), the STDB was to concentrate its efforts on solving specific problems in the areas of biotechnology, materials technology, and electronics. In order to do so, the STDB was to focus on four main areas of activity:

1. strengthening the existing institutional framework,
2. reviewing S&T policy
3. supporting research, development and engineering (RD&E).
4. encouraging industrial development & providing technical support to industry.

* Formerly known as the Ministry of Science, Technology and Energy

In addition to STDB, three other national centers were established under the Office of the Permanent Secretary, MOSTE, to function as specialized R&D agencies for each of the three priority technology areas, namely, biotechnology, materials technology and electronics. They are the National Center for Genetic Engineering and Biotechnology (NCGEB), the National Metal and Materials Technology Center (MTEC)*, and the National Electronics and Computer Technology Center (NECTEC). In brief each national center acts as a funding and coordinating agency to facilitate collaboration among the government sector, universities, and private firms in developing Thailand's industrial technology and capacity in each of the three priority technology areas.

The STDB program and the three national centers have since evolved into important S&T resource institutions for the country. Their various activities provide numerous support and services, from identifying user needs and relevant S&T resources or supplies, to organizing or providing funding to address those needs. In view of its vital role for S&T development in the country, legislation of a Science and Technology Development Bill to establish a permanent institution was passed by the Parliament on 30 December, 1991. With the formal enactment of this bill, the National Science and Technology Development Agency (NSTDA) was born, and now operates freely as an independent institution. The Act brings together under its umbrella the above four former institutions of: STDB, NCGEB, MTEC, and NECTEC.

The transformation of the STDB and the three national centers into the NSTDA is bound to have significant implications for the future S&T development in the country, particularly in the three priority areas of technology. As an end-of-project final review of the STDB Project will not be forthcoming until 1994, it has been deemed necessary at this juncture to undertake a partial review of the project so far in order to provide policy inputs for the organization and future planning of the NSTDA. This study is conceived as a component of that review.

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* Formerly known as the National Center for Metal and Materials Technology (NCMMT)

1.1.2 Objectives of the Study

RD&E activities have constituted by far the largest share of the work and funding undertaken by both the STDB and the three national centers mentioned above (NCGEB, MTEC, NECTEC). Given the importance of RD&E for these organizations, as well as for Thailand's future technological development, the purpose of this study is to examine five RD&E projects which have been undertaken in the field of electronics technology in order to determine the strengths and weaknesses of electronics RD&E in Thailand. In so doing, the findings from the case studies are to serve as a guide for policymakers and will also help indicate the future potential of the electronics technology industry.

Using the case study method, each of the five studies is to identify the factors which affected the outcomes of the RD&E projects in question: these include, amongst others, the procedures involved in the selection of projects, the quality of the research teams, levels of funding, appropriateness of subject matters, impacts on industry, timeliness to the market, and support systems. An account of the achievements of each RD&E project will also be made including some of the things that could have been done during the projects but which were not.

1.2 SCOPE OF THE STUDY

The scope of this study is as follows:

1. To conduct a literature review of the Office of the Science and Technology Development Board (STDB) and National Electronics and Computer Technology Center (NECTEC) to examine their conception and implementation.

2. To gather information and opinions related to RD&E programs as well as other aspects of operations of STDB and NECTEC through interviews with a number of administrators, researchers and industrialists who are familiar with electronics technology and with these and other relevant institutes.

3. To hold a workshop for a group of stakeholders, including high-level management staff from NSTDA, industrialists, academics, and the project research teams, in order to reach a consensus on the selection of:

- five or more RD&E project case studies,
- case-study questions and propositions, and
- case-study evaluation criteria.

4. To undertake an investigation of the selected case-studies with the following major goals in mind:

- to determine the outcomes of the RD&E projects and identify the factors that influenced their outcomes,
- to identity any major problems encountered by the projects and the methods used to solve them,
- to outline the common lessons learned from, and the reasons for, the projects' successes and failures, and
- to draw policy implications from the case-study findings.

1.3 METHODOLOGY

The study involves a number of stages with major tasks and activities as follows:

1. An investigation into the status of electronics technology RD&E in Thailand.
2. A detailed design of the case study including propositions for the study, data collection, data analysis linking data to propositions, criteria for case evaluation, and case-study report writing.
3. Selection of at least five RD&E projects supported by STDB and NECTEC as case-studies.
4. Conducting the case-studies according to the case-study design laid down in (2).
5. A presentation of the case-study analysis, common lessons learned, and policy implications from the findings by means of a workshop and formal report.

An account of the status of RD&E in the field of electronics technology was to be made through various means, including a review of records of the Office of STDB and NECTEC, other literature surveys, and interviews with relevant administrators, industrialists, and academicians.

The process of picking appropriate propositions for the case studies, the choice of case evaluation criteria, and the selection of five or more RD&E projects as case studies, was to be carried out through a workshop which was to seek consensus among stakeholders consisting of research teams, high-level management staff from NSTDA, and some external experts from academia and industry. Where necessary, the Analytical Hierarchy Process (AHP) was to be employed as a tool to expedite and systematize the selection of propositions, case evaluation criteria and the case studies.

Based on the framework set by the case-study design, and using the case-study propositions and evaluation criteria identified at the workshop, the research teams were then to proceed with the next stages of the case-study; namely, collecting the evidence, analyzing the evidence, and composing the case-study reports. Sources of evidence were to include RD&E project proposals and reports, physical evidence like sample devices or prototypes, field visits to RD&E project sites, interviews with RD&E project researchers/ investigators and users, and any other sources that were deemed relevant.

In analyzing the findings from the case studies, common lessons about RD&E performance were to be derived and, together with the current status of RD&E in Thailand, policy implications for RD&E in the area of electronics technology were to be drawn.

Results from this study have been presented to a number of stakeholders at a workshop, thus allowing for a discussion of the findings so far and the means of improving them. The workshop also provided background information to the group of participating stakeholders to assist them in the identification of the future potential of the electronics technology in Thailand and to help them derive appropriate strategies for the realization of that potential.

CHAPTER 2 CASE STUDY TECHNIQUES AND EVALUATION CRITERIA

2.1 CASE STUDY TECHNIQUES

Traditionally, there have been prejudices against the use of case study techniques as a method of evaluation. These prejudices have included their supposed lack of rigor, the difficulty of making generalizations, and their time consuming nature. Professor Robert K. Yin* has clearly demonstrated that all these prejudices can be overcome through careful research design and execution. By following his procedures, we hope to make sure that the case studies conducted by our investigators are both thorough and compatible so that common lessons can be drawn from them.

When conducting case study research, the first task is to clarify what questions you are interested in answering. These are the "how" and "why" questions which help define what it is you hope to learn. However, these questions do not by themselves point to what should be studied.

In order to determine how and why certain phenomena occur, propositions that seek to explain their occurrence need to be developed. To take an example, if we wish to know why there is a lack of RD&E researchers in Thailand we may propose that this is because researchers are not well paid. By testing this and other propositions against the available evidence, investigators can focus their attention on certain data and, by proving or disproving a particular proposition, create the basis for generalization.

In this study, multiple case studies are to be used to investigate a number of RD&E projects at the project level. The number of cases need not be large for we are using replication logic instead of sampling logic for making our generalizations. Replication logic is analogous to that used in repeating certain critical scientific experiments and is not the same as sampling logic where a number of samples are assumed to represent a larger pool of a popula-

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* Robert K. Yin, "Case Study Research : Design and Methods"

tion. However, each case must be carefully selected to serve a specific purpose within the overall scope of inquiry.

The analysis of the case study evidence will focus on the theoretical propositions. The dominant mode of analysis will be pattern matching. In addition to the analysis of individual cases, the report will contain sections on cross-case analysis and policy implication derived from the analysis.

In conducting their studies, the investigators will, before venturing out to collect data, prepare a case study protocol consisting of an overview of the case study, field procedures, case study questions and a guide for the case study report. In collecting data, they will look for as many sources of evidence as possible.

During data collection, care will be exercised when checking the consistency of data from multiple sources. A database will be created for data storage and retrieval. Finally, the investigators will have to make sure that they can create a chain of evidence to support their case.

In this particular case sources of evidence are to comprise of documentation, interviews, direct observation, and physical artifacts. More specifically, documentation is to include project proposals, interim and working reports, working papers, final research reports, published papers and articles, correspondence between the research team and its sponsors, and minutes of relevant committee meetings. The interviews can start with the research project leader and could then expand to include other stakeholders of the project. The identification and interviewing of users undoubtedly constitutes a very important component of the study. A field visit to the research project site is deemed essential to provide investigators with certain insights necessary to make judgements, especially relating to intangible aspects of the project, while also allowing for the observation of the research products in action.

2.2 PROPOSITIONS AND CRITERIA FOR EVALUATION

In this study, our task is to evaluate five research projects in the field of electronics which were supported by the STDB and NECTEC. Case selection was made through consultation between the study team and NSTDA officials. One project was selected from the STDB, and four projects were selected from NECTEC using the following criteria:

1. The project has been completed or is almost completed.
2. It has the potential for commercialization and utilization.
3. The selected projects represent a mixture in terms of subject matter, experience of institutions, geographical locations, physical infrastructure, personnel, and research personnel.

On June 3, 1992, a workshop was organized for NSTDA officials, researchers, and industrialists in order to develop the propositions that would serve as the units of analysis for the case-studies. Initially, the researchers proposed five propositions while NSTDA officials added an additional three. Workshop participants were also asked to suggest further propositions (as many as they liked) by writing them down on cards. Each card was then read out and those with similar ideas were grouped together. Following further integration of the various propositions in order to reduce their number to manageable proportions, five main propositions were agreed to as follows:

1. <u>Thai researchers are capable of producing concrete results.</u> Obviously, not all Thai researchers are capable of doing so. Thus, the task of the investigators here is not only to clarify the proposition but also to look for how and why certain groups of researchers succeed while others do not. Some participants suggested that the failure to produce results can be attributed to the lack of professionalism and commitment of some researchers, while others suggested that the full impact of research depends on the results of several related projects, requires multi-disciplinary inputs, and invariably needs a large number of RD&E man-hours. Other possible reasons mentioned included the failure to link RD&E to the advanced education system, the absence of career paths for university researchers, and the lack of creativity

on the part of researchers, which in turn can be traced down to an education system whose ultimate goal is to pass university entrance examinations rather than to encourage independent inquiry.

2. RD&E cannot be achieved without strong technological infrastructure. By infrastructure we mean the manpower, physical research facilities, suppliers, technical and information services, financing mechanisms, laws and regulations, and organizations that support the RD&E process. In this case, investigators are to look into the effects that the lack of infrastructure has on RD&E performance. During the workshop, the participants expressed concerns related to government financial support & fiscal incentives for RD&E, and the monetary rewards and social status for RD&E personnel.

3. RD&E can be better linked to the country's present social and industrial needs. This proposition looks at the demand for, and supply of, RD&E as well as the linking mechanisms at various stages of development. On the supply side, some argue that researchers do not know the country's needs for technology. The demand side is more complex as there is no clear demand or commitment from the private sector to RD&E. Suggestions were made that this is because the private sector is not even aware of local S&T capabilities, while others felt that the overconcern for secrecy on the part of some Thai industrialists prevented more direct communication with local S&T personnel.

4. Commercialization of RD&E needs policy, planning and management. Participants complained of no policy, unclear policy and the inability to link policy with implementation. Some advocated policy directions in which research would lead industry, while others thought that RD&E could be more effective if coupled with international technology transfer activities that would allow for the absorption, adaptation and application of conventional technologies. For this proposition, the investigator's task is to examine how the policy, planning, and management of an RD&E project, from the conception of a research idea to the completion of the project and beyond, can affect the project's commercial success.

5. <u>There are no short-term gains from RD&E projects though there are possible long-term gains.</u> This proposition arises from the concern that the benefits from RD&E should not be limited to short-term, direct and tangible gains. RD&E capabilities will most likely be built up in stages. In the initial stages, RD&E's primary impact may be in human resource development. Even successful RD&E projects require long gestation periods before their economic and social impacts can be felt. Here, the investigators will look for both the short-term and long-term gains from RD&E projects.

During the workshop the participants decided to give each proposition equal weight rather than ranking them using the Analytical Hierarchy Process (AHP) (see Appendix 2.1). In the second session, workshop participants were asked to propose criteria that could be used to evaluate the five propositions. The lists of criteria were compiled and are shown in Appendix 2.2. Although a closer look at the list reveals that not all of them are actual criteria (some sound more like recommended actions) they are, nevertheless, included for the sake of completeness.

The criteria to evaluate the first proposition dealing with the capabilities of Thai researchers can be divided into three categories. The first category concerns academic achievements like number of papers published, knowledge gained and experience gained. The second looks at how a researcher's working environment affects their RD&E capabilities. Surprisingly, quite a number of criteria fell into the third group, which tends to see utilization as the ultimate measure of successful research.

The criteria for the second proposition spelt out what the participants meant when referring to "technological infrastructure". The criteria can be grouped into eight categories: manpower, physical research facilities, suppliers, technical services, finance, law and regulations, institutions, and others. For manpower, physical research facilities, suppliers, and technical services, their number and quality may be used as indications of their adequacy. By finance, we refer not only to the level of funding, but also to how the money is used to fund various aspects of the research. As some laws and regulations can be real hindrance to R&D they were also included. R&D organizations need good management as well as linkages to other institutions.

The last group of criteria deals mostly with intangibles like research atmosphere, previous experience of researchers and the like.

The third proposition relates to the supply of, and demand for, RD&E, as well as looking at the links between the two. Criteria for evaluating the supply of RD&E are much more practically oriented than the ones used to evaluate the academic achievements of researchers in the first proposition and hence more difficult to quantify. On the demand side, the issue is even less clear. Perhaps one of the best indicators for supply, demand as well as the links between the two is the number and size of RD&E projects funded by the private sector.

The fourth proposition concerns policy and management for RD&E commercialization. It is divided into three categories: policy, management, and institutions. We may look at the existence of policy for RD&E promotion as well as its effectiveness, the efficiency of project management, and the institutional framework which supports RD&E.

The fifth proposition tries to measure gains from RD&E from a broader perspective. Criteria can be divided into concrete results, indirect results and time considerations. Concrete results are tangible and visible, including both academic, economic and industrial ones. Indirect results are the by products of RD&E, and are also sometimes quite tangible. The final set of criteria suggest that the visible effects of any gains, whether concrete or indirect, are likely to materialize during different time periods depending on the time it takes them to filter through the socioeconomic system.

This workshop received favorable feedback from the participants. They thought that the card technique allowed them to express their ideas in parallel and without hindrance. The intensity of communication was much higher than the traditional "one speaker at a time" approach. Thus, an atmosphere of participation was created.

APPENDIX 2.1

ANALYTICAL HIERARCHY PROCESS (AHP) METHOD

1. INTRODUCTION

In the ten years since its introduction, the AHP has been used by decision makers to gain insight into a wide variety of complex, costly, and important decision problems. Golden, Wasil, and Levy provide over 150 reference papers that apply the methodology in 29 different areas, ranging from health care to space exploration. While many of these papers apply the AHP to real-world problems, few provide detailed insights into the practical considerations that users (such as the conductors) must address in order to facilitate a successful decision-making process. Thus, this paper aims to review the decision-modelling process when applying the AHP to solve problems.

2. STEPS IN USING THE AHP

In using the AHP, a single decision maker or a group usually proceeds from problem identification, through an assessment of alternatives, to the final selection of a course of action. The overall process consists of the following ten steps.

Step 1: Define the Problem

It is important to establish whether the decision problem concerns the allocation of resources, the choice of the best alternative, or the planning of a future course of action. Once this has been clearly defined, the facilitating team can provide advice on the development of a workable structure to tackle the problem. A workable structure must cover all factors and must properly relate alternatives to objectives, possibly through an intermediate level of criteria. Members of the facilitating team with experience in applying the AHP and an Management Information System/Operations Research (MIS/OR) background usually possess the skill required to determine the general outline of a hierarchy that is appropriate for a particular problem.

Step 2: Select the Decision Group

The facilitators assist the client in the selection of a decision-making group. This group could include senior decision makers, technical staff, and advisors (from outside the department or organization) with an external perspective on the problem. It is important to select a group which collectively has the necessary expertise and information to "attack" the decision problem. Sometimes external advisors may be clients of the organization which the decision is intended to benefit. Furthermore, if the decision must stand up to outside scrutiny, it may be essential to include potential adversaries in the group. Typically, groups consist of six to twelve members but larger groups can also be used. We point out that the decision-making process is more "efficient" (mainly faster decisions) in smaller groups (12 members or less). However, "effective" decision making (acceptance of the final decision and easy implementation) often requires a large group so that all stakeholders can be represented.

Step 3: Identify Issues and Objectives

The first task of the group is to identify the issues and objectives which need to be considered in the decision. This step is important since it solidifies the group with a specific decision-making, problem-solving focus. The facilitators assist by helping to identify important factors, recording them, and by preparing draft definitions in written form. The facilitators continually funnel written materials to the group so that details are documented and potential problems over semantic issues are averted. This allows the group to focus on the task of generating pairwise comparison matrices for the criteria and alternatives.

Step 4: Develop the Structure of the Hierarchy

The decision-making structure is an organized, hierarchical depiction of the decision problem in terms of the choices to be made, the objectives that are to be pursued, and the interests and criteria that must be taken into account. It is constructed by the group with the help of the facilitators

Step 5: Judge the Importance of the Decision Factors

Once a workable decision-making structure has been established (i.e., a structure that covers all factors and models the problem), the next step is to judge the importance of the decision factors. Factors are evaluated in a pairwise manner. Decision makers are asked to verbally judge two elements in terms of their relative importance to the objective to which they contribute. The verbal judgments are then converted into a numerical scale and entered into a computer program that performs the mathematical calculations and produces a set of weights. Woods Gordon developed a mainframe computer package which is used on time sharing for very large hierarchies. This program contains several features designed to tally scores for projects with a large number of alternatives. The Expert Choice microcomputer package is used for problems that contain a smaller number of criteria and alternatives. We should point out that factors shown to have little importance can be dropped at this stage of the process.

Step 6: Evaluate Alternatives

The decision alternatives that appear at the bottom level of the hierarchy are compared by the decision-making group.

Step 7: Report on Results

The judgements of the group are synthesized and the overall priorities of the alternatives are calculated.

Step 8: Check Reasonableness

The group must allow time to consider the reasonableness and the implications of the AHP result. It is possible that some of the results may not seem appropriate once the decision makers have "stepped back" from the element by element evaluation and have had time to consider the results of the process. It is important to provide an opportunity for the decision makers to think through and understand the implications of the decision and, if necessary, to revise the process. For example, a revision is necessary when a key decision factor has been omitted or the hierarchical structure fails to take into account an important consideration. The group would then "backtrack", that is return to earlier steps in the decision process and revise judgments, factors, or alternatives. This step also allows the group to recover from any "buyer's remorse" about the final decision. The consultants should always be willing to address any criticisms about the analysis so that the group can realize that the final results are sound and not the result of some mysterious decision process.

Step 9: Finalize Choices

Once the reasonableness of the results has been carefully checked, the decision-making group convenes to resolve any outstanding issues and to finalize their decision.

Step 10: Documentation

The final step involves documenting the decision-making process. It helps to reinforce the soundness of the approach and also allows the group to easily review the process should the problem's characteristics change. A formal report would be drafted that states the definitions of decision factors, includes judgments about the factors and their importance, and documents the underlying rationale of the selection process. The report ranges in length from 20 pages to over 200 pages depending on the complexity of the project. Initial drafts of the report are circulated during the actual decision-making process and the report continues to evolve in the form of handouts for the workshop sessions. After the decision process is finished, the document usually requires only minor editing before it is completed.

A full project that followed these ten steps would last about eight weeks. This assumes three workshop sessions with the decision group. The first workshop is held in week 2 or 3 to identify broad issues and objectives. The second workshop, which occurs in week 4, is the main decision-making session in which the group would develop the hierarchical structure, judge the importance of the decision factors, and evaluated the alternatives. For a problem with a large number of criteria and alternatives, this session could span two days. The final workshop occurs in week 7 and is devoted to reviewing the results of the group's deliberations and to finalizing the group's decision.

APPENDIX 2.2

CRITERIA FOR EVALUATION OF THE FIVE PROPOSITIONS

<u>Proposition 1</u> Researchers can provide concrete results

a) <u>Academic</u>
- Number of papers published
- Number of seminars given
- Number of grants received
- Number of citations
- Number of M/Ph.D. graduates
- Prototypes (products and processes)
- Quality manuals
- Problems solved, knowledge learned, experience gained
- Knowledge learned applicable to university's teaching
- Adaptive and innovative steps
- RD&E results meets proposal objectives
- Expert judgement

b) <u>Environment</u>
- Background of researchers
- Commitment and devotion of researchers
- Physical research facilities
- Research atmosphere

c) <u>Utilization</u>
- Economic returns
- Number of patents
- Marketable products
- Potential for export
- Benefits to end users (agriculture and industry)
- Social impact
- Technological spill-over
- Strategic research needs

<u>Proposition 2</u> RD&E needs technological infrastructure

a) <u>Manpower</u>
- Research staff (Number and quality)
- Number of M/Ph.D. graduates
- Researcher's work load and types of duties
- Number of technicians/research assistants
- Training and coaching of researchers

b) <u>Physical research facilities</u>

c) Suppliers
- Suppliers of parts and components
- Supporting industries
- Time taken for equipment acquisition

d) Technical services
- Information on modern technology (literature, computer database access)
- Standards and testing capability
- Established S&T indicators (statistics)

e) Finance
- Level of funding
- Remuneration to researchers
- Rewards
- Bureaucracy in grant management

f) Laws and regulations
- Intellectual property protection
- Import tax on research equipment and supplies

h) Institutions
- Management of organizations
- Cooperation between laboratories and institutions
- Linkage between industry and know-how centers
- Strong graduate study program

i) Others
- Research atmosphere
- Related projects
- Length of research time in an area of expertise
- Division of labor based on expertise
- Geographical location
- Government support for S&T

Proposition 3 RD&E lacks supply, demand and linkage

a) Supply
- Solution to problem, application-oriented
- Technology transfer component
- Selection of research topics
- Benefits to end users
- Number of papers published
- Number of works with private sector
- Number of patents (sold)
- Prototypes
- Consultancy

b) Demand
- Size of market
- Private sector participation
- Competitive pressure to induce demand for technology
- Tax incentive for RD&E in industry
- Clear private sector demand
- Number and size of R&D projects funded by private organizations
- In-house capabilities of production enterprise

c) Linkage
- Researchers are bad salesman
- Build up linkage organization
- Economic incentives for linkage
- Coordination with other research groups
- Manufacturing associations to promote linkages
- Advertisements of real problems and skills available
- Understanding, collaboration and intensity of communication between researchers and private company

Proposition 4 Commercialization needs policy and management

a) Policy
- Clear policy
- Tax as an obstruction
- Integrate policy with implementation
- Existence and effectiveness of policy and management organizations
- Clear understanding of RD&E objectives
- Explicit RD&E policy of private sector
- Incentive to commercialize local RD&E work
- Government commits reliable financial support to project with well-defined goals and realistic time frames

b) Management
- Project management
- Marketing and business strategy
- Private sector participation
- Cost-benefit ratio
- Comparative earnings between professionals
- Bureaucracy in grant management
- Strong leadership
- Response to private sector demand
- Closely monitor targets of R&D project
- Understand industrial and social needs
- Understand R&D process and product innovation
- Inadequate use of liaison personnel
- Exposure of prototypes and researchers to public
- Procedure that research and industry must go through in order to commercialize
- Involvement of high-ranking government officers in promoting commercialization
- Convince industry to exploit RD&E for commercialization

c) Institution
   - Pragmatic support program in commercialization
   - Improve support industries
   - Commercialization organization required

Proposition 5 No short-term gains from RD&E

a) Concrete results
   - Patents, royalties, licensing agreements
   - Marketable products
   - Demand from users
   - Economic value
   - Number of papers published
   - Improved products/processes

b) Indirect results
   - Number of students in the research project
   - Number of new researchers
   - Knowledge learned and transferred
   - Creditability
   - Publicity
   - Capability strengthening
   - Researcher-user linkage

c) Time considerations
   - Time span taken to commercialize RD&E results
   - Depth of knowledge gained as a function of time
   - Size of research team as a function of time
   - Potential for future benefits
   - Size or complexity of technology
   - Nature of RD&E projects (e.g. adaptive VS innovative)
   - Categorization of research types (e.g. basic, applied, development)
   - Should not emphasize short-term gain but concentrate on human resource development and research quality
   - Short-term gain possible if research is problem-oriented
   - Market size for expected RD&E output

CHAPTER 3 RD&E IN THAILAND

3.1 AN OVERVIEW OF R&D IN THAILAND

Many countries, particularly industrialized and newly industrialized countries, invest up to 3% of their annual GNP on R&D. The reason is simple: R&D is an essential component in the creation of strong capabilities in high technology as well as in manufacturing. With many high technology fields undergoing rapid growth and in light of their high value, having the ability to compete in these fields can lead to higher levels of wealth generation and hence to higher standards of living for a country's citizens.

3.1.1 R&D in the Industrialized World

If we consider the country with the world's largest GNP, the U.S.A., the National Science Foundation (NSF) estimated that in fiscal year 1990 about US$ 150 billion was spent on R&D in all fields, which translated into about 2.8% of the country's GNP (or two times Thailand's total GNP in the same year). According to a more recent NSF report, the U.S. had 77 full-time R&D professionals per 10,000 of population in 1988, or nearly 2 million R&D personnel.[1] To compare Thailand had in 1987 a mere 4,000 researchers, or the equivalent of less than 1 researcher per 10,000 population.

Contrary to what is generally believed among developing countries, Thailand included, private sector firms in most industrialized countries account for a much greater share of R&D expenditures than governments. Most companies set aside a substantial portion of their sales revenue for R&D, either for in-house R&D laboratories or for contracting out to independent research organizations. This is particularly true in rapidly developing and high growth technological industries such as biotechnology, advanced materials, and electronics, where the share of revenue used for R&D expenditure is often the greatest.

Looking at the field of electronics, we can note that many of the top electronics companies in the industrialized world spend a percentage of their revenues on R&D which is often far in excess of their countries' overall average spending on R&D (see Table 3.1). To take some examples, IBM Corp. of

Table 3.1 Top Electronics R&D Spenders in Relation to Sales

Country	No. of Companies	R&D Expenditure (US$ millions)	Sales (US$ millions)	Percent of Sales
Canada	3	727	5,448.0	13.3
France	5	3,755	40,499.0	9.3
U.S.	52	44,146	546,038.4	8.1
Germany	12	8,759	128,379.7	6.8
U.K.	7	2,346	36,111.1	6.5
Japan	22	16,854	280,305.8	6.0

Source: Compiled using Elsevier Advanced Technology data cited in IEEE Spectrum [October 1990 [1]]

of the U.S. spent US$ 44 billion or 8.1% of sales on R&D in 1989, Siemens AG of Germany spent US$ 8.7 billion or 6.8% of sales, while Philips of the Netherlands spent US$ 2.3 billion or 8.2% of sales. Indeed, some companies' R&D expenditures are so enormous that they can amount to a considerable percentage of a nation's R&D budget: Thomson-CSF's R&D budget in 1988 represented 43 percent of France's total R&D budget for electronics, and 5.5 percent of the country's total R&D budget.[1]

Although the figures quoted above are often very large, it is nevertheless hard to firmly establish a direct relationship between R&D and subsequent profit growth. However, of one thing we can be sure: R&D is a vital source of innovation, and less innovative firms are likely to be less competitive, particularly in high-tech industries and services.

3.1.2 A Look at South Korea and Taiwan - the NIEs of Asia

Many newly industrialized and developing countries such as South Korea, Taiwan, Brazil, India and China have made and continue to make considerable R&D investment in areas which they have deemed as vital components of their industrial and social development.

In South Korea, there are currently at least 12 national research institutes under its Ministry of Science and Technology (MOST), many of which have played an important role in the country's technological development and industrial growth. Although many of these institutes were under various ministries for a number of years, the government decided in 1981 that further development in a number of strategic industries demanded high technology and large-scale multidisciplinary R&D projects; thereby leading to the reorganization which placed these institutes under MOST's tutelage.

Throughout the 1980s, these national research institutes actively collaborated with the private sector in undertaking R&D projects whose aim was to save resources and strengthen the country's international competitiveness. With the government providing between 50 to 70 percent of project funds and the private sector contributing the remaining funds, the number of national R&D projects grew from just 25 in 1982, to 54 in 1985 and 151 in 1989.

In addition to these national R&D institutes, the South Korean government has also encouraged the private sector to set up its own in-house research laboratories through the use of tax incentives and financial assistance. As a result, many of South Korea's Chaebols (conglomerates) now maintain large and modern research laboratories that rival those of the national research institutes in both scale and resources.

As a whole, the total amount of R&D expenditures which the country has invested has increased rapidly from just US$ 7.7 million in 1965 to US$ 480 million in 1980, and US$ 3,870 million in 1988; an increase of over 500 percent in just a little over two decades.

In 1988, South Korea's R&D expenditures represented about 2.1% of its GNP, of which the private sector shared up to 75% of the expenditures. In the same year, the country had some 56,500 researchers working among over 2,800 research institutes, representing a ratio of 13 researcher per 10,000 of population (see Table 3.2).

Like South Korea, the Taiwanese government has actively promoted applied research and technology development through a number of state R&D institutes, which include (among others) 36 research institutes under the Ministry of Economics and 4 under the Ministry of Communications. In addition to promoting basic research activities in the country's universities, the government has also encouraged private firms and state enterprises to set up their own in-house research laboratories to develop their products and services.

Table 3.2 A *Comparison of* R&D Infrastructure among South Korea, Taiwan and Thailand

	South Korea	Taiwan	Thailand
Population	('90) 43.0 M	('90) 20.2 M	('90) 56.6 M
GNP per Capita (in US $)	('90) 4,968	('90) 7,990	('90) 1,191
GNP growth	('90) 6.8%	('90) 5.2%	('90) 10%
Inflation CPI	('90) 9.4%	('90) 4.1%	('90) 6.8%
Student graduate (S&T)	('89)	('87) 249	('90) 5
Ph.D	19,429*	4,103	525
M	NA	38,829	5,076
B			
S&T Researchers	('88) 56,500	('88) 35,437	('89) 4,084
per 10,000 population	13.0	17.8	0.74
per 10,000 persons in labor force	27.0	41.8	1.3
R&D Investment (in US $)	('88) 3,870 M	('88) 1,559 M	('89) 114 M
% of GNP	2.10	1.22	0.17
share of private R&D	74.5%	43.2%	5.53%

Note: * Figure represents combined Ph.D. and Master degree enrollment

Source: 1. MOST, South Korea

2. Taiwan Statistical Data Book, 1989.

3. National Research Council and NESDB, Thailand

Notable among the government's research institutes is the Industrial Technology Research Institute (ITRI), which is a good example of the government's initiative in assisting Taiwan's industrial sector. ITRI is particularly active in helping small and medium-size industrial firms become competitive through the provision of technical services, training, and contract research for the private sector.

Although investment in R&D in Taiwan has not been as heavy as in South Korea, Table 3.2 shows that in 1988 the country still managed to invest US$ 1,559 million or 1.2% of its GNP for R&D, of which 43% came from the private sector. Moreover, in the same year, there were over 35,400 researchers in Taiwan, or some 18 researchers per 10,000 of population, which was actually a slightly higher ratio than South Korea in the same year.

Looking to the future, ITRI estimates that by 1995 Taiwan's R&D investment should increase to 2% of GNP, of which the private sector share is expected to rise to 60% (compared with 40% a decade ago). The number of S&T researchers is also expected to increase to 43,000, or some 20 researchers per 10,000 of population.

As this brief overview suggests, both countries have shown and continue to show high levels of commitment to R&D investment, both in the development of R&D infrastructure (e.g. government sponsored research institutes, adequate research personnel) and in a willingness to involve the private sector in R&D. It would be fair to say that such a commitment to R&D has played, and will continue to play, a large part in these countries' social and industrial development.

3.1.3 Thailand: Still to get its Acts together

In contrast to some of its neighbours Thailand has so far failed to develop any significant technological capacity, save for perhaps in the area of agro-industry. The best illustration of this fact can be made by comparing some vital statistics on R&D infrastructure with those of South Korea and Taiwan. Although both South Korea and Taiwan have, unlike Thailand, already attained the level of newly industrialized economies (NIEs), such a comparison can be a useful indicator of what it may take for Thailand to attain such a level (see Table 3.2 for following statistics).

Beginning with R&D investment, Thailand spent a meagre US$ 114 million on R&D in 1989 compared with US$ 1,559 million for Taiwan in 1988 and US$ 3,870 million for South Korea in 1988. More significantly, as a percentage of GNP these figures were equal to 0.17% for Thailand, 1.22% for Taiwan and 2.10% for South Korea. Looking at the share of private sector in R&D investment the figures are even bleaker, with private sector funding accounting for 5.5% of R&D in Thailand (1989), 43% for Taiwan (1988) and 75% in South Korea (1988).

Although, as we mentioned above, the number of researchers in Thailand inevitably pales in comparison with the number in the U.S, the situation does not turn out to be significantly better when Thailand's record is set out against that of her regional neighbours. Thailand's ratio of 1 researcher per 10,000 population, as against about 18 per 10,000 population in Taiwan, and 13 per 10,000 of population for South Korea in 1988, does not augur well for the future of R&D in Thailand. Moreover, the figure for Thailand includes full-time equivalent researchers, many of whom are not engaged in full-time research, thus additional factors like the efficiency and devotion of researchers as well as the research environment are not accounted for. We could also add that Thailand's poor R&D infrastructure inevitably leads to less efficient research, thus making it difficult to compare the value of a researcher in Thailand with that of their colleagues in other countries.

The final, and perhaps most important, factor with which to compare the R&D efforts of Thailand with her regional neighbours relates to the number of science and engineering graduates, particularly postgraduates, which are being produced.

In 1990, Thailand produced only 5 Ph.Ds, 525 master-degree holders and 5,076 bachelor-degree graduates. This is in stark contrast with Taiwan, a country with less than 40% of Thailand's population, which turned out 249 Ph.D. holders in 1987, 4,103 master-degree and 38,829 bachelor-degree graduates. The conclusion here is clear: no matter how much the country may increase its future investment in R&D, any development of R&D (and hence technological capacity) cannot be achieved without adequate and well-trained R&D personnel. The failure to recognize and rectify this situation may yet play a large part in undermining any future efforts which Thailand makes to develop its R&D capacity, as it is doubtful whether the efforts of the STDB and other national centers to provide S&T scholarships to train postgraduate students, however praiseworthy, will alone be sufficient to overcome this potential bottleneck.

As we have shown, Thailand still has a long way to go before it can match the efforts of some of the NIE's in the field of R&D, both in terms of R&D funding, infrastructural development and manpower production. Indeed, Thailand needs to develop a much more active approach to R&D if it is even to begin to compete with regional heavyweights like South Korea and Taiwan.

Having outlined some of the broader indicators of R&D capacity we can now turn to an examination of more specific indicators which can further illustrate the extent, or the lack thereof, of technological development in Thailand. These include, amongst others, the level of R&D funding by sector and the extent of payments for foreign technology acquisition.

As we mentioned at the beginning of this section, most of the country's R&D activities have focused mainly on agriculture. Others areas which have received a significant proportion of R&D funds include social development and medical and public health.

As shown in Table 3.3, taken from a TDRI study,[2] the breakdown of research, development and survey (RD&S) budgets classified into areas of development confirms the emphasis of research on the agricultural sector. With the exception of 1987, the research budgets allocated to agriculture ranged from one third to over half of the country's total budget in RD&S during the decade from 1978 to 1987, and it has only been in recent years that other areas have managed to make any impact on the overall distribution of the RD&S budget.

Nevertheless, even in the best year R&D still only represented 0.4% of the nation's GNP, and this is without subtracting the survey component which could vary widely from year to year from as little as 10% to over 30% of the total. Moreover, the figures indicate that from 1978 to 1987 there was no discernible increase either in the percentage of GNP or the percentage of the national budget devoted to R&D.

Table 3.3 R&D and Survey Budget of the Whole Country by Area of Development (million baht)

Area of Development	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Agriculture	797	559	661	1,024	1,097	920	1,783	1,464	1,188	734
Industry & Energy	109	131	141	248	147	128	717	783	573	223
Natural Resource	2	2	3	151	51	17	31	370	534	N.A.
Environment & Conservation	15	25	22	29	25	54	16	109	50	N.A.
Communi. & Transport	48	64	107	170	172	68	51	46	27	2
Science & Technology	101	97	82	208	175	N.A.	N.A.	N.A.	N.A.	314
Medicine & Public Health	79	121	87	74	117	130	105	178	225	218
National Defense	137	164	200	222	824	0	42	16	14	59
Social Development	43	37	44	145	183	86	280	99	164	575
Education, Religion & Culture	21	23	9	52	175	35	87	128	210	181
Other Areas	116	108	151	226	305	217	183	280	160	360
Total	1,468	1,331	1,507	2,549	3,271	1,655	3,295	3,473	3,145	2,664
(as % of GNP)	0.32	0.24	0.22	0.33	0.40	0.18	0.34	0.35	0.30	0.22
(as % of National Budget)	1.81	1.45	1.38	1.82	2.03	0.94	1.72	1.66	1.44	1.17

Note: 1) 1978-1983 From National Budget Alone
2) 1984-1987 From National Budget and Outside Fundings
3) The 1987 figure does not include the survey budget

Source: National Research Council, MOSTE (1987)

Not surprisingly, given the lack of R&D investment in Thailand, expenditure on the acquisition of foreign technology (see Table 3.4) rose from 1,433 million baht in 1982 to 5,334 million baht in 1989, which represented an annual growth rate of 20.6 percent (in current terms). The rapid expansion of

Table 3.4 Remittance for Foreign Technology Licensing

(Unit : Million baht)

Year	1982	1983	1984	1985	1986	1987	1988	1989
Amount	1,433	1,611	1,954	2,022	2,036	2,383	3,440	5,334
Growth	-	12.4%	21.3%	3.5%	0.7%	17.0%	44.4%	55.1%

Source: Ministry of Science, Technology and Environment

the economy in 1988-1989 caused in part by the rapid expansion of the manufacturing sector led to especially high growth rates in technology acquisition expenditure which, in those two years, exceeded 40%.

Thus, in spite of having the highest real economic growth rates in the world from 1988 to 1990, Thailand's rising payments for foreign technology combined with a weak state of technological development suggest that Thailand can be expected to remain largely dependent on foreign technology, at least into the near future.

3.2 THE ROLE OF THE SCIENCE AND TECHNOLOGY DEVELOPMENT BOARD (STDB)

3.2.1 The Establishment of STDB

The Science and Technology Development Board (STDB) came into being in July 1985 with the appointment of the STDB Board of Directors. The establishment of STDB was essentially the outcome of the initiatives in collaborative science and technology development efforts between the U.S and Thai governments which had begun in 1983.

With the formal signing of an agreement in April, 1984, during the state visit of former Prime Minister Prem Tinsulanond to Washington, D.C., a team of experts from industry, universities, and government agencies in the U.S. was provided by the U.S. National Academy of Science under the assistance of the USAID Science and Technology for Development Project. Led by Dr. Ernest Briskey, the team began to undertake the task of designing an S&T development project with their Thai counterpart - the Thailand Science and Technology Program Advisory Council.

The underlying concern of the project was how Thailand could best develop self-reliance in S&T for the purpose of industrial development given the various constraints on science and technology development in the country, and at a time when the country was experiencing rapid industrialization. This rapid industrialization, led by strong export growth and an influx of foreign investment from countries who found Thailand's manufacturing costs highly competitive, suggested the need for more active S&T policies if the country was to reduce its reliance on foreign technology. The philosophy behind the project design was "problem oriented, opportunity focused, and demand driven".[3] A number of special studies were commissioned to provide up to date background material to the project design team. These included the "Status of Science and Technology in Thailand", "Constraints to Thai Development: Role of Science and Technology," and "Key Problems in Science and Technology in Thailand".

3.2.2 The Mission of STDB

The STDB was set up as an organizational "driving force" which would be responsible for the development of a rational S&T support system that would enhance national productivity and was conceived with the main goal of "providing an institutional framework to achieve self-reliance in science and technology in Thailand".[4]

The purpose of the STDB Project was to develop STDB into a S&T institution to support the acquisition of the following capabilities:

- to make deliberate, rational choices between importing specific technologies or developing them locally;
- to import suitable foreign technologies on favorable terms;
- to adapt imported technologies to suit local conditions;
- to generate new products and processes through domestic RD&E where appropriate and plausible;
- to achieve technological mastery in application of these technologies; and
- to sustain, advance and diffuse all these capabilities through education and training and through the continuing development of the S&T institutional infrastructure.

In short, STDB was designed to carry out the mission of enhancing the "effectiveness and extent of public and private sector applications of S&T to Thailand's development".[4]

3.2.3 Four Main Areas of Activity

Having being entrusted with the goals outlined above, STDB's activities were then grouped into four main elements: (a) strengthening the existing S&T institutional framework; (b) science and technology policy; (c) research, development and engineering (RD&E); and (d) industrial development support.

a) Strengthening the Existing Science and Technology Institutional Framework

This element of STDB's activities aimed to create opportunities for interaction and cooperation between users and producers of RD&E; to establish effective linkages between the industrial/agricultural sectors, the RD&E community, and government policymakers/regulators in order to achieve an optimal management and utilization of S&T resources; and lastly, to lessen local dependence on foreign technology by enhancing Thai RD&E capability, particularly in key priority areas.

In short, the program sought to build a framework which would provide an avenue for the establishment of links and cooperation among company chief executives and technical professionals, university and other public sector RD&E personnel, and government policymakers and administrators, using the STDB as a broker.

b) Science and Technology Policy (STP)

The STP Program's main objectives were "to influence policies and practices in the country in order to stimulate the development and utilization of S&T capabilities and to upgrade the S&T policy analysis capabilities in Thailand". In order to achieve these objectives, the program financed activities to:

- strengthen the capacity of public and private sector organizations to undertake their own necessary policy studies,
- analyze important policy issues through policies studies,
- support and promote professional exchanges and active interactions between policy analysts and relevant policy planners and decision makers beyond the usual dissemination methods of publications, seminars and conferences.

c) Research, Development and Engineering

RD&E activities which were considered fundamental to industrial development focused on three priority areas: biotechnology and genetic engineering, materials and metals, and applied electronics and computers. Emphasis was placed on the development, transfer, and use of technology to enhance the industrial competitiveness of Thai industries. RD&E activities were carried out by S&T personnel in universities, government research institutes and agencies, as well as private firm laboratories. Out of a total budget earmarked for the STDB Project of about US$ 49 million, an amount of US$ 30 million was allo-cated to support RD&E activities.

RD&E activities funded by STDB could be further sub-dividual into three programs: designated RD&E, competitive RD&E, and company-directed RD&E.

The Designated RD&E Program provided funding support to selected institutions to work on problems which had been designated as high priority. These RD&E projects were designed to build up institutional capacity by solving current as well as future problems faced by the industry in a particular area through the provision of the necessary S&T infrastructure.

The program also aimed to assist designated RD&E institutions to link themselves with relevant leading institutions in the U.S. This was done by allocating funds within each designed RD&E project for technical support from the linked institution in the U.S.

The Competitive RD&E Program was directed principally at solving specific private sector problems. These projects were expected to develop improved or new processes/products, or to improve state-of-the-art technology in industry which could be relevant to the country's industrial growth.

The projects that came under competitive RD&E activities were mostly demand-driven and geared to the needs of firms. Nonetheless, these RD&E activities have helped and will continue to help build technological capacity among RD&E institutions.

The Company-Directed RD&E Program aimed to stimulate the building of RD&E capabilities within small and medium-sized Thai firms. The objective was to promote and facilitate these firms' ability to undertake self-directed RD&E activities.

Originally, assistance provided to these firms came in the form of low interest loans from a pool of funds supplied by STDB, the government, and three financial institutions who administered the fund. Though loans were offered at attractive rates, firms seeking them were required to back them up with collateral. This requirement resulted in low participation rates and prompted changes that allowed the incorporation of a grant component to the program whereby participating firms shared 50% of the project costs.

Under this program, firms could undertake in-house RD&E or could seek to take advantage of the S&T resources within universities and government laboratories.

Implementation procedures:

For Designated RD&E project funding, the process began with the identification of designated areas of RD&E by the STDB, after which project proposals were solicited from research institutions and universities. The ensuing proposal review process consisted of the following formal steps:

1. Preliminary proposal screening by STDB officers to assess suitability and ensure that they meet proposal preparation guidelines and project criteria.

2. Review of proposals by the Technical Review Panel (TRP) to assess the technical aspects of the proposed project.

3. Review of proposals by the Technical Advisory Committee (TAC) to ensure that all or most of the project criteria are met, as well as to set priorities between competing proposals.

4. Approval of the proposals by the Executive Committee (EC) which gives the overall assessment and approval in principle.

5. Review of the project's proposed budget by the Management Review panel (MRP) (later called the Budget Committee or BC) to make revisions in the budget where necessary with the approved project's principal investigator before final formal agreement was signed.

Membership on the three key committees (TAC, EC and MRP/BC) was made up of STDB senior management staff, representatives from a number of relevant ministries and government offices and, in the case of the TAC and EC committees, representatives from the private sector. NAS was also represented on the TAC committee and USAID had an observer on all three committees.

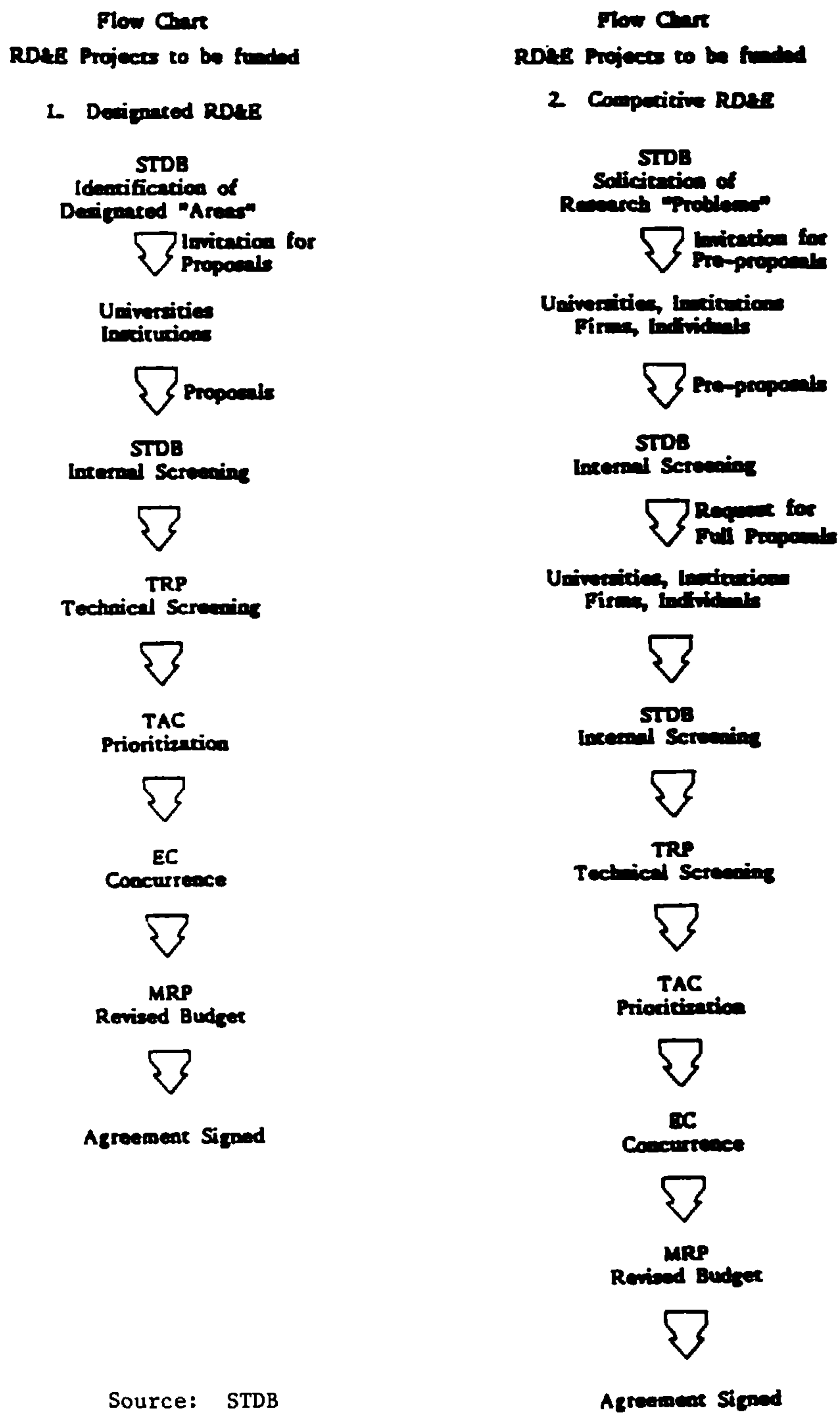
The funding process for Competitive RD&E projects was essentially the same as that for the Designated RD&E, with the exception that it required an additional step which involved the submission of a short project pre-proposal (of about 2 to 5 pages in length). Those eligible for funding included research institutions, universities, firms, or even individuals. Once the pre-proposal was judged by STDB officers to be appropriate and of good potential, a full proposal was requested and was then followed by the proposal review process described above.

The procedures for Designated and Competitive RD&E funding are shown in a flow-chart in Figure 3.1.

For the company-directed RD&E projects, the process was much less complicated. Firms applying for grants started by submitting a short and simple application form provided by the STDB which was then reviewed by a program officer. If the proposal was deemed worthy of support, the officer submitted his recommendation to the Program Committee consisting of senior STDB staff, the Team Leader of the NAS Technical Assistance team and a DTEC representative with a USAID observer. Projects approved by this committee were final and would be reported to the EC for acknowledgement purposes only.

The Graduate Fellowship Program was considered to be an RD&E support program whose aim was to increase the number of M.S. and Ph.D. professionals in the three priority technical areas which faced an acute short supply of such professionals. The program also funded workshops, conferences and other professional exchanges in support of RD&E activities. The program made

Figure 3.1 Process in Funding RD&E Projects by the STDB



Source: STDB

provisions to finance 210 Ph.D. and M.S. degree fellowships in leading Thai universities well staffed by overseas-educated faculty members.

Candidates seeking fellowships would need to be nominated by university faculties with ongoing graduate programs in the three priority areas. Applications were judged and selected based on considerations of the applicant's academic record and work experience (if any), the expressed study and/or research interest, and faculty members' opinions on the applicant's research potential.

d) Industrial Development Support (IDS)

The fourth element which made up STB's activities included the following components:

- Standards, Testing and Quality Control Program (STQC)
- Technical Information Access Center Program (TIAC)
- Diagnostic/Research Design Service Program (D/RDS)

The STQC Program aimed to strengthen standards and metrological capability for calibration. It also sought to improve modern quality control systems and practices in order to raise the quality standards of local products; particularly those destined for export markets with their stringent standards and safety requirements. STDB provided funding to finance short and longer term technical assistance to standards, testing and quality control organizations. This funding was used to upgrade personnel (through workshops and training in the U.S.) as well as equipment which could then be used to improve the quality of a number of specifically targeted products.

The TIAC Program was set up to create and operate a modern information service to provide reliable, up to date and low cost business, technical and scientific information to both the scientific and the industrial/business communities in Thailand. The program sought to subsequently develop Thai S&T databases and eventually evolved into an on-line S&T database vendor.

The D/RDS program's objectives were to stimulate the development of a Thai technical consulting services industry and to promote a greater awareness and utilization of these services by local firms; particularly in cases where firms needed to diagnose technical problems or design RD&E activities to solve those problems.

The mechanism used to achieve the program objectives was to contract an outside organization to act as a broker to bring together the users (industrial/business firms) and the providers (S&T experts in universities, public laboratories and private consulting firms) of technical consulting services. Major RD&E activities designed to tackle important problems faced by Thai industry which had been identified could then be given further RD&E financial support by the STDB.

e) New Programs Outside the STDB Project Paper

In addition to the activities carried out under the four main elements contained in the original STDB Project Paper, three other new programs were subsequently initiated, two in 1990 and one in 1991.[3]

The first new initiative in 1990 was the Support for Technology Assessment and Mastery Program (STAMP), which was to assist firms intending to acquire foreign technology. Assistance provided came in two forms: provision of matching funds and expert assistance in selecting the most appropriate technology for their requirements; and the Project Initiation Fund (PIF), which sought to enhance the chances of success of proposed or on-going RD&E projects which were considered to have significant potential benefits for the country's technological and/or economic development.

The latest initiative launched in 1991 was the United States - Thailand Commercialization of Science and Technology Program (UST/COST). The programs four main objectives included:

1. the facilitation of the commercialization of RD&E projects and available technologies, both Thai and foreign;
2. the identification of key U.S. experts to liaise U.S. and Thai technology suppliers and users;
3. the encouragement of commercial cooperation among Thai and U.S. private sectors;

4. the stimulation of the sharing of technology, financing and management expertise between firms by means of joint-ventures, licensing agreements or technology transfer.

3.2.4 Work Accomplished

During the nearly seven years of STDB operations from July 1985 to April 1992, the STDB Project has proved to be an interesting and innovative cooperative initiative between the government of Thailand and USAID in developing S&T capacity for industrial development in Thailand.

In a mid-term evaluation report[5] of the STDB Project by a 4-member team headed by a U.S. professional S&T consultant, although the team identified and suggested a number of opportunities for improvement, the STDB Project and its operations up to that point received high commendation. The team deemed the Project as "one of A.I.D.'s most creative projects for institutional development" and said that the "STDB is operating effectively as a resource institution, identifying needs of users as well as relevant science/technology resources, and organizing/funding programs to address these needs", while "staff members are competent, enthusiastic and hard-working to achieve STDB's goals". Finally the study team recommended that the Project be extended for three more years from September 1992 to September 1995.

However, following political changes in Thailand in February 1991, USAID's assistance was curtailed and as a result no new activities have been allowed since then, while existing activities are only to be funded by USAID until September 1992. This has meant that many targets have not been reached.

A summary of the STDB project's activity targets and accomplishment to date is given in table 3.5 and a list of RD&E projects funded by STDB can be found in Appendix 3.1.

Table 3.5 Activity Target and Accomplishment of STDB

Activities	Target	Status	(Unit)
1. Expenditure Budget	1,295	N.A	Million Baht
2. Designated and Competitive RD&E Projects	108	94	Projects
3. Company-Directed RD&E Projects	23	8	Projects
4. Fellowships	210	221	Persons
5. P.I.P.	11	9	Projects
6. STP studies	10	4	Projects
7. STAMP	17	4	Projects
8. TIAC Information Services	8,000	1372	Cases
9. D/RDS projects	100	3	Firms
10. STQC			
- Workshop/Seminar	110	18	Times
- Training	22	15	Persons
- Equipment Acquisition	154	65	Pieces

Source: STDB

Out of a total of 94 projects classified as designated and competitive RD&E, 58 projects are in the area of biotechnology, 24 are in materials technology and 12 in electronics. A similar disproportional distribution of RD&E activities among the three areas existed for the much smaller number of company-directed RD&E projects. Of the total eight projects, six are in biotechnology while one each is in materials technology and electronics.

3.3 ROLES OF NECTEC

3.3.1 The Structure

The National Electronics and Computer Technology Center (NECTEC) was found in 1986 as a research and development agency for electronic and computer-based technologies under the Office of Permanent Secretary, Ministry of Science, Technology and Environment (MOSTE). It was governed by the two committees: "The Policy Board" and "The Executive Board", both comprise members from the government and private sectors, and chaired by the Minister of MOSTE.

NECTEC acts as a coordinating agency among the government sector, universities and private sectors in the quest to create innovations in electronics and computer technology in Thailand. In playing this significant role, a number of research and development sub-committees were set up to provide technical analysis and advice as well as strengthening ties with private sector in these fields.

3.3.2 The Missions

In order to bolster up Thailand's manufacturing of electronics and computer technologies and industries. NECTEC's goals were set as follows:

- to develop the capability of research and development institutions in electronic and computer-based technologies,
- to provide efficient technical services and effective disseminations of electronics and computer technologies.

Besides, NECTEC sponsored visits of various experts in order to widen knowledge and experiences of Thai researchers.

Since the attachment of NECTEC with NSTDA in 1991, the missions of NECTEC have become dual. Along with the NSTDA's mission, they are to support RD&E in the public and private sectors, as well as to make its own investment in carrying RD&E to commercialization. More specifically, the missions of NECTEC are as follows:

- to accelerate RD&E in electronics and computer technology in Thailand both in the government and private sector to stimulate and serve the manufacturing industries.
- to support RD&E through computer and telecommunications network in order to provide information services and linkages among R&D institutes in these fields.
- to disseminate and transfer electronics and computer technology from R&D projects and from techno-economic databases of both domestic and foreign sources to the users in the public and private sectors.
- to establish the central R&D laboratories which provide favorable environment and facilities to the researchers in cooperative R&D projects.
- to build up more capable manpower for knowledge generation and technology diffusion.

- to use computer and telecommunications system as a tool to develop learning and working skills.

3.3.3 The Past Performance

NECTEC's performances in the past mainly emphasized development of electronics and computer technology in the following issues:

a) R&D Supports

During 1988-1991, the government budget for NECTEC amounted over 170 million baht. It was allocated to support 12 R&D programs (164 projects) as follows:

- Computer System Technology. It aims to boost domestic manufacturing of computers, especially microcomputers and workstations. Sixteen projects under this program were supported. For examples, 16-bit computer system, 32-bit computer, Eternet LAN card for Standard IEEE 802.3, 8088 incircuit emulator, Thai-English electronic dictionary, prototype for pocket electronic dictionary, engineering workstation (SPARC).

- VLSI Design and Fabrication. This is to develop capability of Thai researchers in designing complex integrated circuits. Twelve projects were supported, i.e. design and fabrication of prototype IC, CAD software for VLSI design NECTEC I and II, commercialized VLSI design for low-cost automatic digital tester, inter-university EDA network, etc.

- Development of Sub-Fractional Motors for Electrical and Electronic & Computer Appliances. The program emphasizes on advanced electric motor design technology.

- Biomedical Electronics and Instrumentation. It focuses on the research and development of electronic and computer biomedical instruments. Eight projects were supported, i.e. computerized X-ray tomography, electrocardiogram, whole body hyperthermia machine, development of X-ray tube, etc.

- Industrial Electronics and Instrumentation. This program supports research and development of various types of electronic circuits, being used by the manufacturing industries to increase the efficiency and quality of production. Twenty-two projects were sponsored, i.e. universal data logger, industrial automatic pattern tracing and cutting machine, development of a high performance AC drive, instrumentation for food texture measurement, computer numerical control vertical milling machine, etc.

- Materials and Devices Technology. It places the emphasis on the development of electronic devices. Thirteen projects were supported, i.e. optoelectronics, design and fabrication of the prototype of silicon rectifier for mass production, development of glucose sensor and instrumentation, etc.

- Artificial Intelligence. This program aim is at enhancing communication between computers and human users through various means. Nineteen projects were supported, i.e. development of electronic dictionary for machine translation, automatic recognition of Thai-English characters, Thai sentence analyzer, automatic fingerprint identification system, etc.

- Computer Software Development. It is to support research and development of software for the benefits of both the government and the private sectors. Thirty-four projects were sponsored, i.e. pilot software for a relational database management system, clinical package, database system of engineering properties of soil in Thailand, image processing system for remote sensing, development of the authoring system for the video interactive lesson, etc.

- Computer Network. This program is to develop the most efficient use of computer facilities through networking. Sixteen were projects supported. Members of the library information computer network are the following universities: Mahidol University, Kasetsart University, Chiang Mai University, Khon Kaen University, Chulalongkorn University, KMIT (Lat Krabang, Thonburi, North Bangkok), etc.

- Telecommunications Equipment Development. It aims to build up local capability to manufacture telecommunications equipment for domestic market on the competitive basis. Eighteen projects were sponsored, i.e. microprocessor-controlled UHF frequency synthesizer, optical fiber data communication system, development of a wireless conference intercom system, electronic modular switching system, development of pilot scale industrial process for through-hole plating, design and construction of a radio frequency shielded enclosure.

- Computer Software Development for Industry. It is a training service for the government and private sector. Two projects were carried out. They were the use of CAD and CAE software for design and development of industrial projects.

- Technology Transfer and Human Resources Development. The program aims to transfer advanced technology from developed countries, to support theses at master and doctoral degree levels, to organize seminars, and to publish text-books in Thai. Four projects were supported, i.e. technology transfer project, the northern region CAD technology transfer center project.

The RD&E projects funded by NECTEC during 1988-1991 are shown in Appendix 3.2.

b) Electronics and Computer Research and Service Center

Four research and service units on electronics and computer technology were established as NECTEC's network in the following universities:

- Research and Service Unit on Data, located at Chulalongkorn University.
- Research and Service Unit on Motor Design Technology, KMIT Lat Krabang.
- Research and Service Unit on Computer Design Technology, Kasetsart University.
- Research and Service Unit on Computer-Aided Design, located at NECTEC, KMIT Lat Krabang, KMIT Thonburi, and Chiang Mai University.

The budget used for the establishment, operation cost as well as R&D support of these four research and service units accounted for 16.2 million baht during 1989-1991.

c) S&T Manpower Development

Being aware of the severe shortages of S&T manpower in electronics and computer technology areas, NECTEC therefore offered a number of fellowships at the bachelor, master and doctoral degree levels to officials and public at large in order to increase the quantity of high level manpower to serve the increasing demand of the academic institutes as well as industries. In addition, specialized training programs (i.e. computer-aided design, software design, etc.), and technical seminars are regularly organized by the NECTEC to provide knowledged to the public and private sectors. NECTEC also published books and other documents in these fields for public consumption.

3.3.4 The Early Success

Its early success can be seen from the research results of some outstanding R&D supported projects in terms of commercialization and knowledge generation as summarized in Table 3.6.

Another successful performance of NECTEC is computer software training and service program. So far, NECTEC has provided training and services on computer-aided design as well as other related software program to nearly 1,000 people from both the public and private sectors.

3.3.5 The Next Step

With the current status of being autonomous and having a more flexible administrative system, NECTEC plans to expand its R&D support as well as strengthen its own technological capabilities. The requested budget of 1,084 million baht during 1992-1996 will enable NECTEC to boost up the electronics and computer technology in Thailand in the following programs:

a) R&D Supports

NECTEC will provide financial and technical supports to the aforementioned 12 projects in broader scope. It will focus more on the commercialization of R&D projects and the development of competitiveness in electronics and computer industries. The estimated budget to further sponsor to the 12

Table 3.6 Results of Some Outstanding R&D Projects

Name of Projects (or Products)	Researchers	
	Private Companies	Universities
1. <u>R&D infrastructure</u>		
1.1 Standard codes for Thai characters	DEC, HP and others	Thammasat
1.2 E-mail Computer Networks	DEC, HP, IBM	KMIT,Thammasat/ Chulalongkorn/AIT
2. <u>Commercialized projects or products</u>		
2.1 32-bit Microcomputer	Tavon Computer	Kasetsart
2.2 Telephone	Interphonic	Kasetsart
2.3 Hand-held Dictionary	Tavon Computer	Kasetsart/KMIT
2.4 Private Automatic Branch Exchange (PABX)	Interphonic	Kasetsart
- model DX		
- model AX		
3. <u>Projects to be commercialized within 1-2 years</u>		
3.1 Medical X-Rays Tube	Kongsak X-Rays	KMIT
3.2 Facsimile Machine	Interphonic	Kasetsart
3.3 Microwave Oven	Saijo Denki	Kasetsart
3.4 CT-Scanner	Kongsak X-Rays	KMIT
3.5 Digital PABX	Century Electronic System	Kasetsart
3.6 Analog PABX		
- model 616	Dynamics International	Prince of Songkhla
- model A 32128	Genius Communication System	KMIT

R&D projects during 1992-1996 will be about 517 million baht. The support will cover the development of computer hardware, computer software and telecommunications equipment to meet market needs, especially to serve the niche market in Thailand as well as in the world. In particular, new softwares appropriate for local users will be developed in the immediate and short term period, e.g., spell checker, spreadsheet, Thai graphic, etc. The decrease in the share of imported electronic and computer products in the domestic market, and the increase in the export value of such products are expected in the near future.

b) Electronics and Computer Research and Service Center

In addition to the continuous support for the existing R&D and service units as mentioned in section 3.3.3, NECTEC plans to establish its own research laboratories. The laboratories which may be set up during 1992-1996 are:

- Machine Translation Laboratory
- Laser and Photonics Technology Laboratory
- Software Engineering Laboratory
- Computer Network Laboratory
- Electromagnetic Compatability Laboratory
- Computer-Aided Design Laboratory
- Artificial Intelligence and Expert System Laboratory
- Computer System Technology Laboratory
- Printed Circuit Board Fabrication Laboratory
- Telecommunications Laboratory

c) S&T Manpower Development

The development of S&T manpower will be given high priority by NECTEC. Fellowships program, and in-house professional development will be carried out to ensure that NECTEC's personnel will be developed both in number and calibre. Those grantees studying abroad will start to return to NECTEC in 1994. The returning students will total 68 in the year 2002 and will be a significant human resource base in the fields of electronics and computer technology for NECTEC and Thailand.

Furthermore, NECTEC will continue to serve the public by means of training programs, seminars, and technical information services.

3.4 ROLES OF NSTDA

A brief background of STDB and the emergence NSTDA were provided under section 1.1.1 of this Report. It was noted that NSTDA, as it is now set up, will bring together under one umbrella the four former S&T institutions, namely, STDB, NCGEB, MTEC, and NECTEC.

Unlike other government agencies or statutory boards, NSTDA operates under a special law which frees it from normal government bureaucracy while it still receives annual government budget allocations and, when necessary, additional endowment funding.

The many special privileges endowed upon NSTDA include a competitive salary scale on par with the private sector, the authority to freely manage its own income and expenditure, and to support technology investment of the private sector or even make its own investments as it deems fit.

According to the first Director of NSTDA, Dr. Yongyuth Yuthavong,[6] NSTDA has set three major goals:

1. To provide RD&E support systems.
2. To support and to undertake RD&E and technical services.
3. To venture into technology investment.

Under the first goal of providing RD&E support systems, NSTDA will devise a financial support system to manage grants and loans, a manpower support system, and information and other support systems by restructuring and enlarging the role of TIAC. It will also establish systems for determining priorities among areas for support.

Under the second goal, which relates to RD&E implementation and technical services, NSTDA aims to develop a strong human resource program to attract, retain and upgrade its manpower and to build up a high quality S&T manpower base. It also will establish a staff exchange program with network institutions around the country. A particularly significant and noteworthy difference in the missions of NSTDA from the former STDB is the dual mission to support RD&E and to undertake its own in-house RD&E. In addition, NSTDA plans to provide consultancy, technical and training services to the public.

Under the third goal of technology investment, NSTDA will continue with the Commercialization of Science and Technology (COST) Program (formerly UST/COST) and the Science and Technology Acquisition and Mastery Program (STAMP). In addition, NSTDA will launch two new programs. The first is the "Incentives for Modernization of Production and Loans for Application of New Technology" or IMPLANT Program which, together with STAMP, provides technology upgrading for industries. The second is the "Investment in New Ventures for Enhancing Science and Technology" or INVEST Program which aims to provide venture funds either to the private sector or for NSTDA itself to invest in technology enterprises, especially in world leader countries, for the purpose of technology transfer to Thai industries.

APPENDIX 3.1

LIST OF RD&E PROJECTS FUNDED BY STDB

No.	Project Title	Pricipal Investigator	Starting Date	Ending Date
	BIOSCIENCE & BIOTECHNOLOGY			
1	Employ Plant Regeneration and Other Tissue Culture Methods in Clonal Propagation and Improvement of Aracaceae	Dr. Kamnoon Kanchanapoon Faculty of Science Department of Biology (PSU)	01-Sep-87	31-Aug-90
2	Production of Modified Starch with Desired Rheological and Physical Properties from Cassava Starch	Dr. Chaisagna Taeratanachai Fuculty of Graduate Studies (MU)	01-Sep-87	31-Aug-90
3	Development of Specific DNA Probes for the Diagnosis of Babesiasis in Cattle	Dr. Chariya R. Brockelman Faculty of Science Department of Microbiology (MU)	01-Sep-87	28-Feb-91
4	Improved Broodstock Maturation Techniques for the Grant Tiger Praw (Penaeus monodon) in Thailand	Dr. Piamsak Menasveta Sichang Marine Science Faculty of Science (CU)	01-Sep-87	28-Feb-91
5	Develop and apply Plant Biotechnological Methods for the Production of Virus Resistant Plants	Dr. Supat Attathom Plant Genetic Engineering Unit (KU)	01-Sep-87	31-Aug-91
6	Development and Application of Tissue Culture Methods for Rapid Multiplication and Improvement of Coconut and Arecanut	Dr. Oradee Sahavacharin Faculty of Agriculture (KU)	01-Oct-87	30-Sep-90
7	In Vitro Selection for Soybean Lines Toletant to Saline Soil and Acid Sulfate Soils	Dr. Peerasak Srinivas Faculty of Agriculture (KU)	01-Dec-87	31-May-91
8	Consturction of Hybrids from Aspergillus sp. for High Yield Citric Acid and Glucoamylase Activity	Dr. Supapong Bhuwapatnanapum Faculty of Agro-Industry (KU)	16-Oct-87	15-Oct-90
9	Research and Development for a Complete Cycle of Seaweed Hydrocolloid Industry in Thailand	Mrs. Suwalee Chandrkrachang Fuculty of Sciences (SWU)	01-Feb-88	30-Jul-90
10	Improvement of Aquaculture of Giant Fresh-water Prawn) Macro-brachium rosenbergii de man) Through Hormonal and Reproductive Mainpulations	Dr. Boonserm Poolsanguan Faculty of Sciences (MU)	01-May-88	30-Apr-92

No.	Project Title	Pricipal Investigator	Starting Date	Ending Date
11	The Development of Biotechnology for an Improvement in the Production of Dairy Cattle	Dr. Kanok Pavasuthipaisit Faculty of Science Department of Biotechnology (MU)	01-May-88	30-Apr-92
12	Application of Tissue Culture Techniques for Improvement of Steriod and Alkaloid Yield from Solanum and Duboisia Spp.	Mrs. Phannipha Chumsri Faculty of Pharmacy Department of Pharmacognosy (MU)	01-May-88	31-Dec-91
13	Prevention and Control of Alfatoxin in Corn	Dr. Chamnan Chutkaew Faculty of Agriculture (KU)	01-Feb-88	31-Jan-91
14	Dry Bean (Phaseous Vulgaris) Improvement Through Mutation Breeding and Tissue Culture Technique	Dr. Siranut Lamseejan Department of Applied Radiation and Isotopes Faculty of Science (KU)	03-Oct-88	02-Oct-91
15	Biological and Economical Studies on the Mekong Giant Catfish	Mr. Sanay Pholprasith Department of Fisheries (MOAC)	01-Oct-88	30-Oct-91
16	The application of Biotechnology for Processing and Product Improvement of Fermented-Rice Noodle	Mrs. Lawan Kraidej Faculty of Science (KU)	01-Nov-88	31-Oct-90
17	Comprehensive Study of the Control, Treatment and Prevention of the Diseases of Cultured Penseus Monodon Fabricius	Dr. Chalor Limsuwan Faculty of Fisheries (KU)	01-Nov-88	31-Oct-90
18	Development of Innovative Technique for Local Production of Bacterial Agents for Biological Control of Agricultural Pests	Dr. Amaret Bhumiratana Department of BIO Technology (MU)	01-Nov-88	31-Oct-90
19	Industrial Fish Sauce Fermentation by Recycling System	Mrs. Saipin Chaiyanan (KMITT)	01-Nov-88	31-Oct-90
20	Potential Utilization of the Rock Salt-Affected Area in the Northeast of Thailand for Aquaculture and Fisheries Development	Mr. Anand Tunsutapanich Department of Fisheries (MOAC)	01-Apr-89	31-Mar-92
21	Tissue Culture for the Propagation and Development of Papaya that are Tolerant to Papaya Ringspot Virus	Mr. Boonyuen Kijvicharn Department of Science Faculty of Agriculture (KKU)	15-Jul-89	14-Jul-92
22	Halophytes	Dr. Somsri Arunin Department of Land Development (MOAC)	15-Jul-89	14-Jul-92

No.	Project Title	Pricipal Investigator	Starting Date	Ending Date
23	Development of Silkworm Seed Technology for Commercial Production	Dr. Somsri Kantaratanakul Department of Entomology (KU)	01-Jun-89	31-May-92
24	Establishment of Vitality Lines of Thai Silkworms and Determination Their Modes of Inheritance	Dr. Panapa Saksoong Department of Genetics Faculty of Science (KU)	15-Oct-89	14-Oct-92
25	Application of Vegetative Propagation to Improve Timber Yield of Red Gum (EUCALYPTUS CAMALDULENSIS DEHAH)	Dr. Somkid Siripatanadilok Department of Forest Biology Faculty of Forestry (KU)	01-Oct-89	30-Sep-92
26	Genetic Improvement of Clarias Macrocephalus by Induction of Gynogenesis and Hybridization	Mrs. Uthairat Na Nakorn Faculty of Fisheries (KU)	01-Jan-90	31-Dec-92
27	Maintenance of Soil Fertility and Improvement of Crop Yield in Highland by Biofertifizer, Mycorrhizal Fungi	Dr. Omsub Nopamornbodi Dept. of Agriculture (MOAC)	01-Mar-90	28-Feb-93
28	Ruminant Nutrition Technology Research Project (RUNTERP)	Dr. Metha Wanapat Faculty of Agriculture (KKU)	08-Dec-90	07-Dec-92
29	Development and Adapting Rhizobium Technology for Legume Cultivation in Northeast Thailand in Support of the ESARN KHEOW	Dr. Juckrit Homchan Faculty of Agriculture (KKU)	01-Mar-90	28-Feb-93
30	Development of Postharvest Machinery for Durian Export Industry	Dr. Bundit Jarimopas Faculty of Agriculture (KU)	01-Mar-90	28-Feb-93
31	Technical Development and Economic Assesment on Disease Control, Storage and Ripening of Durian Export	Dr. Jingtair Siriphanich Faculty of Agriculture (KU)	01-Mar-90	28-Feb-93
32	Pineapple Improvement and Multiplication on by Aseptic Techniques for Canning Industry in Thailand	M.L. Charuphant Thongtham Faculty of Agriculture (KU)	01-Mar-90	28-Feb-93
33	Utilization of Vesicular-Arbuscular Mycorrhizae (VAM) for Yield Improvement of Tomato in the Northeast of Thailand	Dr. Sawaeng Ruaysoongnern Faculty of Agriculture (KKU)	02-Apr-90	01-Apr-93
34	Production of Potent, Polyvalent Purified Horse Antivenoms for Effective Therapy of Snake Venom Poisoning	Dr. Kavi Ratanabanangkoon Department of Microbiology Faculty of Science (MU)	03-Jul-90	02-Jul-93
35	Disposition of Antimicrobial Drugs in Tiger Giant Prawn (Penaeus Monodon)	Dr. Malinee Limpoka Faculty of Veterinary Medicine (KU)	25-Jul-90	24-Jul-92

No.	Project Title	Pricipal Investigator	Starting Date	Ending Date
36	Technological Assessment of Intensive Shrimp Cultivation in the Songkhla Basin with Emphasis on Water Quality	Dr. Upathum Pavaputanont Department of Fisheries Songkhla (MOAC)	23-Jul-90	22-Jul-93
37	Improvement of Disease Resistance to Blast, Btawn spot and Bacterial Leaf Blight in Aromatic Tice Through Tissue Culture	Mr. Narong Singburaudom Department of Plant Pathology (KU)	15-May-90	14-May-93
38	Evaluation of Thai Herbs and Spices for Export	Dr. Wanchai De-Eknakul Faculty of Pharmaceutical Sciences (CU)	03-Sep-90	02-Sep-93
39	Production of Monoclonal Antibodies Specific to Cymbidium Mosaic Virus and their use for Diagnosis	Mrs. Renu Vejaratpimol Department of Biology (SU)	02-Oct-90	01-Oct-93
40	The Production and Testing of Lateinizing Hornorne Releassing Hornorne Analogues for Fish Propagation	Mr. Panu Tavaratmaneekul National Imland Fisheries (MOAC)	01-Oct-90	30-Sep-93
41	Application of Azolla for Rice Production in the North East of Thailand	Mr. Prayoon Swatdee Department of Agriculture (MOAC)	01-Oct-90	30-Sep-93
42	ECO-biotoxicological Studies of Organotin Pesticides and Proposed Control Measures for Freshwater Aquaculture	Dr. Pornsawan Visoottiviseth Department of Biology Faculty of Science (PSU)	01-Oct-90	30-Sep-93
43	Commercial Production of High Value Biochemical Compounds From Rubber Plantation Waste	Dr. Rapepun Wititsuwannakul Faculty of Science (PSU)	01-Feb-91	31-Jan-94
44	Strain Selection Mass Production and Field Application of Hirsulella Thompsonil for the Microbial Control of Agricultural Mites In Thailand	Dr. Angsumarn Chandrapatya Department of Entomology (KU)	03-Dec-90	02-Dec-93
45	Development of Rapid and Specific Immunodiagnostic Methods for Pseudomanas Pseudomallei Infection	Dr. Surasakdi Wongratanacheewan Faculty of Medicine (KKU)	02-Jan-91	01-Jan-94
46	Development of Enzyme Technology for Production 6-Aminopenicillamic Acid	Dr. Vithaya Meevootisom Faculty of Science (MU)	02-Jan-91	01-Jan-94
47	Indentification for Mulberry Root Rot Disease and Its Control	Mr. Sompark Siddhipongse Department of Agriculture (MOAC)	02-Jan-91	01-Jan-94
48	Development of Asiatic Canker Resistance in Pommelo Through Genetic Engineering	Dr. Surawit Wannakrairoj (KU)	01-Jun-92	31-May-95

No.	Project Title	Pricipal Investigator	Starting Date	Ending Date
49	In Vitro Breeding for Photoperiod-Insensitivity in Aromatic Rice	Dr. Prapa Sripichit (KU)	01-Jun-92	31-May-95
50	Biological Control of Root Knot Nematodes Meloidogyne Spp. With Paecilomyces Spp. and Verticilium Spp. in Highland Agriculture	Dr. Sueksak Sontirat (KU)	01-Jun-92	31-May-95
51	Control Management of Mosquito Bug, Helopeltis Sp. on Cashew	Ms. Parnpen Chayopas Dept. of Agriculture	01-Jun-92	31-May-95
52	Rapid Detection of Cholera	Ms. Wanpen Chaicumpa (MU)	01-Jun-92	30-Nov-93
53	Mass Production and Application of Trichoderma Species for Biocontrol of Sclerotum Rolfsii Sacc.	Dr. Chiradej Chamswarng (KU)	01-Jun-92	31-May-95
54	Selection of Strains and Improvement of Reproduction	Dr. Prapee Sretarugsa (MU)	01-Jun-92	31-May-95
55	Development of an Immunodiagnostic Assay for Circulation Fasciola Gigantica Antigens Using Monoclonal Antibodies	Dr. Prasert Sobhon (MU)	01-Jun-92	31-May-95
56	Population Genetics and Sexual Behavior in the Management of Dacus Species of Fruit Flies in Thailand	Dr. Visut Baimai (MU)	01-Jun-92	31-May-95
57	Development of Rapid Screening Method for Selecting Aspergillus-Resistant Corn Strains	Dr. Maitree Suttajit (CMU)	01-Jun-92	31-May-95
58	Improvement of Garlic Productivity Through The Establishment of Disease Free Stacks and Superior Clones Selection	Dr. Prasartporn Smitamana (CMU)	01-Jun-92	31-May-95
	MATERIALS TECHNOLOGY			
59	Ceramic Materials and Products for Electronic Industries (Part I: Material Development)	Dr. Tawee Tunkasiri Faculty of Science (CMU)	01-Sep-87	31-Aug-90
60	Development of High Power CO2 Laser for Materials Processing	Dr. Pichet Limsuwan Department of Physics Faculty of Engineering (KMITT)	01-Dec-87	31-Aug-91
61	Improvement of Rubber Product Manufacture Through Efficiency Processing	Dr. Krisda Suchiva Department of Chemistry Faculty of Science (MU)	20-Nov-87	19-Aug-91

No.	Project Title	Pricipal Investigator	Starting Date	Ending Date
62	Ceramic Materials and Products for Electronic Industries (Part II: Development of Ferrite Products for Radio and Television Appliances)	Dr. Charussri Lorprayoon Dept. of Materials Science Faculty of Science (CU)	01-Oct-87	31-Mar-91
63	Organotin Compounds Innovative Uses of Tin	Dr. Lek Uttamasil Department of Chemistry Faculty of Science (CU)	01-Oct-87	30-Sep-90
64	High Efficiency Low Cost Shuttle Kiln	Mr. Ampon Wattanarangsan Dept. of Materials Science Faculty of Science (CU)	01-Jan-87	31-Dec-89
65	Beneficiation Process of High Quality Kaolin	Dr. Ladawal Chotimongkol Metal and Material Technology Dept. (TISTR)	04-May-88	04-Nov-90
66	Scientific Technique for Improving Color of Gem Minerals	Dr. Ladawal Chotimongkol Metal and Material Technology Dept. (TISTR)	04-May-88	04-Aug-90
67	Appropriate Process Control of Kaolin	Dr. Quanchai Leepowpanth Dept. of Mining Engineering and Mining Geology Faculty of Engineering (CU)	10-Mar-88	09-Sep-90
68	Theoretical Investigations of High Temperature Superconductivity and Coordination of Superconductivity Projects in Thailand	Dr. Viruih Sa-yakanit Faculty of Science (CU)	09-Nov-88	08-Nov-91
69	An Investigation of the Magnetic Properties of High Tc Superconductors and of Possible Structural Transitions Preceding the Transition into the Superconducting Phase	Dr. Rassmidara Hoonsawat Dept. of Physics & Mathematics Faculty of Science (MU)	16-Nov-88	16-Nov-91
70	Research on High Tc Superconductors: Operative Machanisms in High Tc Super-conductors	Dr. Suthat Yoksan Department of Physics Faculty of Science (SWU)	01-Dec-88	30-Nov-91
71	Research on High Temperature Superconductivity : Thermal Property	Dr. Pongsri Mangkorntong Faculty of Science (CMU)	01-Dec-88	30-Nov-91
72	An Investigation of the Crystal Structures and Transport Properties of the High Tc Superconductors and of the Effects of the Fabrication Process in the Production of High Tc Superconductors	Dr. Narongsak Chaichit Department of Physics Faculty of Science (SU)	01-Dec-88	30-Nov-91

No.	Project Title	Pricipal Investigator	Starting Date	Ending Date
73	Fabrication, Characterization and Applications of High Tc Thin/Thick Film	Dr. Poonpong Boonbrahm Department of Physics (PSU)	15-Nov-88	14-Nov-91
74	Modification of the Annealing Processes in the Fabrication of "High Technology" Ferrites and YIG Garnets to Achieve Optimal Magnetic Properties for USE in Microwave Devices	Dr. Santi Vatanayon Dept. of Physics & Mathmatics Faculty of Science (MU)	30-Jun-89	29-Jun-92
75	Use of Natural Rubber in Rice Huskers	Dr. Boontham Nithi-Uthai Faculty of Science and Technology (PSU)	21-Nov-89	20-Nov-92
76	Developments of New Products and Services for the Ceramic Industry of the Northern Region	Dr. Kanchana Keowkamnerd Faculty of Science (CMU)	02-Oct-89	01-Oct-92
77	Development of Nickel-Zinc and Other "High technology" Ferrites for Use in UHF (400 & 800 MHZ) Telecommunication Equipment	Dr. Pongtip Winotai Faculty of Science (MU)	01-Nov-89	31-Oct-92
78	Prolonging the Lifetime and Improving the Quality of Asphalt in Flexible Pavement	Dr. Saiyavit Varavinit Faculty of Science (MU)	01-Feb-90	31-Jan-93
79	Heavy Ion Implantation in Metal and Alloys	Dr. Thiraphat Vilaithong Faculty of Science (CMU)	01-Feb-90	31-Jan-93
80	Development of Technically Specified Natural Rubber for Industrial and Engineering Application	Dr. Jariya Boonjawat Department of Biochemistry (CU)	01-Feb-91	31-Jan-94
81	Preparation of Thai Coals for Water and Waste Water Treatment	Dr. Benjavun Ratanasthien (CMU)	01-Jun-92	31-May-95
82	Development of Low Cost Toughened Plastics Utilising Ground Waste From the Rubber Industry	Mr. Pranee Phinyocheep (MU)	01-Jun-92	31-May-95
	APPLIED ELECTRONICS & COMPUTER TECHNOLOGY			
83	Research and Development on Engineering Production of Small and Medium Size EPABX	Mr. Narong Yamphayak (TISTR)	26-Nov-87	14-Feb-90
84	Development of a Computer Aided Engineering (C.A.E.) System for Electronic Design	Dr. Ekachai Leelarasmee Faculty of Engineering (CU)	01-Feb-88	01-Aug-91
85	Research and Development of Switched Mode-Power Supplies	Dr. Mongkol Dejnakarintra Faculty of Engineering (CU)	15-Nov-87	14-May-90

No.	Project Title	Pricipal Investigator	Starting Date	Ending Date
86	Research and Development on Engineering Production of Large Size PABX of SPC, PCM and TDM Type	Mr. Pramote Srisuksant Faculty of Engineering (KU)	01-Nov-87	30-Apr-91
87	Electronic Equipment for Energy Management in Spining Industry	Mr. Banterg Suwantrakul Faculty of Energy and Materials (KMITT)	01-Jun-88	31-Oct-90
88	Development of the Thai Microcomputer Package for General Application	Dr. Pichit Sukcharoenpong Faculty of Engineering (KU)	01-Mar-88	30-Jun-90
89	Laser Diode Fabrication	Dr. Somsak Panyakeow Faculty of Engineering (CU)	11-Dec-89	10-Dec-91
90	Data Acquisition System for High Performance Liquid Chromatograph	Mr. Wichit Sirichote Faculty of Science (KMITL)	01-May-90	30-Apr-91
91	Development of Local Thai Capability for CAD-CAM/CIM Control and Technology Transfer	Dr. Somkiet Rujkietgumjorn Department of Industrial Engineering (KKU)	01-Aug-90	31-Jul-93
92	Activated Carbon Electrode Biosensors for use in the Food Industry	Mr. Werasak Surareungchai School of Energy & Materials (KMITT)	01-Oct-90	30-Sep-93
93	Pulsed Electromagnetic Fields (PEMFS) for Osteogenesis	Mr. Peerapong Prinyaroj, M.D. (PSU)	01-Aug-92	31-Jul-95
94	Development of Computer Software for Radiotherapy System	Mr. Vorachai Tangvoraphonkchai,M.D. (KKU)	01-Oct-92	30-Sep-95
	COMPANY-DIRECTED RD&E			
95	Quality Improvement and New Product Development of Diagnostic Reagents for Medical Laboratories	Mrs. Sunee Keeratipaisal Seam Co., Ltd.	04-Apr-89	03-Sep-92
96	Scale-Up Tissue Culture Protocal of Plantation Crops and Adaptation for a Commercial	Mrs. Supranee Kavinlertwattana Thai Orchids Lab Co.,Ltd.	14-Aug-90	13-Aug-93
97	Development and Improvement of Existing Fish Sauce Factory to Utilize the New Production Process	Mr. Piroon Rattanaprasit Pichai Co.,Ltd.	25-Sep-90	24-Sep-93
98	Production of Agar from Seaweed	Mr. Swai Paiboonsirijit Pure Agar Co.,Ltd.	26-Nov-90	25-Nov-93

No.	Project Title	Pricipal Investigator	Starting Date	Ending Date
99	Production High Quality of Legume Inoculant	Mr. Montri Rongtrakoontien Bangkok Seeds Industry Cpp.,Ltd	29-Jan-91	28-Jan-94
100	Development of Technology for the Processing of Potential Aquaculture Feed Organisms	Dr. William H. Klausmier Aquastar Laboratories Co.,Ltd	29-Jan-91	28-Jan-94
101	Rubber Dams and Rubber Sheet Lining for Reservoirs	Mr. Kriang U-Udomying Sang Thai Rubber Factory Co.,Ltd.	31-Mar-89	30-Mar-91
102	Development of Personal for Software Research and Development	Dr. Kanchit Malaivongs Institute of Thai Information Technology Co.,Ltd.	06-Dec-90	05-Dec-97

Source : STDB

APPENDIX 3.2

List of RD&E Projects Funded by NECTEC

No.	Project Title	Principal Investigator
	ARTIFICIAL INTELLIGENCE PROGRAM	
1	Development of Electronic Dictionary for Machine Translation	Ms. Nuantip Tantisawetrat Department of Languages and Social Studies (KMITT)
2	Text Generation System for Machine Translation	Dr. Ruttikorn Varakulsiripunth Faculty of Engineering (KMITL)
3	Development of an Input-Output and a Support System for Machine Translation	Dr. Chaiyoung Wongchaisuwat Department of Computer Engineering (KU)
4	Development of an Integrated System for Machine Translation	Mr. Booncharoen Sirinaovakul Department of Computer Engineering (KMITL)
5	Automatic Recognition of Thai-English Characters	Dr. Chom Kimpan Faculty of Engineering (KMITL)
6	The Analysis of Thai Language for Machine Translation	Dr. Kingkarn Thepkanjana Faculty of Arts (CU)
7	A Royal Thai Academy Dictionary Database	Mr. Nontawat Chancharoen Department of Computer Engineering (KU)
8	A Thai Text to Voice System	Ms. Sudaporn Laksaneeyanawin Faculty of Arts (CU)
9	Development of An Expert System Shell	Ms. Voranuch Koedsinthuchai Faculty of Engineering (KMITT)
10	Development of System Support for English-Thai Machine Translation	Mr. Yuen Puvorawan Department of Computer Engineering (KU)

No.	Project Title	Principal Investigator
11	A Thai-Sentence Analyser	Ms. Ampai Pornprasertkul (AIT)
12	A Thai Character Recognition System	Mr. Pipat Hiranyawaditchakorn (NIDA)
13	The Potential Application of NLP for Thailand	Mr. Booncharoen Sirinaovakul Department of Computer Engineering (KMITL)
14	Reliability Improvement of Character Recognition on Microcomputer	Dr. Chom Kimpan Faculty of Engineering (KMITL)
15	An Automatic Fingerprint Identification System (AFIS)	Mr. Kanchit Maitri Faculty of Engineering (KMITL)
16	An Electronics and Computer Dictionary on Microcomputer	Mr. Nontawat Chancharoen Department of Computer Engineering (KU)
17	An Expert System for Plastic Processing	Dr. Montri Vongsri Faculty of Engineering (CU)
18	Expert System in Insurance Law	Dr. Chom Kimpan Faculty of Engineering (KMITL)
19	An Apparel Pattern Marking Support System Using Genetic Algorithms	Dr. Vilad Woovong Faculty of Computer Science (AIT)
	COMPUTER NETWORK PROGRAM	
20	Library Information of Mahidol University	Ms. Wipa Koisukho Office of University Library (MU)
21	Library Information of Sukhothai Thamathirat Open University	Ms. Sompit Cusirpituck Office of Documentation and Information (STOU)
22	Library Information of Kasetsart University	Ms. Piboonsin Watanaponges Office of University Library (KU)

No.	Project Title	Principal Investigator
23	Library Information of Chiang Mai University	Ms. Jaruporn Pongsrivat Library (CMU)
24	Library Information of Prince of Songkla University, Hat-Yai Campus	Ms. Jiree Sukamart Central Library (PSU)
25	Library Information of Khon Kaen University	Mr. Apai Prakobpol Instruction Resources Centre (KKU)
26	Library Information of Chulalongkorn University	Ms. Walaiporn Heamarajata Institute of Academic Services (CU)
27	Library Information of King Mongkut's Institute of Technology, Ladkrobang	Ms. Suree Buhngamongkol Central Library (KMITL)
28	Library Information of King Mongkut's Institute of Technology, Thonburi	Ms. Emorn Srinilta Library (KMITT)
29	Library Information of King Mongkut's Institute of Technology, North Bangkok	Dr. Sowwanee Sikkhabandit Institute of Central Library (KMITNB)
30	Library Information of Silpakorn University, Sanamchan Palace Campus	Ms. Malinee Sripisuth Library (SU)
31	Computer Network Phase 1-3	Dr. Pairash Thajchayapong Computer Research and Service Centre (KMITL)
32	Code and Software Studies for Computerized Patent Data Base	Dr. Charoen Vashrangsi Department of Science Service (MOSTE)
33	Library Information of Rajamangala Institute of Technology	Ms. Yoopadee Tauboonyasuppachai (RIT)
34	The Development of Computer Network	Ms Jaruporn Pongsiriwattana (CU)
35	Computer Aided Management and Services of Biological Museum	Mr. Chamnan Apiwattanasorn Department of Entomology Faculty of Tropical Medicine (MU)

No.	Project Title	Principal Investigator
	VERY LARGE SCALE INTERGRATED CIRCUIT DESIGN AND FABRICATION PROGRAM	
36	Design and Fabrication of an IC Prototype	Dr. Somkiat Supadej Faculty of Engineering (KMITL)
37	CAD Software for VLSI Design–NECTEC I	Dr. Boonwat Attachu Department of Computer Engineering (KMITL)
38	CAD Software for VLSI Design–NECTEC II	Dr. Borworn Papasaratorn Faculty of Engineering (KMITT)
39	Commercializable VLSI Sample Design A Chulalongkorn University	Mr. Suyut Satayaprakorb Faculty of Engineering (CU)
40	Commercializable VLSI Sample Design at KMITT	Mr. Prasert Kanthamanon Faculty of Engineering (KMITT)
41	Commercializable VLSI Sample Design A KMITL	Mr. Watchara Chutviriya Department of Computer Engineering (KMITL)
42	Design and Fabrication of a VLSI Circuit for Small/Medium PABX	Mr. Korakot Jiranapakul Faculty of Engineering (KU)
43	The Development of VLSI Design Technology in Thai Universities	Dr. Borworn Papasaratorn Faculty of Engineering (KMITT)
44	A Commercializable VLSI Design for a Low-cost Automatic Digital Tester	Mr. Kreokchai Thongnoo Department of Electrical Engineering (PSU)
45	The Design and Fabrication of Educational VLSI Circuits	Mr. Bunchong Piyathumrong (KMITL)
46	An Inter-University EDA Network	Mr. Pipat Kositpanthawong (KMITT)
47	A Commercializable ASIC Design for Hard Lock	Mr. Prasarn Tantisanont Faculty of Engineering (KMITL)

No.	Project Title	Principal Investigator
	BIOMEDICAL ELECTRONICS AND INSTRUMENTATION PROGRAM	
48	The Development of An ICU Monitoring System Prototype for 4 Patients	Mr. Manus Sangworasit Department of Electronics (KMITL)
49	A Computerized X-Ray Tomography Prototype	Dr. Pairash Thajchayapong Computer Research and Service Centre (KMITL)
50	Electrocardiogram	Mr. Narong Buabtong (RIT)
51	Design and Prototype Construction of a Signal Averager For Medical Application	Mr. Booncharoen Vongkitisuksa (MU)
52	A Whole-body Hyperthermia Machine	Mr. Vicharn Lawwittaya Department of Radiology (CMU)
53	Development of X-Ray Tubes	Dr. Pichet Limsuwan Faculty of Engineering (KMITT)
54	A Real-Time Computerized Imager for High Energy Radiotherapy	Mr. Supachai Chaisawasdi Department of Radiology (CMU)
55	A Radiotherapy Incubator Unit for Children	Ms. Supawadee Swadipornpallop Department of Electrical Engineering (KKU)
	TECHNOLOGY TRANSFER AND HUMAN RESOURCE DEVELOPMENT PROGRAM	
56	Technology Transfer Project (Seminar, Textbook)	TPA, KMITT, AR Information and Publication Co.,Ltd.
57	The Northern Region CAD Technology Transfer Centre Project	Dr. Tawanwong Krairojananan Department of Electrical Engineering (CMU)
58	Short Course Design in Plastic Technology	Dr. Krisada Suchiva Department of Chemistry (MU)

No.	Project Title	Principal Investigator
59	The Translation NWA STATPAK statistics Package Manual	Mr. Tomorn Meedej Faculty of Agriculture (RIT)
	MATERIALS AND DEVICES TECHNOLOGY DEVELOPMENT PROGRAM	
60	Fabrication of a Semiconductor Pressure Transducer Prototype for Biomedical Application	Mr. Somsak Cheersirikul Faculty of Engineering (KMITL)
61	Optoelectronics	Mr. Chumphol Antarasen Department of Electrical Engineering (CU)
62	Design and Fabrication of a Silicon Rectifier Prototype for Mass Production	Mr. Wisudhi Thitiroungruang (KMITL)
63	Research and Development of High TC Superconductor Microbridge Josephson Junction	Mr. Pichet Limsuwan Department of Physics (KMITT)
64	The Design and Fabrication of a DMOS Power MOSFET	Mr. Somchai Wongmetta (KMITL)
65	A Hybrid Pressure Transducer IC	Mr. Somsak Cheersirikul Faculty of Engineering (KMITT)
66	Research and Development of a Carbon Dioxide Laser	Mr. Pipat Choksuwatanakul (KKU)
67	Amorphous Silicon Solar Cell	Mr. Dusit Kraungam Department of Electrical Engineering (CU)
68	Development of a Glucose Sensor and Instrumentation	Mr. Mana Sriyuthasak Department of Electrical Engineering (CU)
69	Utilization of Laser Diode for Industrial Measurements	Mr. Achariya Sono (PSU)

No.	Project Title	Principal Investigator
70	GaAs Schottky Diodes	Mr. Tanawit Chuligawit (CMU)
71	The Development of Piezoelectric Crystal Biosensor for the Determination of Organophosphorus	Ms. Pornpimol Srikamta Pilot Plant Development and Training Institute (KMITT)
72	Development of Fiber Optic Pressure Sensors	Mr. Suwan Kusamrang Faculty of Science (KMITL)
	INDUSTRIES ELECTRONICS AND INSTRUMENTATION DEVELOPMENT PROGRAM	
73	A Universal Data Logger	Mr. Chusak Limsakul Faculty of Engineering (PSU)
74	The Development of a Sensor and Signal Amplifier Prototype	Dr. Chaiwat Chaiyakul Faculty of Engineering (KU)
75	An Industrial Automatic Pattern Tracing and Cutting Machine	Dr. Kosol Petchsuwan Faculty of Engineering (KMITL)
76	An AC Motor Controller	Mr. Worawit Tayati Department of Electrical Engineering (CMU)
77	Industrial Robot	Mr. Bunterng Sawantrakul Faculty of Engineering (KMITT)
78	A Feed Mix Control System	Mr. Boonyarak Sarakkanont (KMITL)
79	A Sugar Content Measuring System for Sugarcane	Mr. Wattana Kasang (KKU)
80	A Programable Control System	Mr. Krisada Wisavateeranont Department of Electrical Engineering (CU)
81	A Digital Signal Processor Based on Fourier Analysis	Mr. Manoon Puangpool (KMITNB)

No.	Project Title	Principal Investigator
82	A Digital PID Controller	Dr. Somboon Chongchaikij Department of Electrical Engineering (CU)
83	Development of a High Performance AC Drive	Mr. Worawit Tayati Department of Electrical Engineering (CMU)
84	A "SCARA" Assemble Robot	Mr. Pichit Lerksanant (KMITT)
85	Coreless Induction Furnace	Mr. Chayant Khumpai (KMITT)
86	Phase-Locked Controller for Industrial Control Appilcation	Dr. Yothin Prempraneerath Faculty of Engineering (KMITL)
87	A Study of Rubber Content Measurement	Mr. Mongkol Leeprakorbboon (KKU)
88	A Construction of a Robot Manipulator Prototype	Mr. Amnuay Sidhichareonchai (PSU)
89	Instrumentation for Food Texture Measurement	Mr. Kittichai Bunjong (KMITL)
90	Development of an Industrial Prototye for Microwave Oven	Dr. Pramote Srisuksant Faculty of Engineering (KU)
91	The Development of a Solid State RF Power Amplifer for Ion Pulsing System	Mr. Teerawan Boonyawan Institute of Science and Technology Research and Development
92	A CNC Controller for Vertical Milling Machines	Mr. Kawin Sonthipermpoon (KMITL)
93	Design and Development of a CNC Controller for Wire-Cut Machines	Mr. Panya Laoanunthana (KU)
94	Development of Electronic Balance-of-System (BOS) for Photovoltaic System	Mr. Sirichai Tepa (KMITT)

No.	Project Title	Principal Investigator
	COMPUTER SOFTWARE DEVELOPMENT PROGRAM	
95	An Integrated Software Package for Restaurant	Mr. Vudhipong Techadhumrongsin The Computer Center (PSU)
96	A Development of Software for the Appropriation of Government Budget	Mr. Somchai Thayarnyong Institute of Computer Service (CU)
97	Pilot Software for a Relational Database Management System	Ms. Archa Theerachethmongkol Faculty of Computer (PSU)
98	A Software Package for Clinics	Ms. Tawin Puang-kaew (PSU)
99	An Export Management Program for the Canning Industry	Mr. Sinchai Kamolphiwongsa (PSU)
100	A Preliminary Study for the Planning of the Development of Thai Thesaurus for Science and Technology	Ms. Sasithorn Suntharak (TISI)
101	Development of Thai Characters Typesetting for Computer	Mrs. Panonkorn Chanchareon (KU)
102	A Preliminary Study for Setting Standard to Computer Programming Using Using Thai Language	Ms. Kanya Seupsakul (TISI)
103	An Application Oriented Simulation for Computer System Design	Dr. Wittaya Watcharawittayakul Computer Division (NIDA)
104	A Development of a Software Package to Prepare Children for Kindergarten	Mr. Chalong Tubsri (CMU)
105	Database System of Soil Properties in Thailand	Mr. Wichai Sangvorapatansakul (KMITT)
106	Development for Common Specifications for Thai Application Programs	Mr. Taveesak Koranantakul The Information Processing Institute for Education and Development (TU)

No.	Project Title	Principal Investigator
107	Development of a Computer Aided Design Software for Electric Motor (I)	Mr. Sulee Bunchongjitr (KMITL)
108	The Design and Implementation of the Thai Kernel for the UNIX Operating System	Dr. Duangkaew Sawamipak Faculty of Sciences and Technology (TU)
109	Basic Software Package for Applications Development in Thailand	Dr. Taveesak Koranantakul The Information Processing Institute for Education and Development (TU)
110	Program in Aid of Distance Learning	Ms. Raveewan Auapuntviriyakul (NIDA)
111	A Statistical Software Package : Sampling Techniques	Ms. Montipaya Chumuang (PSU)
112	Development of a Job Sequence Program forMicrocomputer	Mr. Piphob Laobunchong (CMU)
113	A Thai Text Spelling Check Program	Dr. Taveesak Chanwittayanuchit Department of Surgery Faculty of Medicine, Ramathibodi Hospital (MU)
114	A 2-Dimension Computer Aided Design Software	Mr. Pipat Supphasirisanti Faculty of Engineering (KMITT)
115	An Image Processing System for Remote Sensing	Mr. Phusak Cheevawit (KMITL)
116	The Development of Thai Kernel System under the X-Window Environment	Mr. Phuchong Uthayopas (KU)
117	The Design and Implementation of a Server under the Unix System for Local Area Network Using MS	Dr. Duangkaew Sawamipak Faculty of Sciences and Technology (TU)
118	Integrated Database Management System (IDBMS)	Mrs. Sumalee Phisithkasem (TU)

No.	Project Title	Principal Investigator
119	LOB-TALK System	Mr. Veera Reawpitak Department of Computer Engineering (CU)
120	A Thai Text-Environment with Word Separation and Dictionary Maintenance	Mr. Taveesak Koranantakul The Information Processing Institute for Education and Development (TU)
121	Thai Spelling Check System	Mr. Yuen Phuworawan Faculty of Engineering (KU)
122	Integrated Computer Simulations in Neurophysiology	Mr. Dhamrongsak Bulyalerd (CMU)
123	Development of Micro Computer Software on Work Measurement for Thai Factories	Mr. Piphob Laobunchong (CMU)
124	Development of the Authoring System for the Video Interactive Lesson	Mrs. Mathuros Chongchaikij (KU)
125	Computer Instructional Course Wares and Development	Mr. Chuang-chothi Puntuweth Suan Sunandha Teachers' College
126	The Development of Computer-Managed and Special Functions in Thai Authoring System	Mr. Wudhipong Techadhumrongsin Computer Center (PSU)
127	Development of a Thai Authoring System	Mrs. Nongnuch Wantanawaha Technological Promotion Association (Thai-Japan)
128	Imaging Tools	Mr. Montol Anan Department of Computer Nakornrajsima Teacher's College
	COMPUTER SYSTEM TECHNOLOGY PROGRAM	
129	Development of a Learning Kit for Microcomputer Hardware System	Mr. Ekkachai Sangin (CMU)

No.	Project Title	Principal Investigator
130	The Development of a 32 Bit Computer	Dr. Punsak Sirirachatapong Faculty of Engineering (KU)
131	A Still Image Data Base System on Personal Computer	Dr. Suriyan Tisayathikom Department of Electrical Engineering (CU)
132	Ethernet LAN CARD for Standard IEEE 802.3	Dr. Wittaya Archdornwiset (KU)
133	A 8088 In-circuit Emulator	Mr. Somchat Rangchareon (RIT)
134	A UNIX-Based Engineering Workstation	Mr. Surasith Wannakairoj (KMITL)
135	A 16 Bit Computer System	Mr. Wicha Sripunyapong (KMITL)
136	A Training Kit for Microcomputer Application in Industrial Process Control and Analysis	Mr. Wichai Aeamsinwatana (KMITT)
137	A Thai-English Electronic Dictionary	Mr. Bunchong Piyathumrong (KMITL)
138	The Development of a Prototype for Pocket Electronic Dictionary	Mr. Jarae Lerdsudwichai (KU)
139	The Establishment of a Laboratory for the Testing of Electronics and Computer Products	Dr. Yothin Prempraneerat Faculty of Engineering (KMITL)
140	A Prototype of AT-Compatible Mainboard for Industrial Application	Mr. Lonarong Tungtrakul (RIT)
141	A Feasibility Study into the Production of Symmetric Multiprocessor Computer	Dr. Worachad Wangpreedalerdkul (CMU)
142	Development of Training Set for 16 Bit Microcontroller	Dr. Tawanwong Krairojananan Department of Electrical Engineering (CMU)

No.	Project Title	Principal Investigator
143	Design and Development of a SPRAC Engineering Workstation	Dr. Punsak Sirirachatapong Faculty of Engineering (KU)
144	Optical Mark Reader for Checking and Analysis Test	Mr. Kanit Kaimuk Faculty of Science (PSU)
	TELECOMMUNICATION EQUIPMENT DEVELOPMENT PROGRAM	
145	A Microprocessor-Controlled UHF Frequency Synthesizer	Mr. Chanin Wong-ngamkum (KMITT)
146	An Optical Fiber Data Communication System	Mr. Vuttichai Sittiarttakorn Faculty of Engineering (KMITT)
147	A Design and Construction of Radio Frequency Shielded Enclosure	Dr. Bandit Rojaraganont Department of Electrical Engineering (CU)
148	A Telephone Emergency-Record-Answer (TERA-II) Unit	Mr. Tawin Paung-ma Department of Telecommunication Engineering (KMITL)
149	The Development of an Industrial Prototype in Cellular Mobile Telephone	Mr. Tawin Paung-ma Department of Telecommunication Engineering (KMITL)
150	The Development of a Wireless Conference Intercom System	Dr. Tawanwong Krairojananan Department of Electrical Engineering (CMU)
151	The Development of Office Automation Equipment for Industrial Production	Dr. Suthad Pathompong (KU)
152	The Development of a Facimile Machine FOR Industrial Production	Mr. Pramote Srisuksant Faculty of Engineering (KU)
153	The Development of ISDN PABX for Industrial Production	Dr. Chaiwat Chaiyakul Department of Electrical Engineering (KU)

No.	Project Title	Principal Investigator
154	A Small Key Telephone System for Business Applications	Mr. Soontorn Witusurapun (PSU)
155	The Development of Lightweight and Small Size Dish Antenna for T.V.R.O.	Mr. Wiwat Paolinjong (RIT)
156	An Electronic Modular Switching System	Dr. Sinchai Kamolphiwong (PSU)
157	The Development of Large Size PABX with 6000 Lines Capacity Industrial Production	Dr. Pramote Srisuksant Faculty of Engineering (KU)
158	The Development of a Digital Switching System for Rural Application (TDSS-1R)	Ms. Veerapunt musiksarn (PSU)
159	The Design of a BPSK Channel Unit for Satellite Communication System	Mr. Tosaporn Simtrakul (CAT)
160	The Development of Medium Size PABX with 32 CO Lines and 128 Extension Lines	Mr. Pholpaduang Paduangkul (KMITL)
161	The Development of a Pilot Scale Industrial Process for Through-Hole Plating (Fourth Phase:1991-1992)	Ms. Pantip Monthachitra School of Energy and Materials (KMITT)
162	A Compact Radio Link for Point to Point Communication	Mr. Chanin Vongngamkham (KMITT)
	COMPUTER SOFTWARE DEVELOPMENT FOR INDUSTRY PROJECT PROGRAM	
163	The Use of CAD/CAE Software for Design and Development of Industrial Products	Dr. Sujjatipaya Tusaneeyapun (KU)
	RESEARCH AND SERVICE UNIT ON ELECTRONICS AND COMPUTER PROGRAM	
164	Research and Service Unit on Database	Dr. Jarumart Pintong Department of Computer Engineering (CU)

No.	Project Title	Principal Investigator
165	Research and Service Unit on Motor Design Technology	Dr. Tongbai Arthasetha (KMITL)
166	Research and Service Unit on Computer System Technology	Dr. Punsak Sirirachatapong Department of Computer Engineering (KU)
167	Research and Service Unit on Computer Aided Design	Dr. Suraphon Tumnark (KMITT)

REFERENCES

[1] G. Kaplan and A. Rosenblatt. "The expanding world of R&D", IEEE SPECTRUM, October 1990, p.28-33.

[2] TDRI (1990). "The Baseline Data Project: S&T Infrastructure and Development in Thailand, prepared for the Office of the Science and Technology Development Board, Bangkok.

[3] Richard B. Kalina. "Final Assignment Report", Science and Technology For Development Project, No.493-0340, Bangkok, March 1992.

[4] United States International Development cooperation Agency, Agency for International Development, Washington, D.C., Project Paper Thailand "Science and Technology for Development (439-0340), June 1985.

[5] "Mid-Term Evaluation of the USAID/THAILAND Science and Technology for Development Project", USAID Contract No.493-0340C-00-9072-00, Prepared by R. Black et al. for MOSTE, Thailand, March 1990.

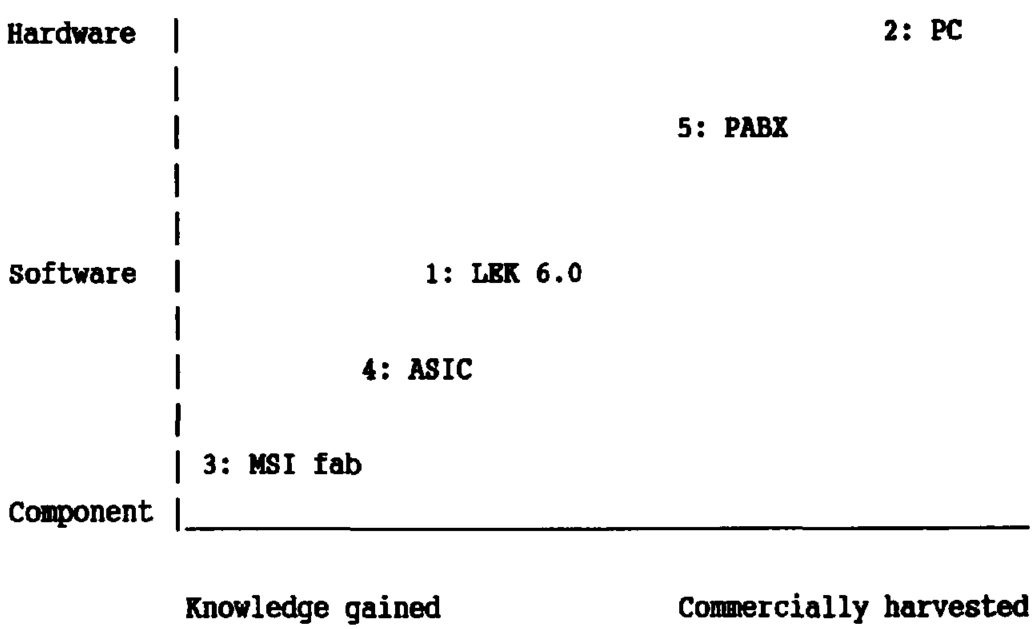
[6] Yongyuth Yuthavong. "The Science and Technology Act, 1991 and the National Science and Technology Development Agency". A presentation to the Forum on S&T Policy held on June 4, 1992 at Thailand Development Research Institute.

CHAPTER 4 CASE STUDIES ANALYSIS

4.1 CASE SELECTED FOR STUDY

Five case studies in electronics hereafter are selected according to the three main characteristics. First is product coverages. Second is possibilities for commercialization. And, third is propositions to be tested. Those characteristics in each case study can be summarized as follows (see Figure 4.1):

Figure 4.1 Characteristics of Case Studies



Notes:
Proposition 1: Researchers can produce concrete results
Proposition 2: Technological infrastructure is essential to R&D
Proposition 3: R&D does not link to industrial needs
Proposition 4: Commercialization of R&D needs management
Proposition 5: There is no short-term economic gains

4.1.1 Product converged.

Case studies are selected to cover all types of product level and range. For hardware equipment, whereas the Personal Computers (PC) project represents computer hardware equipment, the Private Automatic Branch Exchanges (PABX) project addresses issues on telecommunication hardware equipment. Meanwhile, the software sector is represented by the Linear Electronic Circuit (LEK 6.0) project. For component electronics, while the Application Specific Integrated Circuits (ASIC) project gives insight into VLSI design, the Integrated Circuit Fabrication (IC fab) project examines the possibility of MSI fabrication.

4.1.2 Possibilities for commercialization

The five case studies selected cover projects which can and cannot be commercialized. The two polars are that while the IC fab project aims for knowledge gained, the PC project demonstrates a commercializable project. LEK 6.0, ASIC, and PABX projects lie between these two polars.

4.1.3 Propositions to be tested.

Although all five case studies are to be tested against all propositions, each case study is aimed to focus on some propositions. The PC project is to emphasize the essence of technological infrastructure on R&D activity. The PABX project aims to examine the possibility of short-term economic gains. The ASIC project attempts to demonstrate the issue of management of commercialization. The LEK 6.0 project shows researcher's performance through concrete results. Lastly, the IC fab project explains the industrial linkage.

4.1.4 Characteristics of each case study.

a) Case 1: Personal Computers (PC)

The project starts with an objective to produce an industrial prototype of 32-bit microcomputers. It should be categorized as a reverse engineering type of research. The project selects a very reasonable topic and scope of work, with possible commercial values. It sets out with a very modest goal and does a very modest modification of an available schematic diagram. The product is both technically and commercially successful. However, although the PC 386-SX model resulted from the project, at present, ceased to yield benefit to a local computer manufacturing firm, knowledge and experience gained from the project has evolved to a higher plane of engineering workstations.

b) Case 2: Private Automatic Branch Exchanges (PABX)

The PABX project is a part of the NECTEC's attempt to develop office automation equipment comprising cordless telephones, key telephones, and facsimiles. The analog PABX, capable of handling 250 lines of communication and expandable to 400 lines, is the first product completed in 1991 and has since been commercialized by a local telephones manufacturing firm. It is, in fact, a modification and scaled-down of another PABX project funded by STDB.

c) Case 3: Application Specific Integrated Circuits (ASIC)

ASIC is an integrated circuit designed to function specifically to particular tasks or purposes. The project is to apply VLSI design for ASIC chip to depict Thai language on the 16 bit micro-computers. This is to design an ASIC chip to put on a monochrome graphic computer card (the so-called Hercules card). It is rather ambitious, new, and innovative to Thai researchers although it is both technical feasible and economic sound. The prototype, at present, has not been transferred to a Thai card manufacturing firm as planned since the market opportunity has gone.

d) Case 4: Linear Electronic Circuit (LEK 6.0)

LEK 6.0 is a software package for the analysis and design of linear as well as switching electronic circuits. It can be classified as an electronic design automation product. For the past 10 years, it has evolved through several versions. Gradually, its performance and user interface have been improved. At present, the package has been licensed to a software company in Thailand for further development for marketing.

e) Case 5: Medium Scale Integrated Circuit Fabrication (MSI fab)

The research is a series of research on semiconductor technology of an university which is capable of producing discrete devices such as diodes, transistors, MOSFET, thyristors, etc. The project aims to fabricate 10 micron ruled ICs by using nMOS technology and mask fabrication and alignment in Thailand. With equipment suitable for discrete device fabrication, the research team succeeds to produce medium scale ICs having electrical characteristics comparable to ICs available in the market some years ago. The prototype is not commercializable.

4.2 CASE 1: PERSONAL COMPUTER (PC)

Company: Tavon Computer
Interviewees: Dr. Pansak Winyaratana (KU)
: Dr. Promote Srisuksanti (KU)
: Asst. Prof. Chaiwat Chaiyakul (KU)

Reporter: Asst. Prof. Prayoon Shiowattana

4.2.1. Background

This research is a project in the program on Computer Technology System sponsored by the National Electronics and Computer Technology Center (NECTEC). The Computer Technology System Program has set out its directions on R&D as follows:

1. Development of computer hardware having potential commercial value and related software to run on the hardware (research on microcomputer design falls into this category). Other targets include, for example, graphics accelerator, add-on cards for peripherals, communication cards etc.,
2. Development of computer systems for automatic control in industry,
3. Development of computer system for engineering and research; for example, the development of Engineering Workstations (EWS).

a) Project objectives

The project began in the 1988 fiscal year and ran for 3 consecutive years. Its primary aim was to design, develop and test a 32-bit microcomputer prototype with the following characteristics:

- CPU: INTEL 80386SX 32-bit microprocessor
- 512 kbytes main memory which can be expanded to 8 Mbytes
- Supporting peripherals such as DMA, CTC, RTC and DRAM controllers fabricated in three VLSI chips
- Four 16-bit extension slots and three 8-bit extension slots, compatible with ISA bus in PC/AT
- Being tested under PHOENIX 386SX BIOS and can run all IBM PC/XT/AT softwares

b) Project results

It is clear that this is not a research project in the strict sense of the term, but should rather be classified as product development and a part of pre-production engineering project. The research team had a very good combination of backgrounds, connections, and knowledge which enabled them to successfully complete this type of project.

The outcome of the research was a prototype for the 32-bit microcomputer that is workable and marketable. Following its introduction into the marketplace, many thousands were sold with no major defects. This was partly attributable to the low price of the PC in comparison with those of imported PC.

One major outcome of the project, besides such physical results, was the breaking of a psychological block that seemed to surround many so-called "hi-tech" products.

c) Research team

The team was composed of six researchers led by Dr. Pansak Sirirajatapong who had research experience in the area of microprocessor control while doing his Ph.D. dissertation in France. The three joint researchers from the academic field had expertise in various areas including software development, digital design and analog circuitry. These researchers were supported by three research assistants, one of whom was an electronic engineering graduate with a number of years in computer sales and maintenance. The other two were graduate students in the Department of Electrical Engineering.

The last two researchers came from the private sector. One of them was the general manager of local computer assembly firm with good connections in Taiwan. The other, with an electrical engineering background, had set up his own software house and developed it into one of the country front runners in this area.

d) Topic setting

The identification of the research topic was basically a market oriented one. One of the members who help set the topic is the owner of a computer assembly firm who has a deep understanding of the potential microcomputer market in Thailand. On top of that, with his inside information of the computer business in Taiwan, he knew of the possibility and commercial benefit of doing design and development of microcomputers.

The other member is a policy maker with a Ph.D. in computer engineering. There are two other researchers, one rather senior and another in his early years of research. All four discussed approaches in setting up a modest R&D program that could help upgrade local technological capability and at the same time to convince high ranking officers of the competency of local researchers. They finally agreed to start a research project on 32-bit microcomputer design.

In the beginning, the goal was to develop 32-bit microchannel with the available CPU but following a brief study the team concluded that the microchannel was not commercially feasible as it could infringe upon an IBM patent. They then decided to work on the 32-bit microcomputer with an available INTEL CPU which they accessed through one of their friends.

e) Research process

The project, whose objective was to produce a workable and marketable prototype of a 32 bit microcomputer, can be broken down into the following stages;

1. In the very first period (Oct. 1988 - Dec. 1988) the decision over what type of microcomputer to design had to be made. IBM's microchannel was targeted but later on this idea was abandoned due to cost associated with patent. The researchers then focused on an IBM compatible with INTEL CPU 80386SX which was the only chip that the researchers could have access at that time.

2. In the second period (Jan. 1989 - Apr. 1989), following the decision to shift to the design of an IBM compatible microcomputer, the researchers started their work with an available schematic diagram of a microcomputer provided by the CPU maker. Modifications were made to the available circuits, mainly with an aim to keeping the cost low while retaining acceptable function and quality. The PCB used was basically a single sided one using wire wrapping to connect points which could not be connected via the board.

One major difficulty encountered during this period was the problem of how to attach an SMT chip onto the PC board as the socket for the chip was not available in the country and would take six weeks to order. The researchers decided instead to make some adaptations by producing a single sided PCB onto which the SMTs were loaded. The board was then connected with the main PC board through wire wrapping.

In order to do such modification, techniques of producing about 12 mil. line width PCBs and the knowledge of how to solder SMT chips onto the board without electrically damaging the chips were required. The first technique was available in Thailand, whereas the later was obtained as information from Taiwan through the industrialist.

The complete prototype was given a test run for the first time in April 1989 and passed the test with only minor modifications needed.

3. In the third period (May 1989 - Sep. 1989), following all modification, and testing to ensure the reliability of the circuit design, the prototype circuit was then sent to Taiwan for multilayered PCB fabrication. Following delivery of the first batch of PCBs, which took around two months, a further test run revealed deficiencies in the fabrication of the PCBs and it was not until September that all corrections were made and complete boards used in the test run.

The first debut of Thai-designed microcomputer was then made at a press conference in October of the same year.

4.2.2. Problems Encountered

Some major difficulties which the project faced can be identified as follows:

a) Demand conditions

The research project was initiated under strong pull from both market and technological demands. In terms of commercial value, there existed and continues to exist a huge low end market need for cheap but operationable computer sets. One immediate goal of the project was to respond to such potent users. On the other hand, the NECTEC also needed to achieve some concrete results and show to the public impressive achievement so as to gain stronger government support to fuel further R&D projects. The project could successfully fulfil both such commercial and technological goals.

b) Supply conditions

Some major problems in related with supply conditions could be listed as follows:

1. Electronics components and parts used in the project were mostly specialized and were not available in Thailand, and were also difficult to get access to without good connections. This led to increased costs and the lengthened the procurement process.

2. Basically, the components and parts being used were for high frequency purposes. Most of them were Surface Mount Devices with spacing between pins of only 25 mil. The soldering of such devices needed special devices not available at the time, therefore high manual skill was needed in order to do a proper soldering job.

3. The researchers faced difficulties in getting access to a QFPP type socket and had to design a special PCB for interfacing between the chip and the main PC board.

4. The researchers lacked necessary information on BIOS, and as a result many weeks were needed to disassemble the program from the BIOS in the EPROM.

c) R&D capabilities

The research team has proved themselves to be capable of problems solving and self-education in the research process. With just basic background on microprocessor research in the beginning, they had learned much more during their endeavor. CAD for printed circuit board design had to be mastered as a new tool for microcomputer development. Many adaptations, mentioned earlier were made to achieve immediate goal under the limit of supply conditions.

d) Technological infrastructure

This case study of microcomputer research convincingly showed that technological infrastructure is not only an essential element for technological development, but also for R&D activities as well. Detailed discussion of this problems will be analyzed in the next section.

e) Commercialization

The research project comprised members from three important sectors, namely Government-University-Industry, from the beginning. As a result, commercializability was integrated as an essential part of the project and any difficulties in connection with this was one important agenda to be taken care of. Consequently the commercialization process of the R&D result has been very smooth and effective.

4.2.3. Analysis and Lessons Learned

a) Thai researchers can produce concrete results

It is clear that this is not a research project in the strict sense of the term, but should rather be classified as product development and a part of pre-production engineering project. The research team had a very good combination of backgrounds, connections, and knowledge which enabled them to successfully complete this type of project.

The outcome of the research was a prototype for the 32-bit microcomputer that is workable and marketable. Following its introduction into the market-place many thousands were sold with no major defects. This was partly attributable to the low price of the PC in comparison with those of imported PC.

b) Technological infrastructure is essential to R&D activity

Manpower

Shortages of S&T manpower is among the most serious problems this research team encountered. The general shortage of S&T manpower makes it difficult to find suitable and competent research assistants for the project. This is because economic returns are far better for those who work in the private sector. Moreover, those who worked for the team, either as research assistant or as graduate students, would leave to work in private sector once they had learned enough. The researchers then had to train a new group of research assistants over and over again. Knowledge accumulation, which is one of the most important and essential aspects of effective R&D, could therefore hardly be realized.

Suppliers

Suppliers of necessary information and special electronics parts and components have played a very important role in the timely completion of the project. The industrialist involved in the project has very good connections in Taiwan and could thereby ask for favors in multi-layered PCB fabrication. This venue was also used to acquire the necessary electronic components.

In order to facilitate R&D and engineering work in electronics, the timely availability of reliable components at a reasonable price promptly is an essential need that must be promoted.

Technical Services

Environmental testing for electronics equipment is an essential part of the quality control and assurance process. Given the high level of competition in the electronic products sector both domestically and internationally, the upgrading of products as well as the assurance of their quality is indispensable for local electronics firms. However, equipment for environment test are usually very expensive, thus small and medium sized firms cannot afford to have such equipment installed.

Providing such services to such local electronics firms could be considered as one way of upgrading and strengthening those firms' product quality and consequently their production technology. Furthermore, by doing such test, one could obtain valuable information which could be utilized for further product improvement. Since there exist very limited services, both in terms of quality and quantity, of this kind in the country, the promotion of such activities should be seriously considered by the relevant agencies.

EMI Testing

The product has not received any EMI test, which is a necessary precondition for export to most industrialized countries. The reason is that there is no testing facility of this kind available in Thailand. Given the export potential of such products the government should see to it that such a facility is made available, either in the government or the private sector.

EMI testing is also very important in the product development stage. During this stage careful monitoring should be made of the electromagnetic noise emitted from a circuit and proper measures taken to reduce it to a minimum. This is the best solution for EMI, as it costs far less to deal with EMI at this stage than to take measurements when products have been assembled.

Computer-Aided Design

The researchers have come to realize that in order to minimize the lead time of the development process, computer-aided design is one very important tool that is needed. This is because the complexity of the circuit makes it arduous, if not impossible, for the manual design of a PCB board. CAD can help design engineers in terms of time and it can also reduce human error on wiring misses which are inevitable in the manual design of such complex PCBs. Information related to CAD is not widely available and it took sometime for the research team to come across an appropriate software program.

PCB Fabrication

Another problem related to technical services is the lack of PCB fabrication capability in Thailand. Although multi-layered PCBs are already produced here these are for export only. Production to design services are therefore only available for double-sided plate-through-hole PCBs, with weeks of lead time.

As for multi-layered PCBs, their production has to rely on makers in Taiwan. Lead time for fabrication of PCBs from design is not long (a few weeks) for the 386SX model of microcomputer. However, when it comes to the PCBs for the 386DX model, researchers have to wait for months for PCBs. Given such facts, it is evident that if Thailand is to compete in the international market she also needs capability related to PCB fabrication in the country, especially multi-layered PCBs for microcomputers.

c) R&D does not respond to industrial needs

The project was basically a demand pull one which was completed in a timely manner and commercialized with satisfactory results. One major reason behind this was because the industrialist was involved, and had a stake in the success or failure of the project from its very beginning. Not only was he involved from the stage of the topic selection but he was also consulted periodically on the market viability of the target being set. The rapid procurement of essential components, and fabrication of necessary PCBs were made possible through his connections. For product oriented R&D then, the involvement of the private sector is a prerequisite for success.

d) Commercialization of R&D results needs management

R&D activities, with any commercial impacts at all, have to integrate a management aspect into their arena. As could be clearly seen from the case, there existed many aspects in carrying out the works. They included market aspect, short and long terms planning aspects, human resource development aspect etc.. Such wide range of activities could not be effectively handled by a researcher. There exists need for a dedicated S&T manager who is capable of coordinate all these aspects, effectively in terms of management, in order to steer the works towards the set goal.

There also exist many problems which could be handled through good management. For example, unreasonably low remuneration that only served to further hamper the project. With demand for engineering manpower increasing rapidly, starting salaries for new graduate engineers are currently around twice those of research assistants. Therefore, the project faced difficulties in recruiting competent research assistants.

e) There is no short-term economic gain from R&D project

The project, though starting with the short-term goal of commercialization of an adapted microcomputer design, has evolved to include more long-term goal in mind. Having achieved the short-term goal, the researchers have set other goals which emerged in response to some of the problems identified during the development process of the microcomputer. These include the in-house capacity in CAD and multi-layered PCBs.

Furthermore, the project made it clear to the researchers that in order to compete effectively in the global market more long-term goals have to be set and achieved. These include amongst others more fundamental research on digital circuit design and IC design.

It is suggested here that a reverse engineering approach or problem-solving approach could be a very effective way of accelerating the learning process for researchers in countries like Thailand. Through such an approach, one can focus efforts on resolving limited but critical problems. By continually climbing the learning ladder in this manner researchers will be able to reach the technological frontiers in a shorter space of time while not forgetting the real purpose of doing research.

f) Others

1. The project chose a very reasonable topic with possible commercial value and set out a very modest goal, to do a modest modification of an available schematic diagram.

2. The project team was composed of an excellent combination of members. The industrialist involved had clear insight of the potential as well as the feasibility of the research. His access to information, services and component sources in Taiwan proved to be crucial to the success of the project. Other members included a very capable policymaker with a solid academic background in electronic and computer technologies, as well as two very dedicated researchers with a long list of accomplishments and solid training in this subject area.

3. Some spill-over effects which can be mentioned are:

- the transfer of CAD capability to more than 15 engineers,
- the establishment of connections with electronic component sources, parts makers and CPU makers,
- the confidence gained in the successful development of the first Thai-designed microcomputer,
- the transfer of know-how and design techniques from the research team to the technical staff of the Tavon Computer Company.

4.2.4. Conclusion and Policy Implications

1. The formation of research topic is probably the most important aspect of the whole research process. The research topic has to be reasonable and clear and accomplishable objectives must be set. In this case, the research team set out to modify an available circuit in order to reduce the costs of commercialization. The industrialist involved gave an assessment of the commercial feasibility of the project while the two researchers were able to provide a realistic assessment of its technical feasibility.

2. At this stage of Thailand's industrial and technological development, effective research projects should have, in the first place, a clear short-term commercial gain or impact. They should also allow for elaboration of longer-term goals. This case study illustrates how such short and long terms gains can be made compatible with one another.

3. It is not only industrial production which need a very strong and dynamic S&T infrastructural base, but research activities as well. Some immediate needs include: computer-aided design facilities; facilities for environmental, shock, temperature, functional and EMI testing; prototype production facilities for plate-through-hole to multi-layered PCBs and IC chips.

4. There is a clear shortage of capable and dedicated researchers and the situation will continue to aggravate in the near future. Though it needs years of dedicated training to develop one good researcher, it is possible to train a number of good researchers by carrying out reverse engineering types of research. Experienced researchers should join hands in order to map out very basic curriculum and practical training programs that would be the minimal starting points for the training of a researcher. Systematic training would be able to turn out a number of researchers with working capabilities which could be further refined and developed through on-the-job training.

4.3 CASE 2: PRIVATE AUTOMATIC BRANCH EXCHANGE (PABX)

Company: Interphonic (Thailand) Co., Ltd.
Interviewees: Dr. Pramote Srisuksant, KU
Mr. Charn Sudsin, Interphonic.
Mr. Rajaporn Kienprasit, Interphonic.
Mr. Sunant Poonyachareonsin, Interphonic.

Reporter: Dr. Pichet Durongkaveroj

4.3.1 Background

a) Project objectives

The PABX prototype for commercial purpose is a part of a larger project sponsored by the National Electronics and Computer Technology Center (NECTEC) whose focus is the development of the industrial production of office automation (OA) equipment. This scheme is in turn a project under the Telecommunication Equipment Development Program proposed in 1990 which involves R&D on OA equipment such as facsimiles, key telephone systems, cordless telephones and word processors. The rapid expansion of OA equipment use in Thailand, especially in urban areas, has led to their heavy importation and thereby the country's loss in foreign currency.

Nevertheless, the fact remains that the technologies needed to produce such equipment are not beyond the capabilities of local engineers. The problem is that up until recently there has been little in the way of a concerted effort to tackle this state of affairs.

NECTEC, under the leadership of Professor Pairash Thajchayapong, has been instrumental in trying to jump start R&D activities which could lead to the development of marketable products.

The PABX project involved three parties: NECTEC as the funding agency; Kasetsart University's (KU) Department of Electrical Engineering who provides prototype researcher; and Interphonic (Thailand) Co., Ltd. as the manufacturer of the end product. Most of the necessary facilities for the R&D of PABX were available at Kasetsart University and Interphonic's laboratories.

The main objectives of the PABX project (which, incidently, are also those of the overall OA project) are threefold:

- To reduce imports of OA equipment worth 1 billion baht per year.
- To produce manufactured products for export purpose (world demand is vast especially in the European and American markets).
- To enhance the development of the domestic electronics industry.

The first two objectives are long-term possible achievements for this case study while the last objective is achievable in the short-run.

b) Project results

The original proposal specified a PABX prototype of a 12 external line - 48 internal line key telephone. Since then the proposed prototype has gone through a series of changes leading to a final prototype consisting of a 96-line modular hybrid PABX expandable to 400 lines. Although this has led to a deviation from the original proposal, it is seen as a positive outcome both because the final product is a more sophisticated version of the original and because it demonstrates a flexibility in adapting the product to market dynamism.

The project began at the end of 1990 and was completed by the beginning of 1992. Given that the end product was marketable, the completion of the project in a little over one year was considered to be efficient.

The product is a medium-sized hybrid PABX which can be used with both regular and key telephones. From the beginning to the end, the project has been a combined effort between Dr. Pramote and the Interphonic team. The professor's role was to provide concept and design of the circuitry and the software involved. His expertise was derived from his experience in the past, especially from a previous large-scale (2000 lines) PABX project funded by the STDB. Interphonic, on the other hand, has experience in the plastic product business which is advantageous because the design and production of plastic components (e.g. telephone cases) is considered a difficult, time-consuming task. As for PABX, circuit housing is made of metal, hence involves very little of the aesthetic design and plastic mould. Details of the product assembly are carried out by Interphonic.

Interphonic began marketing the product at the beginning of this year under the INTEGRATE brand name. The basic system (BX-96) can handle 96 telephone lines (total in and out lines). The module design is such that additional capacity can be installed merely by the addition of modules up to a capacity of 400 lines (AX-400). Accompanying the PABX is an operator console which has yet to be completed (currently a computer terminal plus a printer is used instead). The operator console is the medium for incoming and outgoing calls as well as data collection for billing purpose. The equipment can also transfer calls directly to their destination if a caller knows the extension number of the destination and is using a touch-tone phone. Obviously, this feature increases the speed of the calling process.

Other features offered by the system range from call transfer to conferencing. Interphonic claims that the company has been providing a comprehensive after-sales service. The product has a one-year warranty and so far Interphonic has served its customers' needs by writing specific software for features that certain customer have requested, free of charge. The company also claims to have standard quality control procedures using advanced equipment such as circuit tester for the PCBA.

In essence, two basic research objectives have been achieved i.e. the end product is marketable and the research capability of the researchers involved is enhanced.

The allocated funding of approximately 1.5 million baht has only covered the researchers expenses and in fact, Interphonic claims to have spent millions more. The ability to compete in both domestic and overseas markets is still far from being attained. Although the domestic market for this type of PABX is wide open, it will still be an uphill battle to compete in terms of reliability and brandname even with competitive services. Although the market exists Interphonic is aiming initially at selected markets within which they could gain a certain level of competitive advantage.

Since the prototype was only completed early this year, its commercial potential has yet to be assessed. The manual and advertising brochures are being finalized. Success will depend on marketing strategies, after-sales service, product quality and pricing. The price has been set lower than similar products in the hope that this will offset the brand name disadvantage. A toll free support service has also been added in order to satisfy customer needs.

One of the users is the Electrical Engineering Department, Kasetsart University. The Patapee Building that houses the Department is within the main campus. Prior to the installation of the PABX system, three telephone lines were used throughout the building to accommodate about 35 telephone locations. Announcements would be made through a loud speaker on each floor for a person to pick up the incoming phone call by a telephone operator. The trouble was that no one wanted to pick up the phone after working hours.

PABX system was installed to replace the above routine over three months ago and has succeeded in:

- enabling efficient internal telecommunications.
- overcoming the no-pick-up problem since only a particular extension will ring.
- allowing callers with touch-tone phone to bypass operator by pushing the extension number by himself/herself.

The new system is, however, not problem-free as users still lack proper understanding in using the system which can at times lead to frustration. External traffic has increased in frequency whilst the number of external lines has remained at three. Under the old system a caller could wait one to two minutes before the operator would respond that the person was not in. Under the new system, which has a Direct Invert Station Access (DISA) feature, a caller has to wait for the operator who (at this time) may not know the extension number (3 digit number) and if a person is not present at his/her desk the phone may ring for quite a while. Thus, more time is consumed.

The researcher stresses the importance of after-sales service. The system has been down two to five times during its three months of use. The system is going to be used for the entire School of Engineering in the future that would accommodate 24 co lines and approximately 100 lines extensions. For the commercial PABX, there will be a remote maintenance service whereby Interphonic's software and hardware will check and detect the customer's system off-site.

The other current user is located at an apartment in Bangkok which used a manual switchboard in the past. The operator is quite satisfied with the new system which provides service to more than 100 rooms. The operator was trained for one day to use the simple system. Currently, the console is not complete and operation is via a PC with a mouse attached. There were some problems at first such as low voice which have been resolved. The round the clock operation also provides billing records of local and long distance outgoing calls with charges printed out daily. Interphonic provides service by modifying software when the apartment wants to make some changes in its billing system.

As mentioned earlier, the PABX project is only a part of the OA development scheme. With the PABX system, regular telephone and key telephone will be available to form a complete set of office telephone system. This PABX project is also, to some degree, a stepping stone in their design and production experiences toward newer systems such as digital PABX, accompanying software etc.

4.3.2 Problems Encountered

a) Demand conditions

Potential customers include offices, apartment buildings and hospitals. The market for PABX at this scale is highly competitive with factors such as product reliability, pricing, after-sales service influencing customer decisions. The main competitors are foreign importers including NEC, Okidata, Alcatel, AT&T, Goldstar, Samsung, Fujitsu and Northern Telecom. Since credibility is the most important criterion for a customer's purchasing decision local PABX maker such as Interphonic is waging an up-hill marketing battle against brand-name products. Not only does a local product need equivalent quality, but its pricing has to be low enough to make the price margin sufficiently attractive to induce customers to take a risk on an unknown product. Consequently, this makes the office building sector difficult to penetrate because of their need for reliability and consequently aversion to taking risks on unknown systems. The more practical target is apartment building where a low price and somewhat reliable product is acceptable. However, this must be accompanied by aggressive after-sale customer service.

b) Supply conditions

There have been problems with component sourcing all along. Thus the researcher has been advising Interphonic not only on new concepts and electronic devices but the sourcing of such devices as well. In addition, the company has had to make frequent trips overseas in order to identify and make contact with suppliers before making purchases. This has placed a heavy financial burden (travel expenses) on Interphonic as the company has had to make one overseas trip per month on average for this purpose.

Constant trouble with the Customs Department has been encountered when importing electronic components. The company complains about the inconvenience and delay in retrieving imported components. Hassles are frequent phenomena in explaining the slight, insignificant (such as different resistor length for different lots of the same components) differences of the imported components which frequently requires informal arrangements to quicken the process.

New components that will be used in the circuit sometimes have to be purchased in lots resulting in wasteful expenses especially when such new components are not used in the final design.

Inadequate testing equipment has posed some problems in the R&D and production activities. Lab equipment such as high potential tester, network analyzer, impedance tester and logic analyzer are too expensive for the firm to invest in.

Local producers of PCBs which can provide PCB prototype within a few days or even a week (instead of a month or more) are needed. Also, precision work are also in demand for plate-through-hole and 4-6 layer PCBs.

c) R&D capabilities

Manpower is the most crucial problem the project researchers were faced with. The project's R&D activities were carried out by Dr. Pramote and 3 research assistants from Kasetsart University plus 7 engineers and 4 technicians at Interphonic. Interphonic finds it hard to recruit R&D engineers most of whom prefer to work on management, sales or installation and maintenance. The very few engineers they have cannot catch up with the schedule in their R&D work plan. Key persons sometimes leave and technicians have high turnover rates. Monetary rewards are not high enough to attract or keep engineers.

d) Technological infrastructure

As mentioned earlier, one of Interphonic's problems is in the testing either of components or products, both of which require sophisticated and expensive instruments. Currently, Interphonic utilizes testing equipment at the University. The company wishes that R&D testing equipment not be taxed at all or taxed at low rates.

Especially in the beginning, Interphonic did not know how to set up R&D management system. There is no mechanism to perform a standards test that would guarantee customer's satisfaction. There is also no existing knowledge of other countries requirements and standards which will certainly help Interphonic's product to be competitive in the long run whether domestically or overseas.

Although Interphonic has been getting training from Kasetsart University, more training program and facilities are needed. Kasetsart University provided PCAD training for PCB design to Interphonic researchers. The software is good but requires time to digest. In the short run, Interphonic opts for a simpler software which is not as good but requires less time to learn how to operate. The Company, however, realizes that it needs to go back to the more sophisticated version in the long run.

e) Commercialization

There is no problem in the commercialization aspect of the PABX module. Only the existence of the competitors' similar product in the market poses the challenge for Interphonic. Otherwise, the market demand is sufficient to cushion reliable and reasonably priced products.

4.3.3 Analysis and Lessons Learned

a) Researcher's capability

Academic

There has yet to be a final report on this project. Other than the lack of time of the researcher at Kasetsart University, it is possible that the PABX report could be a part of the final report on the overall OA development project. The researcher at Kasetsart University did give a basic paper in a workshop on PABX and ASIC Chip Development for PABX in April 1992 at an ASEAN-level conference in Bangkok. The prototype (hardware) is complete in meeting the proposal objectives and more and considered successful in transforming the lab prototype into a commercial product. There are some knowledge gained although more have been already accumulated from the previous STDB sponsored large digital PABX project (that project ended at a prototype level).

Private Sector

As for Interphonic, the company is at a stage of producing product manual and advertising leaflets. Any problems encountered during the R&D activities were normally resolved jointly between Interphonic and Professor Pramote. The company's R&D team is moving on to work on a smaller PABX as well as digital PABX projects utilizing knowledge learned from the past project. Interphonic also has diversified its product line in order to complete the product cycle by producing handfree, single-line, and key telephones. Time spent for hardware in this particular PABX project is about 20% (excluding PCB design). The rest goes into software development.

The overall project personnel include 2 researches with Master's degree in Electronics and Control Engineering, including the Professor. Others have Bachelor degree and all technicians are from technical colleges.

The research facilities include one at the Electronics Engineering Lab, Kasetsart University and a townhouse-turn-electronic lab at one of Interphonic's facilities. Interphonic utilizes eleven PCs, four of which are dedicated to PCB design (i.e. using CAD software) and seven of which are dedicated to software programming. There are two components in the software programming within the PABX itself and the operator console. In all, software takes much more time than hardware development.

It can be concluded that this project shows that the researchers are capable of providing concrete results. The marketable PABX prototype, which is up and running, is such the evidence. This does not, however, go without rooms for improvement. The potential for researchers to do a good job does exist provided that factors such as supplies, manpower, customs procedures can be improved. Given time, when necessary entities for the scheme to be a success fall in their proper places, then the researchers capability can be more productive. On the one hand, researcher in the university can enhance their knowledge base which can be good consultative sources for the industry. On the other hand, private sector can build up more confidence (other than biting the pride on empty stomach as Interphonic put it) in pushing more marketable and profitable products out of the lab prototype. This project is an ideal case study that shows the courage on the part of the private sector to pour in a lot of money betting on the success of the R&D outcome.

b) Infrastructure

From section 4.3.2, there is concrete evidence that technological infrastructure is a necessary factor to RD&E success. We have cited examples of manpower, supplies, technical services, taxation and customs procedure and some institutional problems. In addition, Interphonic's comment on the financial side of the project suggests that the NECTEC grant is minuscule relative to what Interphonic has invested. The company is, however, very satisfied to the fact that NECTEC's initiative and grant has put in the right seeding toward the future potential plantation. Remuneration to researchers is insufficient in an attempt to attract or keep researchers capable of doing R&D. Interphonic feels that self satisfaction and pride is a (non-physical) reward in itself. NECTEC is praised for its grant management (other than its good cooperation and response). By giving the lump sum of grant to the university, researchers can purchase components straight away whereas, in contrast, STDB's regulation forces researchers to pay for the components before reimbursement can be made. It is also the researcher's comment that agency such as STDB has no information or in-house experts. Thus proposal has to be distributed to outsiders for comment. NECTEC has no such procedure in this regard.

The company would very much like to see zero import tax on R&D equipment and supplies and a more smooth customs clearance procedure without which the entrepreneurial spirit seems to be very much demoralized. As for intellectual property right, the company is hesitant in patenting its product for fear that it would open the opportunity for copying even more. Thus, the company is satisfied as it is.

c) Supply, Demand and Linkages

There is no clear evidence from this case study to support the proposition that RD&E lacks supply, demand and linkage. In fact, NECTEC takes on to fund the research for this project after the project has already begun and shown sign of potential success at least at the prototype level. Thus, for this case study the supply (Professor Promote) and the demand (Interphonic) have already been linked to each other. This occurs without the presence of tax incentive for RD&E in industry nor any competitive pressure to induce demand for technology. In the end, it appears that NECTEC has been playing its proper role i.e. providing the necessary linkages and has been praised for its keen response and cooperation.

d) Policy and management

There is evidence in this case study which suggests that commercialization needs policy and management. It is fair to say that NECTEC has done its share in an attempt to commercialize the outcome of RD&E activity. By providing the seed money in this case to university researcher, the private sector then picks up the prototype in order to put it out into the market-place.

However, in order to succeed commercially, the company has suggested several incentives that need to be examined. Whether NECTEC or related agency can or will get involved is another issue. Example of these issues consist of:

- Some form of government procurement policy whereby "Made in Thailand" products gain more opportunity during the bidding process for government or government-related purchasing.
- Tax is an obstruction. Again, this also includes the customs procedure. Relaxation of these obstacles would be a great incentive for the private sector to do RD&E.
- Affirm and make known publicly the commercialized RD&E projects to acknowledge their efforts as well as increase the pride and prestige of this kind of activity.

Whether the company will succeed in the long run is not known. There are many factors involved at this stage including the competitions, the demand, the company's aggressiveness in marketing strategies, the product's quality control and reliability, the production line cost reduction etc. Prior to this end, it is fair to say that NECTEC did not create any mismanagement problem by setting up minimal rules and regulation. This is made possible through a good understanding of the NECTEC leadership in the project and personnel selection to carry out a project - something that requires acquaintance to the market and the technology. It is not the direct responsibility of an agency such as NECTEC to deal with tax, product promotion issues but may be it can be the case that NECTEC can ignite changes. Other than that, to provide training and necessary facilities would also help to promote incentives to do RD&E.

e) Short-term gain

This case study has demonstrated that short-term gain can be achieved from RD&E at a certain level. It is obvious that the product is marketable. Demand from users exist but need to be carefully traced to find the niche where Interphonic can be competitive. It will, however, take a while for the products to go out enmass. The company hopes to produce one thousand lines per month at the end of 1992, two thousand lines per month three months later, and follow the market demand afterward. Interphonic also moves on to develop other product lines utilizing its stock of resources and experiences. Credibility of its PABX is yet to be established. In the mean time, low price and aggressiveness of sales and service must be the compensating factors.

4.3.4 Conclusion and Policy Implications

a) Conclusion

The PABX project can be considered successful in its level of achievement for the period of just over one year. This stems from three sources:

- NECTEC, whose seed money and project management allows the project to move on without much obstruction or unclear objectives.
- University researcher, whose experience from the past helps to provide concept, design, guidance and sourcing information to the private sector RD&E units to accomplish the prototype.
- Interphonic, whose experience in the plastic business helps to speed up the design of a complete product and whose willingness to invest millions in the product development helps to move the prototype onward to a commercial scale.

The accomplishment is not without problems ranging from market demand and supply, lack of supplies, lack of R&D manpower and insufficient infrastructure. On the demand side, it is difficult for local Thai company to compete with brand name product from overseas. On the supplies side, component sourcing has been a major problem. In addition, the tax and customs policy create demoralization as well as cost ineffectiveness. Manpower is a big problem in the infrastructure issue coupled with lack of testing and training centers for this type of technology.

b) Policy implications

The following are policy implications that come out from this case study:

- Regulation on R&D equipment should be revised especially on the tax issue. Electronic parts and components are also taxed too high. Customs regulation need to be redefined and adjusted to provide smooth, efficient import procedure and cut down on unnecessarily costly procedures. Some kind of tax credit may be healthy in promoting RD&E activities.

- Manpower should be dealt with at all levels. Without qualified manpower there can be no qualified product no matter how much they are paid. Training and testing centers should be provided in the form of pooled resources. Information center that provides information such as technical manuals will be of great help to enhance the activities. Standards testing should be set up so that manufacturers can claim their qualification to a qualified product to enhance their competitiveness both domestically and internationally.

- Supporting industry such as PCB makers should be improved. The existing supporting industry provides low quality product as well as takes too much time to produce.

- RD&E management should be taught e.g. how to manage R&D personnel, how to train, how to delegate responsibility and create enthusiasm in the learning process, target planning.

4.4 CASE 3: APPLICATION SPECIFIC INTEGRATED CIRCUIT DESIGN FOR THAI CARDS

Company: International Research Corporation Limited (IRC)
Interviewees: Mr. Chumrudh Savangsamudr (IRC)
: Dr. Boonwat Attachu (KMITL)

Reporter: Dr. Anupap Tiralap

4.4.1 Background

Although the electronics industry in Thailand has expanded at an exceptional rate in recent years, both in terms of its production volumes and product ranges, this has not lead to a concomitant increase in value-added and net foreign exchange generation for the country. One of the primary reasons for this is that the mastery of technology, including product technology and production knowledge, has remained in foreign hands. When compared to her Japanese and Asian NIC counterparts, Thailand has yet to really benefit from the rapid changes in the electronics technology industry and her potential therefore remains enormous. Even among ASEAN countries, Thailand clearly ranks after Singapore and Malaysia in terms of its industrial and technical development. One example of this is the area of very large integration (VLSI) design, the mastery of which has led to a competitive advantage for those manufacturers and countries who have invested in the development of this technology.

In Thailand, VLSI design and, in particular, commercial design for application specific integrated circuits (ASIC), is a fairly ambitious and new area for both researchers and industrial firms. In spite of the risks inherent in attempting to master such technology, the National Electronics and Computer Technology Center (NECTEC) decided to sponsor the ASIC design project because of the huge potentials which the acquisition of this technology had demonstrated elsewhere. Using some basic capabilities in VLSI design of the electronics research center at King Mongkut's Institute of Technology at Lat Krabang (KMITL), NECTEC teamed up with a local firm (International Research Corporation, IRC) to manufacture computer graphic cards for depicting the Thai language.

The rationale for the project was both technically feasible and economically sound. KMITL had already accumulated and demonstrated some capabilities in VLSI design under the ASEAN-Australia Electronics Project. With the equipment and know-how gained from this project, the researchers were confident that it was feasible to design a marketable ASIC chip despite it being a new technology to them. On economic grounds, the IRC believed that if the project succeeded, the potential return on its investment was enormous (reductions of 100 percent in prices were predicted).

As the ultimate goal of the project was to achieve an industrial prototype of a commercial ASIC chip for the depiction of the Thai language, the overall evaluation of the project is that although the project was technically successful, it failed on a commercial basis.

a) Project objectives

General objectives of the project were twofold:

- to build up and accumulate indigenous VLSI design technology for industrial uses, and
- to diffuse this technology to all concerned researchers and users including the private sector.

Further specific objectives placed an emphasis on:

- the development of an industrial prototype of monochrome graphic cards (so called the Hercules card) using ASIC chips for depicting Thai language on the 16 bit IBM-type microcomputers.

- the manufacture of Thai cards locally using the indigenously designed ASIC chip.

b) Project results

By and large, the project achieved both its general and specific objectives. That is to say, the project built up indigenous VLSI design technology for industrial uses and diffused it to all concerned researchers and users (particularly private firms). It also managed to develop an industrial prototype of a monochrome graphics card (the Hercules card) using ASIC chips for depicting the Thai language on a 16 bit IBM-type microcomputers. Only one objective was not achieved; the manufacture of Thai cards using the indigenously designed ASIC chip.

c) Research process

The project, which took a full three years of work, can be divided into four phases. The first two phases, which covered the initial 15 months, largely fulfilled the general objectives of building up indigenous VLSI design technology and diffusing that technology. The third phase, which lasted 12 months, also met the specific objective of designing an ASIC chip. However, during the last 9 months the attempt to develop a marketable prototype failed.

Specific targets and results achieved were as follows:

1. The first phase (July 1988 to December 1988)

Targets:	Results:
- Gathering and studying possible circuits to be designed	- Achieved
- Testing software CIRCAD II on workstations	- Failed and finally used Mentor Graphic software on Apollo workstation
- Hardware acquisition and installation	- Delayed until 1989
- Testing and designing circuits using CMOS technology	- Delayed until 1989

2. The second phase (January 1989 to September 1989)

Targets:	Results:
- Hardware acquisition and installation	- Achieved
- Designing circuits for Hercules cards	- Achieved
- Training personnel for using software and hardware	- Achieved
- Designing ASIC chips	- Partly completed
- Fabricating the designed ASIC chips	- Delayed until 1991
- Designing PCB for Hercules cards	- Delayed until 1991
- Prototyping the Hercules card	- Delayed until 1991
- Testing the card in a working environment	- Delayed until 1991
- Final testing for the prototype of Thai cards	- Delayed until 1991
- Mass production of the designed ASIC chip for the Thai card	- Finally failed in 1991

3. The third phase (October 1989 to September 1990)

Targets:	Results:
- Designing VLSI circuits for ASIC chips	- Achieved
- Building behavioral model for simulation of IC No. 6845 and other related ICs	- Achieved
- Building test vectors for circuit testing	- Achieved

- Simulating the designed circuit using Mentor Graphic software on Apollo workstation	- Achieved
- Fabricating the designed ASIC chips	- Partly achieved as corrections needed
- Designing PCB for Hercules cards	- Delayed until 1991
- Prototyping the Hercules card	- Delayed until 1991
- Testing the card in the working environment	- Delayed until 1991
- Final testing for the prototype of Thai cards	- Delayed until 1991
- Mass production of the designed ASIC chip for the Thai card	- Finally failed in 1991

4. The fourth phase (October 1990 to June 1991)

Targets:	Results:
- Correcting the DRAM design and retesting all the circuits	- Achieved
- Redesigning the ASIC chip	- Achieved
- Fabricating the designed ASIC chips	- Achieved
- Designing PCB for Hercules cards	- Achieved
- Prototyping the Hercules card	- Achieved
- Testing the card in the working environment	- Achieved
- Final testing of the prototype of Thai cards	- Achieved
- Mass production of the designed ASIC chip for the Thai card	- Failed

4.4.2 Problems Encountered

The problems encountered by the ASIC project largely stemmed from an inadequate knowledge base which in turn was a reflection of local R&D capabilities. Although the university's research team was quite capable of VLSI design, the previous experience which it had acquired during the ASEAN-Australia project was not fully applicable to this project. As a result of its underestimation of the difficulties involved in designing VLSI for commercial purposes, the research team was to face many unanticipated delays which would eventually lead to the project's commercial failure.

Another related problem was the inadequate technological infrastructure available in the country. Although the KMITL equipment and services were probably the best in Thailand at the time, they were still not quite good enough to design a marketable ASIC chip and were therefore an important factor in contributing to the project's delays.

The third problem encountered was related to the shift in computer graphics card technology. The primary reason for the failure to market the designed ASIC chip was that it was designed to work on monochrome graphic cards when the market had already switched to the Video Graphic Adaptor (VGA) card as standard.

a) Demand conditions

The projected demand for Thai cards was the basic incentive on the part of all the concerned parties for initiating the project as it was estimated at the beginning of the project that the size of the market for Thai cards was about 36,000 cards a year if the price was set at 3,000-3,500 baht per card. Thus, assuming the project succeeded and that the price was set at the same level, the market value of the cards would be about 120-150 million baht a year, half of which would be profit. However, demand conditions for Thai cards changed rapidly during the period of ASIC chip development and as the price of the VGA graphic cards fell sharply and its technology was improved, the monochrome graphic cards suddenly became obsolete. Therefore, when the project was completed (18 months after the initial plan), the market had gone.

b) Supply conditions

In terms of supply, the resources and manufacturing capabilities that were available were considered to be good. As we have mentioned, the initial assessment of the project's viability was very positive and it was assumed that the project would easily pay for itself. Therefore, both the research funder (NECTEC) and the collaborating firm (IRC) poured in large amounts of money into the project. In fact, the 5.6 million baht which NECTEC poured into the project may have made it the largest project being sponsored by any government funding agency at that time (in addition, the IRC spent about 1.1

million baht on the project), and this is without including some of the services drawn from the Australia-ASEAN project and the KMITL.

Turning to a discussion of manufacturing capabilities, IRC had many years experience in manufacturing (designing, assembling, and testing) the Hercules monochrome card. Therefore, with support from another local firm capable of assembling multi-layered computer boards, it was felt that there would not be any problems with the assembly of the SMT (Surface Mounted Technology) and PLCC (Plastic Leaded Chip Carrier) components.

c) R&D capabilities

Poor R&D capabilities were a major factor which contributed to the project's delays because there were very few researchers capable of the VLSI design of a commercial ASIC chip available in the country. The researchers involved in the project had the ability to design VLSI chips for non-commercial purposes which had been acquired mainly from an Australia-ASEAN project (whose aim was to promote VLSI design among developing countries). However, as the design of non-commercial chips requires less stringent testing requirements for product features and reliability, when the researchers attempted to design a commercial VLSI chip they overlooked some of its minor faults, incomplete features, and its unreliable working performance.

Thus, the project suffered from a lack of a knowledge base relating to hardware equipment, design software, and product testing as all the planned equipment, software, and testing procedures were not applicable. In the end, the final ASIC chip for Thai cards was made possible through the assistance of an engineer who used to work with the Hercules Card company in the U.S. as well as a Hong Kong based electronic design company.

d) Technical services

In addition to the poor knowledge base and research capabilities mentioned above, poor technological infrastructure also played a large part in the project's difficulties.

For example, technical manpower was not adequate as there were not many engineers and researchers in the field. Strictly speaking, it could be said that there were actually only about ten researchers really interested and involved in this field at the time.

Another reasons for the project's delays was the inferior and inadequate facilities available for teaching and training the necessary personnel. As we indicated above, the hardware and software available and used in the Australia-ASEAN's VLSI design project could not be used in the ASIC chip design project. In addition, technical services such as product standards and specifications, product testing facilities, training courses for required personnel, technical information (including data books for products and components), and technical consultancy services for research and product development were almost non-existent.

Last of all, the absence of some supporting industries can be mentioned. As Thailand has no wafer fabrication capabilities, the researchers had to have their wafers manufactured in either Australia or the US, with each fabrication period requiring three months.

e) Commercialization

It would perhaps be fair to state that had the project been completed on time there would have been little problem in commercializing the product given its huge market potential and the well-established market share which the company involved already enjoyed. Although the undertaking of such a project could be questioned on technical grounds, this would be more because the technology was new to Thai researchers rather than because it was beyond their capabilities. Nevertheless, compared to a reverse engineering type project, the ASIC design project bore high investment risks.

4.4.3 Analysis and Lessons Learned

In the following section we will evaluate the project according to the five propositions mentioned earlier. These propositions can be used as guidelines to outline some of the main challenges facing R&D work in Thailand.

a) Thai researchers can produce concrete results

As we mentioned earlier, the VLSI design of marketable ASIC chips was an ambitious and innovative project in the Thai context. However, in spite of delays of one and a half years the KMITL team eventually succeeded in completing the project. Judged on this basis, the researchers could be said to have produced many concrete results. These include the production of a working prototype of ASIC chips and monochrome graphic cards for the depiction of the Thai language. Specifically, these chips:

- were designed as a semi-custom chip (standard cells)
- used Complementary Metal Oxide Silicon (CMOS) technology
- used PJQFP package having 128 leads
- had 7,000 gates inside
- included megacell library of the CRT controller

Apart from the objectives which were met, there were many indirect benefits gained such as seminars given, applicability to teaching, research students trained, knowledge gained, experience acquired, and adaptive/innovative steps undertaken.

In particular, those results related to the knowledge gained, experience acquired, and adaptive/innovative steps forwarded not only benefited KMITL's research team, but also benefitted other university researchers at the King Mongkut's Institute of Technology at Thonburi (KMITT), Chulalongkorn University (CU), and Kasetsart University (KU). More importantly, this was the first time that the VLSI technology was diffused to a local firm and IRC has clearly benefitted from the technical knowledge it has gained even though it was not able to realize any market returns from the project. However, in spite of all of these facts it can be mentioned that there were no reports written and article published.

As we have emphasized above, the project was technically successful but a commercial failure. Therefore, there was no direct research utilization, no marketable product was produced and hence there were no patents, economic returns, benefits to users or social impact. Nevertheless, the project generated technical spill-over effects as outlined in the indirect results section above. More importantly, it was a strategic research need, as one of the reasons why local manufacturers of electronic products ranging from consumer to industrial products are less able to compete in both the domestic and international markets is due to the increasing use of ASIC chips in electronics equipment. Thus, the lower their capability in ASIC design, the more vulnerable an industry is to competitive pressures.

One lesson learned from the case study is that with an adequate budget and a carefully chosen research topic, Thai researchers are clearly able to produce concrete results. The problem is more in the amount of time it takes to carry out a project, which, for projects aiming to develop commercial products, is a vital issue.

b) Technological infrastructure is essential for R&D

As we have said, the most important aspect of the project was the knowledge and experience which researchers brought to the project, including the type and extent of training/education which they had received. The knowledge and experience gained from the ASEAN-Australia project was of particular importance, as without this it would have been almost impossible to undertake the ASIC project.

Of more significance is the fact that university researchers have little opportunity to conduct research aimed at the production of commercial products. This results in many misconceptions among university researchers regarding the potential of laboratory prototypes to be transformed into marketable products. The project strongly suggests that this limited experience combined with the need to adapt to a rapidly changing technological environment needs to be addressed if training and education are to meet research requirements and, in particular, research for commercial purposes.

A serious impediment for R&D in Thailand is the lack of technical services. Standards, testing, training, information, and consultancy services are all inadequate. Data books for IC standards, specifications and designs as well as testing and training courses for IC and VLSI design were not available. Fortunately, the project was able to receive advice from an expert who used to work with the manufacturer of the Hercules graphic card in the US.

Without his assistance, the project would have faced significant problems in accessing the necessary information.

Supporting industries for IC fabrication in Thailand are virtually none. One of the main causes of project's delays was the lead time for wafer fabrication, with each trip for wafer fabrication requiring about 3 months. This in turn meant that it took 12 months to complete the entire wafer fabrication process (6 months for IC fabrication, 2 months for queuing, and 4 months for fault analysis and correction).

The research funding was fairly adequate in the case of the ASIC design project and the grant management bureaucracy was not too cumbersome. However, remuneration for researchers remained low and meant that researchers were forced to seek alternative means of earning supplementary income outside of the project.

The project did illustrate that there are many misconceptions among university researchers who tend to assume that their laboratory prototypes can be easily translated into marketable products. Finally, the project also demonstrated that Thailand's inadequate infrastructure coupled with the limits capabilities of researchers make a project such as ASIC quite risky in a rapidly changing technology field.

c) R&D does not respond to industrial needs

As we mentioned earlier, the working environment within the project was fairly enthusiastic. This stemmed from the good organizational linkages, the economic incentives for the linkage, and the good collaboration and communication between the firm and researchers. NECTEC was able to generate ideas through consultation with the IRC and researchers from the KMITL and even after the projected started, linkages through consultation remained strong until it became clear that the project was not going to be commercialized.

Although the research topic was somewhat new and challenging, it was attractive to both the researchers and to the firm. For the researchers the project offered an opportunity to demonstrate their ability to design a VLSI chip for commercial purposes. Based upon capability gained from the Australia-ASEAN project, the team was optimistic and confident that it could do so. However, as we have noted, the project illustrated that there were many fine points and requirements of the commercial prototypes which were not anticipated in the design of the laboratory prototype.

As the market size was fairly large and the expected returns from the project were enormous, participation from the private firm was very strong. Therefore, not only was the project sponsored by the NECTEC, but IRC also contributed to around 20 percent of the total project's expenditures.

Two lessons regarding R&D's responsiveness to industrial needs can be learned from this project. One is that to make R&D responsive to private sector demand, initiation of the project in the private sector and/or consultation between private and government sectors is needed. The other is that if a particular R&D project is to retain the interest of all the concerned parties, each party must have a stake in the project.

d) Commercialization of R&D results needs management

The project's management benefited both from the close involvement of a private firm committed to making full use of R&D results and from the project's strong leadership. As the director of NECTEC was convinced that the ASIC design could produce many applications and benefits for locally manufactured products he provided strong support for the project. This support included the initiation of research ideas, selling the idea to the private sector, funding and actively monitoring the project and, very importantly, supporting the project until the very end.

As the case study reveals, the process of R&D commercialization, starting from the conception of research ideas to the completion of research projects, and leading to the introduction of products to the market place, is very complicated and needs to be well managed. It is clear that research practices of most university researchers are not applicable to the private sector. Thus, even a project as feasible as the ASIC design project supported by a strong funding base failed to succeed commercially. This demonstrates that good project management relating to topic selection, project execution, and day-to-day problem solving is crucial, since the main reason for the unsuccessful commercialization of the product was the project's many delays.

Nevertheless, to be fair to all of the parties concerned, the project's commercial failure can be largely attributed to the poor understanding of product innovation. In other words, in order to introduce a new product into a rapidly changing market environment, such factors as the fine tuning of a product to meet changing market conditions, the timing of a product launch, and potential project delays must be taken into account. All of these factors are of particular relevance to the field of personal computers, where product lifecycles are getting shorter and shorter.

One lesson learned from this project is that even strong leadership that can provide a project with the necessary vision funding, and coordination by no means leads to a successful commercial product. Apart from strong leadership and private sector participation, product innovation needs good project management that can match market conditions with technical abilities. One way of achieving this is to implement a feasibility study (or, at least, a pre-feasibility study) at the outset of a project to provide information on market opportunities, technology trends, and research capabilities. This is especially true of projects developing products with short product lives but which require long development periods.

e) There is no short-term economic gain from R&D

On a cost-benefit basis, the ASIC design project generated an economic loss rather than a gain. However, judged on its potential benefits and strategic nature, the project yielded a reasonable return as few electronic products can currently remain competitive without the use of ASIC chip technology. Therefore, this project did not actually prove or disprove the theory that there are only short-term gains from R&D projects. The case demonstrated that the possibilities for short or long-term gains from R&D projects really depend upon many factors. Some, such as project management, time, effort, and resources supplied can be controlled. Others, such as shifts in the market caused by changing technologies, cannot. In such a case, no one can prevent changes such as those which led to the use of VGA cards rather than monochrome ones.

Although this project did not yield any results such as patents and marketable products which could generate economic value it certainly gave a number of researchers more experience and knowledge. Needless to say, the knowledge learned and transferred (both personnel in universities and private firms) not only strengthened commercial research capabilities within the country, but also provided an avenue for better interactions both between universities and industry and between researchers and users. Though the economic returns from these benefits are incalculable, they can serve as a strong basis for further improvement of locally manufactured products based upon ASIC chips.

Another lesson learned from this case study is that short-term economic gain from R&D projects can be achieved provided that knowledge base and research capability match commercial requirements. Experienced researchers, adequate research personnel, available technical information and consultants, and existing supporting industries are all decisive to commercialization.

4.4.4 Conclusions and Policy Implications

The ASIC design for Thai cards project is a good example of R&D projects which bear high risks with a potential for yielding high returns. Conclusions can be summarized and policy implications can be drawn as follows:

a) Conclusion

This case study demonstrates that with an adequate budget and a carefully chosen research topic, Thai researchers are clearly able to produce concrete results. Nevertheless, for those aiming at commercial R&D, there is a need to recognize both the importance of the time factor involved as well as the expectations of the market, which may not always match those of university researchers.

This case study has also shown that Thailand's inadequate infrastructure coupled with the limited experience of researchers can make research in a fast changing field such as that of ASIC chip design somewhat ambitious. This is particularly true when a research project is new to the researchers and requires substantial adaptation of previous work. Furthermore, it demonstrates that strong leadership alone, providing vision and securing funding and coordination, by no means leads to the success of R&D commercialization.

Apart from strong leadership and private sector participation, product innovation needs good project management which can match market conditions and technical achievements. Thus, a feasibility study (or, at least, a pre-feasibility study) detailing market opportunities, technology trends, and research capabilities, is required at the outset or during project execution.

As for private participation, the case study suggests that to make R&D results responsive to private sector demand, an initiation from and/or consultation between private and government sectors is needed. In addition, in order to make R&D projects of sustained interest to all concerned parties, each party must have its own stake in the project. Short-term economic gain from R&D projects can be achieved provided that knowledge base and research capability fit with commercial requirements. Experienced researchers, adequate research personnel, available technical information, consultancy services, as well as supporting industries are all decisive factors for the commercialization process.

b) Policy implications

Four policy implications can be drawn from the case study:

First, the topic selected for R&D projects should be an agreed topic between all concerned parties. This is to make sure that each of them has a stake in the project. In the case of Thailand it is recommended that the government agency (the project funder), the private firm (the product manufacturer), and the university (the research) all be involved.

Secondly, private participation in an R&D project right from the onset should be required. This is to inject commercial aspects into R&D projects which are in Thailand largely carried out by university researchers. This would also allow for the termination of projects which are wasting resources and efforts which could be used more productively elsewhere.

Third, the management aspect of commercial R&D projects should be strongly emphasized. This is to increase the possibility of commercialization of R&D results as this is a weakness of researchers. R&D project management is required right from topic selection through project execution and market introduction.

Finally, basic technological infrastructure such as technical manpower and services should be secured before spending money on R&D projects. This is to provide the necessary knowledge and services which will improve a project's technical and/or economic success.

4.5 CASE 4: LINEAR ELECTRONIC CIRCUIT

Interviewees: Dr. Ekachai Leelarasmee, CU
Reporter: Dr. Wittaya Watcharawittayakul

LEK 6.0 is a software package for the analysis and design of arbitrary electronic circuits and can be classified as an electronic design automation product. Over the past ten years it has evolved through several versions, gradually improving its performance and user interface. At present, the package has been licensed to a software development company in Thailand for marketing purposes.

Following a brief overview of the history of electronic design automation, we will outline the project's objectives, background and results before turning to an examination of the problems which the project encountered. It should be noted that in presenting our outline and analysis of LEK 6.0, we will cover the entire ten years of its development rather than limiting our analysis to the three years during which the project received funding from the Office of the Science and Technology Development Board; in so doing we hope to ensure that the process which led to LEK 6.0 is fully understood. Finally, we will outline some of the lessons about research in Thailand which can the project can teach us, before setting out our conclusions and policy recommendations.

4.5.1 Background

This century has borne witness to a pace of technological and economic development which has been unparalleled in human history, and which continues to lead to changes in our lives which were unforeseen only a few decades ago. The invention of electronic circuits in the 20th century has been a major contributor to this development, while also laying the foundation for the "information age" upon which the world has recently embarked. To varying degrees, nearly every product today (e.g. appliances, machinery, automobiles, toys, computers) is comprised of electronic circuits which enable equipment to operate more accurately and rapidly with the minimum of necessary attention.

An electronic circuit is made up of many electronic devices, which are in turn composed of metals and semiconductors whose properties allow for the control of electrical signals. Electronic devices are connected by conducting materials (copper), and the complexity of a particular electronic circuit depends both on the number of electronic devices and the type of connections between those devices. Usually the former indirectly determines the latter; therefore the complexity of an electronic circuit is measured by the number of devices.

The manufacturing technology use to produce a particular circuit depends on a circuit's complexity and characteristics. Circuits which consist of tens to hundreds of devices can be assembled on printed circuit boards (PCBs) whose size can range from a few square inches to approximately one square foot. For circuits which consist of thousands or even millions of devices, large scale integrated circuit (LSI) technology is used; allowing an area of only a few millimeters to perform the equivalent work of tens of PCBs. As the level of integration increases, the process of design and implementation becomes increasingly complicated, and the assurance that particular designs will work is therefore vital. Thus knowing a circuit's characteristics before prototypes and products are built allows for flexibility in circuit design, as well as being the source of significant savings in both cost and time.

Electronic design automation refers to the tools which can aid in the design of electronic circuits. These tools usually consist of software packages which allow engineers to evaluate the particular characteristics of a circuit and, if necessary, to adjust its design accordingly. Doing so allows the engineer to make sure that a circuit design works correctly before the actual circuit is built.

The first popular electronic design software was probably ECAP (Elec tronic Circuit Analysis Program), which was developed by IBM in the mid 1960's .[1] The ability of ECAP to transform circuit descriptions into circuit equations was an important first step in the field. In the early 1970's, a project to create a circuit simulator was begun at the University of California Berkeley. This project eventually lead to a program called SPICE (Simulation Program with Integrated Circuit Emphasis), which had the ability to simulate the behavior of any electronic circuit.[4]

The need for programs such as SPICE arose mainly because circuit designers could not test their designs effectively due to the cost and time of doing so. With the development of SPICE, the 1980s saw the eventual creation of a fully fledged electronic design automation industry as many of the researchers and graduate students who had worked on SPICE set out to emulate its design.

The most important aspects of the SPICE program were its investigation into the techniques used for the representation of electronic circuits inside computers and its ability to simulate circuit behavior. Today, it is these techniques which are most commonly used in circuit simulation software.[2]

Electronic circuit simulation involves heavy computation and graphics use. In the past, such capabilities could only be achieved on large and medium scale computers such as mainframes and minicomputers. Nowadays, however, workstations and personal computers have such capabilities, allowing them to analyze circuits with tens or even hundreds of devices. Using mainframes and supercomputers it is even possible to simulate circuits with thousands or even hundreds of thousands of devices.

a) Project objectives

According to the proposal presented to STDB[3], the project's objectives were as follows:

1. To develop circuit analysis software capable of analyzing arbitrary electronic circuits on 16-bit personal computers and/or 32-bit workstations.

2. To help universities, vocational schools and industry to set up affordable electronic computer aided engineering systems.

According to its original specifications, the software was to include a very good user interface so that minimum computer knowledge was required, and was also to facilitate the inclusion of new devices. Once completed, the program would be able to perform three types of analysis: AC frequency response, DC operating point, and transient response; and would be able to analyze circuits made up of the following devices: resisters, capacitors, inductors, voltage and current sources, diodes, transistors, relays and switches, and operational amplifiers.

Due to the limited power of the target machines, the software was to be made suitable for electronic circuits designed by local industry, whose products (e.g. radio transceivers, inverts, switching power supplies) are made up largely of small electronic circuits. Although there are many variations in the design space for such products, their electronic circuits are not complex and thus the software could help local designers verify and choose appropriate circuit components.

b) Project results

Although the final result was the production of a single diskette, its essence was an accumulation of knowledge brought about by repeated refinements in the software. Included in the software package was a manual which gave examples of both input and output. As the software was able to communicate using electronics circuit terminology rather than computer language, usage of the software was not considered to be difficult.

The primary goal of the project, which was to alleviate the problem of inadequate laboratory experience for engineering students, has clearly been achieved. Copies of the software have been distributed to engineering schools and technical institutes throughout Thailand. At Chulalongkorn University, where about 100 electrical engineers graduate annually, approximately 100 students have used LEK 6.0 for experiments in their electronics design course and plans have been made to expand its use to other courses.

The other goal of the project was to promote the application of electronic design automation in industry. At present, there are a few professional engineers working for various companies (e.g. custom electronic design, satellite servicing and electronic appliances) who are making use of the software in the design of commercial products. These companies have used the software to help design and test small electronic circuits and, in one case, to simulate the behaviors of control circuits in air conditioners.

The circuits which have been designed consist of a few to perhaps tens of electronic components, while more complex circuits need to be divided and tested separately. Essentially, the program has been used to select initial component values on a circuit, which in turn requires repeated simulations to find out circuit sensitivity. By using the software, local designers have been able build circuit prototypes more rapidly and, while for small circuits the design cycle has not as a result been noticeably improved, improvements in the design cycle of more complex circuits have been significant.

Although the use of the software cannot substitute for direct exposure to real circuits, its flexibility does allow engineers to explore design parameters. For students it can provide insight and understanding of circuit functions, thereby shortening training time. On the other hand, as industrial needs require the use of more complex circuits, it is important to have ongoing software support to meet changing requirements. Researchers are however unable to spend the time to cope with day to day problems such as these.

c) Research process

As we mentioned earlier, LEK 6.0 is a continuation of a project that began in 1982 when a local researcher felt that electrical engineering students were suffering from a lack of laboratory practice due to large class sizes, insufficient staff and, most importantly, the lack of available electronic components. Having encountered similar problems when studying in the US, the researcher already had experience in using electronic circuit analysis software to help resolve this problem. Although microcomputers were expensive at the time, the researcher acquired a first generation 8-bit microcomputer (APPLE II) which had no hard disk and only 48 kilo-bytes of memory. Following the specifications of SPICE he wrote his first program known as LEC 1.0 using the BASIC language. The program was capable of analyzing linear circuits and had output text for their frequency response.

In 1983 the project received a small amount of funding from Chulalongkorn University's Faculty of Engineering. Performance tuning led to LEC 2.0, which included graphics output, and (with the help of a senior student) had by 1984 produced LEC 3.0; to which the analysis of DC operating points had been added. With further assistance from another graduate student, the capacity to analyze transient response and some nonlinear component characteristics were added, thereby leading to the emergence of LEC 4.0.

At the time of LEC 4.0's development, personal computers (PC), especially the IBM PC and its clones, were widely used. Given their cost-effectiveness and availability, it was decided to overhaul LEK 4.0 in 1985. With the support of the university's research institute, the software was transferred to a new platform made up of the PC with the Intel 8088 microprocessor and a hard disk and rewritten in PASCAL. The shift to PASCAL facilitated the use of structured programming, dynamic storage allocation, and enhanced graphics, and led to LEK 5.0. This was the first electronic analysis software program in Thailand and its success was reflected in its widespread use within various educational institutions.

Finally, from 1987 to 1991, the project received funding at the national level from the Office of the Science and Technology Development Board (STDB) in the amount of 1.4 million baht. The goals of this phase of the project were to do performance tuning, improve the user interface, design more realistic models of electronic components and to try and commercialize the program.

This latest version, known as LEK 6.0 (the name LEC was replaced by LEK to give it a "Thai" flavor), consists of three components. The first is the input processor, which includes a special text editor for guiding users in describing electronic circuits. The input processor also transforms circuit descriptions into internal computer representations. The second component consists of analysis routines that can manipulate the internal representation of circuits; in other words, it is made up of a series of mathematical routines using numerical analysis techniques. The third and last component is the output processor, which receives the results from the analysis routines and presents them in a graphical form to users.

STDB records indicate that there were six progress reports produced under its sponsorship of the project from February 1988 to January 1991. The first, second, third and fifth cover six month periods, whereas the fourth and the sixth spanned nine and three months respectively. At the time of writing (June 1992) the final report was in the process of being submitted.

The first six months of the project were spent in designing detailed plans, setting up a research laboratory and making a preliminary study of the software's redesign. The acquisition of equipment was however delayed due to government regulations. During the latter half of the first year, 4 microcomputers were purchased and modification of LEK 5.0 was begun. Modifications included the creation of the input processor's text editor as well as the design and implementation of some internal data structures for the storage of circuit topology.

In the first half of the second year the input processor was redesigned to make it more user friendly by introducing a menu to guide users in setting up desired circuits. Electronic components could now be catalogued and re-used, and the method also minimized errors and required less knowledge from users. New techniques for the formulation of circuit equations were also explored.

Between the 19th and 27th months of the project the prototype was completed and the program was able to perform transient simulations of any circuit containing arbitrary connections of various types of components. The following five months saw the addition of frequency response analysis and two circuit components: i.e. a voltage-controlled-voltage-source and a voltage-controlled-current-source. It was also at this time that the software was distributed to the public. Finally, in the last three months the graphics routines were furnished.

At the time of our interview with the researcher (June 1992) the software was complete. In the last year nonlinear electronic component analysis and DC simulation have been added, and the software has been cleaned up and put on a single diskette, allowing it to run on microcomputers with 640 kilobytes without the need for either a hard disk or a math co-processor.

The researcher is currently planning a new version and is in the process of gathering new ideas. He foresees a new software development paradigm such as object oriented programming and Monte Carlo circuit simulation. If schematic input can be used this will improve the user interface to a significant degree, as users will no longer be required to understand cryptic textual circuit descriptions but will be able instead to manipulate circuits directly.

4.5.2 Problems Encountered

a) Demand conditions

Globally, the demand for software similar to LEK 6.0 is enormous, both within the educational and the professional sectors. In 1990, an estimated 960 million dollars worth of electronic engineering software was sold in the U.S., while total sales were expected to continue rising at an annual rate of 10 percent [IEEE, 1991].

In Thailand, the use of electronic design automation software is still a rarity. However, the introduction of LEK 6.0 among engineering students has begun to change this state of affairs, and we can expect that in the near future demand for such capabilities will grow. Indeed, some local companies are already planning to acquire such software, even though the cost of importing it may be several thousands of dollars.

For hobbyists and students, software that can simulate small circuits with tens of devices is adequate, even though practical circuits can have hundreds of devices. Professional usage requires, however, more complex circuit analysis programs with sophisticated graphics interfaces, which in turn require the capabilities of workstation and mainframe computers.

As electronics design software for educational purposes is easily obtainable (through shareware etc.) and cheap, any attempts to sell products in this market requires high volumes to be sold to compensate for the low margin of return.

b) Supply conditions

In the field of electronics design automation, there are a wide variety of software packages available, each of which is designed for a specific area. These areas include, among others, circuit simulation, logic synthesis, electromagnetic field simulation, data acquisition and analysis, and digital signal processing.

Within each of these areas there are in turn a few to perhaps tens of suppliers, most of whom were only established at the beginning of this decade and almost all of whom are based in the U.S.

Given the availability of a huge market and with moderate growth prospects, there still remains room for newcomers who wish to enter the field. However, in order to develop competitive products, a company must have the required technical expertise in electronics, numerical analysis and graphics presentation techniques.

c) R&D capabilities

Perhaps the only area in which the project did not suffer from insufficient capabilities was that of the knowledge base needed to pursue the project. Indeed, the researcher's prior experience was more than adequate for the level of software developed. The difficulties arose instead in the design of the software and in the project's implementation, but even though the researcher had less experience in the latter, the size of this project was small and therefore quite manageable.

d) Technological infrastructure

To examine this area we need to review the project's organization and resources. Formally, this project was conducted by the Digital System Research Laboratory at Chulalongkorn University's Department of Electrical Engineering. Within this laboratory there were three faculty members, each of whom supervised a group of students working on the project. At the time of our interview there were about 5 graduate and 10 undergraduate students working on the project.

The initial proposal stated that the project would require 2 researchers and 2 research assistants, as well as 2 microcomputers and 1 workstation. However, sharp reductions in the cost of computers allowed for the purchase of 6 microcomputers, 2 of which were used to replace the workstation as it was difficult to maintain the software on two different platforms (microcomputers and the workstation). The problem with using the microcomputers was their lack of reliability, which was in turn probably the result of poor assembly and quality control. The lack of support was also a serious impediment when the machine was out of order, as the mean time of repair could be weeks or even months.

Initially, computer equipment could not be purchased due to government procurement regulations. Before 1992, any procurement of computers by Thai government agencies had to be approved by a national level committee as computers were deemed an important strategic resource. Use of computers had to be justified by well defined plans and the approval process therefore took approximately six months. This delay had a ripple effect on the project's time frame and led to an eventual one year delay in its completion.

Turning to the operational aspects of the project, the major problem was the lack of manpower. The research was initially done by only one person who was able to allocate only a limited amount of time to the project. As the researcher points out, research could only be conducted during the semester break (4 months per year) due to his heavy teaching loads and administrative responsibilities. Moreover, the project was unable to hire any research assistants, both because no electrical engineering students were interested in joining and because most of them were unable to program computers fluently and thus were not qualified. Thus the budget for hiring a research assistant was instead used to hire a secretary.

e) Commercialization

The last problem related to the lack of follow up procedures to assess the impact of the software which was distributed; especially that distributed to local companies for practical use. Because the commercial goals of the project were initially never clearly defined, no systematic attempts in this direction were made, and those companies that did use the software were those which had either friends or former students of the researcher working for them. Only after the project was completed was an agreement with a local software company made to attempt to try and commercialize the software, and it was expected that adjusting the product for the market would require a fair amount of time.

4.5.3 Analysis and Lessons Learned

In the following section we will evaluate the project according to the five propositions mentioned earlier. These propositions can be used as guidelines to outline some of the main challenges facing R&D work in Thailand.

a) Thai researchers can produce concrete results

In this particular case, the result was working software. Although similar products exist on the market, the project demonstrates the possibility of developing such software in Thailand. With the researcher having previously dealt (when writing his dissertation) with circuit simulation techniques that were far more complex than those used in the project, he was more than familiar with the various aspects of electronic design, numerical algorithms, programming and man machine interfacing which go to make up the process of electronic design automation.

In its current form, the software is more appropriate as a teaching tool, as its features and interaction remain fairly limited and inflexible due to its restricted hardware. As the electronics industry can afford better and more complete sets of software, any attempts to market the software would necessitate the redesign of the man machine interface and the addition of new simulation techniques in order to provide the program with greater flexibility.

This does not mean, however, that the product cannot be marketed in its current form. Without any further modifications it can still tap in to the software market for low end users such as students and hobbyists who can use it to learn basic electronic circuitry. Nevertheless, at this level profit margins would be low and thus would require huge selling volumes to be profitable.

b) Technological infrastructure is essential for R&D activities

In Thailand, the lack of such infrastructure is a serious handicap for those carrying out research. To begin with, very few professional researchers exist in Thailand, and almost all of those are attached to government agencies. Moreover, continued economic expansion has resulted in the loss by universities of many staff members to the private sector in key areas of science and engineering. Meanwhile, government policy dictates the production of more S&T graduates and consequently teaching loads have increased tremendously. In the case of this project for example, the researcher had to teach two subjects and monitor three laboratory sessions each semester.

The project also indicates the existence of poor interdisciplinary co-operation. As we pointed out earlier, the project was unable to hire any research assistants because there were no electrical engineering students who were interested in joining it. However, if the search had been extended to the Department of Computer Engineering, where knowledge of software development was well established, the problem would have been solved. The lesson to learn from this experience is that the development of commercial products usually involve many disciplines, and hence it is important to identify key areas and get the right researchers at the outset.

The need for improved funding mechanisms to encourage research can also be mentioned, as researchers often appear to be unaware of funding sources. In this case, the researcher began the project without any support and was only later able to acquire a small grant from the university to continue his research. Another point to be made is that the bureaucracy involved in grant management has to be reduced, while better procedures to solicit, grant, monitor and evaluate projects need to be developed as these are often critical in determining the success or failure of a project.

The last point to be made concerns government policies related to the importation of electronic equipment and technical documentation. High import taxes and complex import procedures make the importation of such items very time consuming and expensive, and are a key factor which impedes the development of R&D research in Thailand.

c) R&D does not respond to industrial needs

To begin with, there is a huge gap between research and industry in Thailand's electronics sector. The electronics industry in Thailand consists almost entirely of assembly operations (disk drives, etc.), while there is very little actual product development in the sector. As technical knowledge and manufacturing processes are trade secrets the industry has to rely on foreign experts and equipment, and the main reason that the industry is in Thailand at all is because of the country's favorable labor costs and efficiency.

If the industry is to establish its competitiveness on the world market, the government needs to develop a clear policy of supporting research and development at all levels. As the economies of scale for electronics products are large, there are two potential avenues which could be pursued and towards which the industry is moving: these are integration and specialization. The reason for these moves are that the technology behind every component is highly specialized, therefore assembly plants usually use components and parts from many other factories, which in turn makes it very difficult to remain competitive in all areas.

As for software development, Thai researchers do have the capabilities to produce high quality products but a national policy is needed to guide future development in the field; whether in electronic design automation, office automation or other areas. Finally, mechanisms which can support the continuation of R&D in order to link and distribute ideas and products should be established.

d) Commercialization of R&D results needs management

The need for better commercialization policies and management is important. The government needs to create a better atmosphere for both research and industry, and the types of research to be pursued need to be clearly defined. Marketing support is also needed along with a better understanding of industrial and social needs, particularly at the international level.

In order for products to be marketable, research should not stop with the completion of a prototype as there still remains a long way to go from a prototype to a product. For software developers, the design of the user interface is especially important as end users are usually task oriented. Although standards for man machine interfaces do not exist, there is a similarity in styles in software and these styles need therefore to be emulated.

Currently, government agencies such as the STDB or NECTEC try to locate private companies to market products. However, because most software development companies focus on the design of custom made software, the commercialization of general software packages is difficult.

Another problem for software commercialization in Thailand is the lack of copyright protection laws, whose absence discourages local product development. Also important, especially in the software development industry, is the question of product acceptance and support. Once a product is chosen users usually remain loyal to that product for a long period, thus making it difficult for new products to enter the market.

e) There is no short-term economic gain from R&D

The last proposition concerns itself with the question of whether or not R&D results in only short-term gains. For basic research this is obviously not the case, as the very point of such research is to explore and expand the existing knowledge base and, thereby, propose new alternatives that may yield benefits for the world in the future. On the other hand, applied and development research aims to achieve results that can bear fruit in the short term; i.e. in two to five years. For both types of research the ability to convey findings beyond the confines of technical journals is important, thus mechanisms for the distribution of research results to a wider audience need to be developed.

If we examine software development specifically, we can note that prototypes usually require about one or two years to develop followed by testing periods of three to six months. As such processes need professional analysts and programmers, expecting researchers to assume all these roles is unrealistic.

4.5.4 Conclusions and Policy Implications

a) Conclusion

In this study we have reviewed a software development project whose aim was to develop an electronic design software package for microcomputers. The software was to designed to simulate the behavior of linear and non-linear circuits so as to allow electronic designers to design electronic circuits more efficiently. As the product was designed for low-end microcomputers, its capabilities remain limited and, consequently, its benefits for practical purposes are also limited. However, as we have said, it remains well suited for an educational environment.

LEK 6.0 was chosen for this study because it demonstrates the capacity for long-term commitment to R&D by Thai researchers. Furthermore, it demonstrates that with limited resources Thai researchers have the capacity to accumulate, integrate and exploit knowledge from many technological areas (in this case electronic circuit analysis and software engineering).

The project has lasted a total of ten years, the first seven of which involved little or no funding. This demonstrates the capacity of long-term commitment by Thai researchers and also shows that even with limited resources researchers are able to effectively accumulate, integrate and exploit knowledge from various technological fields. As we mentioned earlier, the major problem was the lack of manpower; other problems included delays in equipment acquisition and the inability to locate collaborators. With appropriate collaboration from software development experts the project would have been completed more rapidly and have appeared more professional.

b) Policy implications

The project illustrates that good software development needs funding sources with clear policies and responsibilities. Good procedures to solicit, follow up and evaluate projects are critical in determining project success.

It also demonstrates that the government needs to promote research through alterations in tax laws and import procedures related to electronic equipment and documentation. There also needs to be a copyright law to create incentives for software development.

The study has also demonstrated that it is important to have clear national policies to support R&D at all levels, from basic research to industrial applications, if the country is to establish itself as a serious competitor in the world electronics market. With the electronics industry moving towards greater component integration and specialization these areas also need to be examined and clear policies established.

Finally, the study shows that there is a need for professional analysts and programmers for the software development process, as well as for better marketing strategies and market analysis.

REFERENCES

[1] W. Banzhaf, "Computer-Aided Circuit Analysis Using SPICE," Prentice Hall, Inc., 1989.

[2] G.D.Hachtel and A.L. Sangiovanni-Vincentelli, "A Survey of Third-Generation Simulation Techniques," Proceedings of the IEEE, Vol. 69, No. 10, Oct. 1981.

[3] E. Leelarasmee, "Development of Computer Aided Engineering (CAE) System for Electronic Design," Designated STDB Proposal, 2nd revision, Agreement No. DSC 87A-3-06-020, Sept. 1987.

[4] L.W. Nagel, "SPICE 2: A Computer Program to Simulate Semi-conductor circuits," ERL Memo ERL-M520, Univ. of California, Berkeley, May, 1975.

4.6 CASE 5: MEDIUM SCACE INTEGRATED CIRCUIT FABRICATION

Interviewees: Dr. Somkiat Supadej (KMITL)
Dr. Manoo Sangwarasilpa (KMITL)

Reporter: Asst. Prof. Prayoon Shiowattana

4.6.1 Background

Given the present development trends of electronic engineering it is evident that electronics products will eventually consist of three major elements: PCBs, ICs and software. In light of this fact the strategic role of IC technology is evident.

The first IC assembly factory in Thailand was set up over twenty years ago. Today, there are more than ten MNC assembly lines operating in the country. Although IC production is considered one of the "hi-tech" industries, investment in the country's IC industry has been mostly in its labor intensive aspects which in turn generates relatively low value added.

During the last two decades, two semiconductor research laboratories have been established within two state universities. As a consequence, high level manpower specializing in this subject area has been continually pro duced. Nevertheless, no serious effort of upstream integration has yet been made by existing IC assembly firms.

This sub-project on the "Design and Fabrication of a Prototype IC" is one of the many research areas incorporated into a project on "VLSI Design" sponsored by the National Electronics and Computer Technology Center (NECTEC). As such, it is a first step into the new field of IC fabrication which, up until now, has largely been the preserve of the industrialized countries.

The project itself is part of an ongoing series of research projects on semiconductor technology which have been undertaken by KMITL's Semiconductor Research Laboratory since its establishment about 20 years ago. During that time, the Laboratory has been able to master basic technologies and know-how and to produce discrete devices such as diodes, transistors, MOSFET, and thyristors. Research on some other specific sensors such as photocells, opto-sensors, and pressure sensors has also been attempted with satisfactory results.

Given the ever increasing role of ICs in electronics industries, and with years of experiences in this subject area, the research team for this particular project decided to tackle IC technology as they felt they had the tools that would be just about capable of basic discrete device production. The main reason for doing so was to gain experience and know-how related to IC fabrication which, though similar to discrete device fabrication, is much more complicated. In addition, the researchers expected that such a project would compliment the research being supported by the Australian government on IC design techniques on workstations.

a) Project objectives

The research team set out to fabricate a 10 micron rule IC and chose to start with nMOS. In so doing they hoped to learn something about the diffusion techniques used in IC fabrication. More specifically the team aimed to master basic technologies and knowledge related to the fabrication of nMOS type invertor circuit. From this process they hoped to learn the techniques and know-how involved in the control of impurities concentrations, their penetration depths, mask alignment techniques etc. Having mastered the techniques of fabrication of single nMOS invertors, they believed that they would then be able to tackle larger scale integrations.

According to the researchers, the objectives of the project were as follows:

- The preparation, development and improvement of equipment and laboratory facilities to establish a limited capacity to fabricate integrated circuits.
- To obtain the necessary information related to the IC fabrication process using existing equipment, and to develop this process into a standard technology.
- To cooperate with a research group on computer-aided design (CAD) in order to develop the capacity to design and fabricate ICs locally.
- To educate and upgrade researchers in IC design and fabrication techniques.
- To draw the attention of policymakers to the importance of IC technology so as to promote the development of an IC fabrication industry.

b) Project process and results

The research process and results of the project can be divided into the following phases:

<u>Preliminary Stage:</u>

In this phase, the researchers put most of their efforts into analyzing the best possible process for IC fabrication using existing equipment. A comparison of the merits of the various fabrication technologies (CMOS, pMOS and nMOS) was made. Finally, the CMOS technology was selected as most commercial ICs have been fabricated using this technology.

Following this decision, a more in depth analysis of the CMOS process was made to establish a standard process which could be used in IC fabrication. Forty-one stages were identified, ranging from the cleaning of the Si wafer, oxidization, P-well deposition, photolithography, drive in, etc. (details of these stages will not be discussed here).

Test run phase:

Some crucial stages were tested in order to insure their repeatability and reliability. These stages were;

- Si wafer surface cleaning,
- Photolithography (both the positive and negative processes)
- Impurity diffusion using both Phosphorous and Boron.

Design of MOS transistor and invertor circuit phase:

During this phase the researchers began by designing discrete nMOS and pMOS transistors. The transistors were then fabricated based on the design and according to their electrical characteristics.

After gaining satisfactory results from the design and fabrication of the discrete n and pMOS transistors, the researchers then endeavored to move to the more complicated design of n and pMOS inverters.

Prototype pattern cutting and mask making phase:

Based on the design mentioned above, prototype patterns were prepared and were then reduced 50 times on to the mask for IC fabrication. Six pieces of prototype masks were prepared for the whole fabrication process.

Fabrication of invertor circuits on the Si wafer phase:

In this phase the prepared Si wafers and masks were used and the invertor circuits were attached to the Si wafer according to the forty one stages process.

Testing phase:

The electrical characteristics of the devices were tested to ensure the repeatability and reliability of the fabricated ICs. Tests were done in the following areas;

- Junctions rectifying characteristics and their capacitance were measured,

- Electrical characteristics of the n and pMOS devices were measured (ie. their transconductivity, breakdown voltage and threshold voltage)

- Electrical characteristics of the invertor circuits were measured (ie. $I_D V_D$ characteristics, invertor transfer characteristics and its switching speed).

c) Project background

The research team consisted of four members. Associate Professor Somkiat Soopadech, the principal researcher, has been involved with semiconductor research since the establishment of the Semiconductor Research Laboratory almost two decades ago. He also has had training experience with two of the largest Japanese IC producers: Oki and NEC. Another of the researchers also had training experience with Toshiba, another one of the largest Japanese IC manufacturers. The third researcher had some training background on IC design from Australia whereas the last researcher had worked with the famous U.S. IC manufacturer, Signetics. All these members made up a very competent and strong team with which to tackle the complicated research which the project entailed.

4.6.2 Problems Encountered

a) Demand conditions

As the research was not trying to break through any new technological boundaries there is no commercial or technological need for this type of R&D research. On the other hand, the absence of clear government policy related to this strategic area means that there is a need for the accumulation of knowledge and the development of human resources in this field.

b) Supply conditions

As the quality of materials (ie. Si wafer, chemicals, water) directly affects the major characteristics of any IC that is produced, the researchers could not use substitute materials. As the materials used were very specialized in nature they had to be imported at a high cost and, in many cases, a minimum quantity had to be ordered even though the quantities were too large for the project. As a result, the researchers had to share this expenditure among many projects.

In measuring the characteristics of fabricated ICs, very specific measuring instruments with a high degree of accuracy are needed such as probes set with adequate probes, C-V curve analyzers, logic circuits function testers etc. As such equipment is not readily available, the modification of some existing equipment was necessary.

c) R&D capabilities

All the researchers who participated in the project possessed the necessary knowledge and experience to allow them to meet the project's basic objectives. However, it must be stressed that the main purpose of the project was to accumulate knowledge and it can therefore not be measured against specific objectives. Finally, it should be noted that Thai researchers will need to acquire a lot more knowledge and experience in this field before Thailand is able to fabricate her own ICs.

d) Technical services

1. IC Design & Mask Fabrication: In designing small scale integrated circuit (SSICs), it is possible to make manual designs of patterns which involve the integration of only a few transistors onto an IC chip. However, in cases involving a higher number of transistor, MSICs, the process of manual design becomes very complicated and time consuming. As this research involved manual design many mistakes were made which delayed the research schedule.

Furthermore, the available pattern cutting equipment for mask fabrication was very basic and was only suitable for manual operations, while the use of such tools for IC fabrication therefore required highly skilled personnel. This method of pattern cutting needs time, patience, skill and great effort.

2. IC Fabrication: The available process at KMITL is adequate and suitable for discrete device fabrication. For IC fabrication, which involves very small sized devices, extreme care is needed in every stage of the fabrication process, starting from wafer preparation, mask fabrication, impurity diffusion and so on.

3. Researcher Salaries: Low or "no" remuneration discourages researchers, especially in a climate where the shortage of engineering manpower has greatly pushed up the starting salaries for new graduates. This also leads to the loss of experienced personnel and their valuable accumulated knowledge.

e) Commercialization

As the project's primary goal was to accumulate knowledge regarding IC design and fabrication, there were no commercial motivations involved.

4.6.3 Analysis and Lessons Learned

In the following section we will evaluate the project according to the five propositions mentioned earlier. These propositions can be used as guidelines to outline some of the main challenges facing R&D work in Thailand.

a) Thai researchers can produce concrete results

As the research itself focused more on the practical aspects of IC fabrication rather than trying to observe any new phenomena, it did not produce any academic papers. It was, however, a first attempt to step into the unknown field of IC fabrication.

Although the parameters and other environmental conditions for IC fabrication discovered during the research were not new findings, they were a valuable starting point in the learning process related to this new technology. What was valuable was not the information itself but rather what was learned about the methodology and process that was used to extract such information.

Given the relatively unsatisfactory research environment, which included equipment that was barely adequate for the fabrication of discrete device, inadequate control of dust, humidity and temperature, and obsolete techniques of impurity doping through diffusion, it was not possible to use modern ion implantation techniques.

However, the research team did manage to produce devices that have electrical characteristics comparable to those available on the market. This indicates that the researchers have acquired some of the knowledge and experience which is needed to tackle this technological area.

b) Technological infrastructure is essential for R&D activities

Manpower

Manpower was a major issue for this research project as many of the technicians and research assistants quit the project for better paying private sector jobs as soon as they could find one. As a consequence, invaluable accumulated knowledge just disappeared and, except for those researchers who remained, the learning process had to be continually restarted.

As no meaningful research work is possible under such a situation. Urgent measures need to be taken so as to rapidly increase the number of qualified S&T personnel. It may even be necessary (if possible) to organize a medium term training courses of about three months duration as such training courses could turn out technicians and research assistants who would be capable of supporting work in semiconductor research laboratories, thereby allowing researchers to tackle the more technical aspects of the research process.

Technical Services

It is necessary for the country to have technological capability in IC fabrication, at least at the prototype fabrication level. Trends indicate that technological development will, more and more, be "integrated and embedded" in IC devices. The lead time which for technological development will, in large part, increasingly rely on in-house capabilities in the fabrication and testing of ICs. If Thai researchers have to rely on other countries to fabricate their designs, the wasted time such services would require would probably negate the potential benefits of many inventions right from their onset which would severely hamper Thailand's ability to compete in the electronics sector.

c) R&D does not respond to industrial needs

There exists no demand for the establishment of an IC fabrication industry in Thailand. This is not because such technology is not necessary for the country but rather because the MNCs consider that Thailand is not suitable for such operations. Policymakers need to make a serious evaluation as to whether or not to induce such a capability and if so, whether this is to be through MNCs or local investors. Once this decision has been made it would then be possible to provide other supporting measures.

Currently, research personnel and teaching staff in this field find themselves in a vicious circle. On the one hand, universities cannot increase their production of graduates in this area of semiconductor specialization as demand for such specific knowledge is relatively low. On the other, the small number of such specialists makes any investment in IC fabrication very difficult, if not impossible. The establishment of a clear policy by the government relating to this strategic technology would be one way of breaking this vicious circle.

d) Commercialization of R&D results needs management

Any attempt to promote R&D activities that could lead to commercial IC fabrication capabilities would require enormous investments. Thus, policy makers first have to decide whether Thailand should go in this field, as well as determining how far the country is actually able to go, given the limited human resources and technical capabilities available.

Once it was made clear that there would be a policy to support IC technologies, there would need to be strong management which could determine realistic short and long-term goals while also making sure that all the necessary resources (especially enough researchers) were made available.

e) There is no short-term economic gain from R&D

For this particular project this proposition is valid, as the project is attempting to develop long term capabilities. However, as some of the other case studies demonstrate, R&D in Thailand can produce both short and long-term gains, both of which can be of benefits to the country.

4.6.4 Conclusions and Policy Implications

a) Conclusion

Though a lot has been learned in the process, the learning process was nevertheless not fast enough to keep up with the very rapid development of IC technology. In learning new techniques by actually doing them, researchers find themselves left even further behind than when they began. This suggests that technology of such scale probably requires different learning methods to assimilate.

IC technology is a huge body of knowledge that could be applied in a wide range of industries. Though the government's policy in this field remains unclear, if it does wish to encourage the development of this technology can do so in a number of ways as outline below.

b) Policy implications

- A relatively passive one of "watching" the development trend of this technology and trying to steer related investments so as to take the most advantage of such developments. Under this option the government may not wish to go beyond the existing assembly line capabilities of Thailand.

- A mildly positive stance that would see the setting up of a service center for IC technology that would include information on IC fabrication, CAD for IC design etc. Under this option the government would be attempting to establish an environment that lay the foundation for the future development of the industry.

- A more positive option is to set as a national policy to develop in this direction, in which case investments in infrastructure that could induce such an industry would be needed.

If the results of such actions were positive, they could then be upgraded into a national project with clear short/medium and long term objectives. Half-hearted support would result in nothing but frustrations for both funders and researchers.

One direct and short cut way to develop IC capability is to use the reverse engineering method. This could begin through the purchase of up to date technology and equipment which would allow the learning process to begin using state-of-the-art technology. By providing services for the fabrication of domestically designed ICs, a lot more could be learned.

It will become necessary in the near future for Thailand to have in-house capabilities for the fabrication of ICs from domestically designed circuits. The situation will become quite similar to that of PCB fabrication which exists at the moment, with more and more researchers feeling it to be necessary that circuits designed should be turned into PCBs domestically, whether double-sided or multi-layered. Two prominent reasons are: first, to keep the design circuit secret in order to prevent it from being abused and, secondly, to reduce lead time between circuit design and prototype testing. The importance of these two factors will become even more apparent as competition in the field increases and as the case of IC design and IC fabrication is similar to that of PCBs the two factors outlined above can also be applied to it.

Finally, the last possibility would be to produce hybrid ICs which would be less costly while at the same time producing some value added. As the technology is far less complicated, this could be a good starting point for the later fabrication of monolithic ICs.

4.7 CROSS CASE ANALYSIS

The case studies have provided us with a comprehensive overview of a number of research and development projects in the electronics sector and, in so doing, have identified some of the positive and negative aspects of R&D in Thailand. Even though the case studies cut across a wide variety of product levels and ranges, they do indicate that there are a number of common elements which characterize the R&D environment in Thailand, while also suggesting that many of these elements need to be changed if R&D is to make a more meaningful contribution to Thailand's economic and social development.

It is the purpose of this section to set out those elements which characterize the R&D environment in Thailand and to outline some of the lessons which can be learned from the case studies' experiences. As in the previous sections, we will use the five propositions which were set out at the beginning of this study as units of analysis.

4.7.1 R&D Capability

The first proposition states that Thai researchers are capable of producing concrete results. Based on the criteria outlined in Chapter 2 we can divide this proposition into two categories: research and academic results, and the utilization of results. The first category examines the number of papers published, the amount of knowledge acquired and whether or not a project's objectives have been met while the second reflects the importance attached to the economic and social impact of R&D and looks at a project's economic and social benefits.

Research/Academic Results

The starting point for such an analysis is to ask whether or not a project has met its objectives; be it the production of a marketable product, the development of a prototype or the cultivation of knowledge. As the case studies show, not only are Thai researchers capable of producing concrete results, but they are often able to do so in spite of the many constraints which hamper R&D work in Thailand (and to which we will return below).

If we compare initial project objectives with their actual output (see below), it is clear that most of those objectives were attained, although we may qualify this statement by noting that the attainment of commercial objectives was somewhat less successful.

Project Objectives

PC:	To develop a 32-bit microcomputer with potential commercial applications.
PABX:	To develop a PABX system which could serve the domestic and international markets (and thereby reduce imports).
ASIC:	To accumulate and diffuse indigenous VLSI design technology and to develop an industrial prototype of a monochrome graphics card depicting the Thai language.
LEK 6.0:	To develop circuit analysis software for the analysis of arbitrary electronic circuits and to assist the education sector in setting up affordable software engineering programs.
IC Fabs:	To master basic technologies and knowledge regarding the fabrication of integrated circuits (IC) and to upgrade personnel and draw attention to the importance of IC technology.

Project Outputs

PC's:	Industrial prototype, marketable product.
PABX:	Industrial prototype, marketable product.
ASICS:	Industrial prototype.
LEK 6.0:	Industrial prototype and diffusion of software to educational institutions.
IC Fabs:	Accumulated knowledge of IC design/fabrication process.

All four projects which set out to produce industrial prototypes (PC, PABX, ASIC, LEK) were able to do so. The MSI Fabs project was in turn able to develop devices which had electrical characteristics which are comparable to those of ICs on the market. Finally, LEK achieved its goal of transferring engineering design software to the education sector.

The success of R&D cannot, however, be measured merely by the production of tangible products. Just as valuable is the accumulation and diffusion of knowledge, as it is this knowledge which will serve as a foundation upon which the future development of R&D capability can be built. As many of the projects tackled technologies which were fairly new to Thai researchers, it is important that the knowledge thereby acquired is used as the basis for the future development of an indigenous knowledge base.

The production of the first Thai made computer was an important milestone for the Thai computer industry. Not only did the PC project overcome the lack of confidence which many Thai researchers seemed to have in their ability to tackle such a "*high tech*" field, but it also permitted the transfer of PC technology to a local company's technicians. Further benefits included the diffusion of computer aided design (CAD) capabilities to a number of Thai engineers as well as the development of links between local industry and researchers. In a similar manner, ASICs delved into technological areas which were, at the time, considered to be fairly new ground for Thai researchers and was able to diffuse this knowledge to a number of university researchers as well as to the private sector.

Finally, given the importance of developing R&D human resources for the sector's future, LEK's transfer of technology to the educational sector could rightfully claim that it may yet have the most far reaching effects of all by assisting in the training of a new generation of engineers.

Although all of the projects did serve to develop and diffuse knowledge to researchers and industrialists the case studies suggest that there is still room for improvement in the knowledge diffusion process.

The lack of research papers and/or reports produced by the IC and ASIC projects was noted as one weakness. Although the IC project disclaimed such a need given that it was not attempting to develop any new technology, an explanation of the research process relating to IC fabrication within the local context could still offer valuable insight to other researchers, especially given the difficulty and expense of accessing such information in Thailand.

More serious was the "loss" of knowledge during the project cycle caused by the tendency of research assistants to leave projects in mid-stream. The low salaries offered for such positions led many research assistants to leave a project as soon as they had gained enough knowledge to work in the much better paying private sector. While it could be argued that the diffusion of knowledgeable engineers throughout the private sector will assist in the future development of an indigenous electronics industry, it also makes it very difficult to develop a knowledge base both during and after a project. This in turn makes it almost impossible to build up groups of core researchers who can develop the knowledge base in a particular area over a longer period of time.

Utilization

The social and economic returns from a particular R&D project are for many the most important measure of a project's success. Of the projects, three (PABX, ASICS, PC) hoped to achieve commercial success, whilst a fourth (LEK) aimed to assist in the development of electronics engineers through the transfer of electronic design software to the university sector.

At the time of writing, it would be fair to characterize the results of the projects as mixed. While the PC project led to the successful sale of thousands of the first "Thai" made computer, attempts to market the ASICs card failed to even get off the ground following an unanticipated change in the graphics card market which rendered it obsolete. While it is inevitable that some R&D projects will fail, it was somewhat unfortunate that ASICs did so, both because of the large amounts invested in it and because of the potential returns which it might have generated (estimated at 120-150 million baht a year). Finally, with the PABX system still undergoing final touches before moving into a highly competitive market the outcome of its efforts are yet to be determined.

LEK has been able to achieve its initial objective of being used within engineering schools in Thailand and has thereby contributed to Thailand's economic and social development. As no concerted effort was ever made to develop it as a competitive product (except possibly at the lower end of the market) it would be unfair to evaluate it along these lines. However, the failure to consider an active marketing policy for what could be a commercially viable product does indicate a certain lack of management of the commercialization process.

4.7.2 R&D Infrastructure

The second proposition states that R&D cannot be achieved without strong technological infrastructure. In discussing the impact of technological infrastructure we are referring to both its technical (e.g. manpower, technical services, research facilities, funding, supporting industries etc.), as well as to its policy (R&D policy, tax laws, import regulations) components. When assessing the impact of infrastructure on R&D we can divide our analysis into the following key areas:

- manpower & facilities
- finance/funding
- technical services
- supporting industries
- government policy framework

Manpower & Education

The ability to undertake any research and development project is ultimately dependent on the availability of capable and dedicated researchers. Whether or not this will be the case depends in turn on a number of factors such as the output of qualified researchers and the rewards associated with R&D vis a vis competing alternatives (as well as more intangible factors like the prestige associated with R&D).

In spite of the importance of manpower development for R&D, the case studies indicate that one of the major constraints on R&D in Thailand is the shortage of available researchers, especially the shortage of qualified research assistants.

The shortage of qualified assistants can be attributed to two factors. The first relates to the shortfall in university engineering graduates as universities, faced with limited budgets and a lack of sufficient teaching staff, fail to keep up with the rapidly increasing demand for such graduates. The second factor relates to the preference of both graduates and university professors to move into the private sector where rewards are higher than in the poorly paid teaching and research sectors (for example, recent graduate engineers are likely to receive twice the salary of research assistants).

As a consequence, those potential researchers who do remain in the university system are overburdened with heavy teaching loads and administrative responsibilities and are, therefore, often unable to devote much time to R&D. A good illustration of this problem is the LEK project, whose principal researcher was not only unable to find qualified assistants but was also unable to devote more than four months of the year to the project due to his other commitments.

The inability to attract and/or retain qualified assistants also led to high turnover rates in three of the other projects (PABX, PC, IC). Uncompetitive salaries for research assistants lead, however, not only to high turnover rates but are also extremely disruptive to the research process.

It should be recognized, however, that the lack of available researchers may sometimes be the result of poor planning. For instance, although the LEK project was unable to recruit any electrical engineering students, this appears to have had as much to do with the students' inability to properly program computers as with their reluctance to work in R&D. As the case study suggests, there may have been perfectly capable and willing students in the computer science department ready to work on the project, but this avenue was not explored.

On a more positive note, the researchers who did participate in the projects not only were well qualified to do so but demonstrated high levels of commitment in spite of many mitigating circumstances.

Those working on the IC project had up to twenty years experience in this field, including extensive experience with leading IC manufacturers in Japan and the US, while the PC project was able to put together a combination of researchers from the academic and private sectors with experience in microprocessors, analog circuitry and software design. The LEK project in turn benefitted from its researcher's previous work in simulation design techniques whose complexity far exceeded the level of knowledge needed for the software involved.

While the academic knowledge of the researchers was important, the PABX and ASICs projects also demonstrated the importance of being able to build on previous R&D experience. Without their previous knowledge of VLSI design attained under an ASEAN-Australia project, it would have been impossible for the ASICs project researchers to achieve the technical success which the design of the ASICs card represented. Likewise, one of the researchers working on PBAX was able to bring to it the experience he had gained on an earlier STDB sponsored PABX project.

One of the factors identified by the case studies as a key to successful R&D, especially those aiming to design marketable products (PC, PABX, ASIC), was the ability to attract knowledgeable and experienced personnel from the private sector. Indeed, the ability to do so was felt to be so important that some of the case study authors suggested that it should be set as a prerequisite for the undertaking of all R&D projects.

Funding/Finance

A key aspect for the undertaking of any R&D is the availability of adequate funding. Adequate funding is, however, not a guarantee of success (as ASICs, one of the largest funded projects ever, illustrates) and dedicated researchers can, in some circumstances, achieve initial results on their own (as LEK illustrates). However, the high cost of undertaking research in the electronics sector necessitates a strong, well managed and flexible funding base.

As the companion volume to this study points out (see "Future Potential of Electronics in Thailand", TDRI 1992), R&D funding in Thailand is far from adequate, lagging behind that of all potential competitors in the electronics industry, with the funding that does exist coming almost exclusively from the public sector. Although the projects we have been reviewing did not in general suffer from a lack of funding, they do point to the need to improve the funding management process.

For example, some projects experienced delays because the STDB had no in-house capacity to assess project proposals, and there was also some concern expressed over USAID's tendency to demand that many of the proposals be re-written for fear that projects might infringe on US patent rights. However, once these obstacles had been overcome, projects were in general adequately funded, although the private sector company involved in the PABX project suggested that while it was happy with the funding provided, the amount was still fairly small in comparison with its own inputs.

The awareness of funding sources was also raised as an issue. The LEK project only reached the stage that it did thanks to the dedication of the researcher and his willingness to work initially without any funding. There is, therefore, some question as to whether researchers are fully aware of funding sources and of the procedures to acquire funding.

As for the actual management of funds, it was suggested that NECTEC's policy of allocating funds for purchases immediately was preferable to the STDB's policy of reimbursing purchases of equipment after the fact. There was also some mention made of the rather bureaucratic nature of the funding management process and indications that there needed to be clearly defined procedures for monitoring and evaluating projects.

Technical Services

When discussing technical services we are referring to such factors as the availability of testing services, national product standards, consultants and information sources (whether in the form of technical literature or national databases).

All the case studies cited deficiencies in the availability of technical services as a serious hindrance to R&D in Thailand; examples of which include inadequate testing and measuring equipment, the absence of national testing standards and regulations, and the lack of up to date information and/or local expertise.

Poor testing facilities (eg. environmental and temperature shock) and/or inadequate equipment make it is very difficult, if not impossible, either to design competitive products or to develop a strong technological base. Any attempt to produce products for the international market, with its high quality control standards, is especially difficult. To take one example, the absence of EMI testing facilities in Thailand meant that the computers produced by the PC project could not meet export standards.

As much of the work in this field involves technology which requires the use of highly accurate measuring instruments, the absence of such equipment makes it difficult both to design and evaluate such technology. The design of integrated circuits for the IC project was very cumbersome as the outdated equipment being used was barely able to meet the needs of the researchers. In addition, in a field where strict environmental controls are crucial for the successful fabrication of ICs, the sub-standard level of these controls further impeded work on the project.

Another difficulty related to working in a field which demands such high levels of precision is the time and effort wasted in trying to manually design such items as PCB boards, whose complex circuitry compounded with human error makes the entire process very laborious (as the PC project's researchers discovered). Many researchers therefore argue that more access to, and information on, CAD techniques is needed if such difficulties are to be reduced.

The knowledge base in Thailand was also cited as a significant impediment in conducting up to date research. Along with the absence of easily accessible information on CAD the lack of technical manuals and local expertise/consultants were also mentioned. ASIC suffered from the absence of IC specification and design data books as well from the lack of training courses dealing with IC and VLSI design; only with the aid of an external expert who had previous experience of graphics card design in the United States were these problems overcome.

The lack of testing equipment and documentation were attributed in no small part to the fiscal and import procedures relating to such items, making their importation both expensive (due to high taxes) and time consuming.

Supporting Industry

If research is to be undertaken in an efficient manner there needs to be an effective local industry from which researchers can obtain reliable and high quality materials and components. As time is often a major factor in determining the success or failure of a project in an environment where technological change is rapid, not having effective local suppliers can lead to lengthy and cumbersome delays in seeking out overseas suppliers and hence to the failure of projects. It is especially important to have local capabilities in the manufacture of IC, PCB and ASIC, as these form the core technologies of the electronics industry.

For PABX, the absence of local PCB manufacturers led to extra time and money being spent on searching for suitable overseas suppliers, thereby elevating the costs of the project to the firm involved. Access to reasonably priced components, especially PCB, was also cited as a major difficulty for the PC project. ASIC suffered from a one year overall delay while waiting for IC fabrication in addition to delays created by the shortage of suitable equipment in Thailand for the design of commercially viable ASIC chips.

Regulatory Atmosphere

The regulatory atmosphere within Thailand, including fiscal policy, import procedures, and intellectual property rights, were often cited as obstacles for R&D. Cumbersome import procedures, the high cost of imported components and equipment, and the difficulties associated with property rights are some examples of these obstacles.

The delays, inconvenience and costs associated with the importation of equipment make it very difficult to conduct efficient and cost-effective research. High taxes on imports (whether electronic components or R&D equipment) also mean that it is very expensive, particularly for small private companies, to undertake their own R&D.

Regulations pertaining to the procurement of equipment by government agencies, such as those governing the use of computers, caused delays of six months for the LEK project. Finally, copyright laws, or the lack thereof, were cited as a significant disincentive for the development of indigenous software, as to do so would lead to little in the way of tangible gains for developers.

4.7.3 Supply, Demand & Linkages

As outlined in Chapter 3, one of the four main areas of activity set out for the STDB when it commenced its work in 1985 was the strengthening of the science and technology institutional framework. Within this framework, two important elements stand out: the creation of opportunities for cooperation and interaction between users and producers of R&D; and the creation of effective linkages between government, researchers and industry.

The third proposition therefore aims to explore the extent to which such links have or have not been established and the means whereby those links can be strengthened. In particular, questions over the awareness of researchers of the country's needs for technology as well as the private sector's awareness of and demand for R&D capabilities will be raised.

Linkages

There is a large gulf in Thailand between the public and private sectors in the area of R&D. Although this is because the industry has traditionally been involved in assembly operations and has therefore had almost no involvement in R&D, it also due to the lack of experience which many university researchers have in the development of commercially viable products. While the motives of university researchers and their private sector counterparts may differ as a result, the case studies indicate that the two sectors can work together and produce successful results, as the PABX and PC projects demonstrate.

In both of the cases just cited, as well as in the ASICs project, the good working relationships and communication established between the public and private sector partners went a long way in helping to achieve the projects' goals. For projects aiming at commercial objectives, one lesson which the case studies can teach us is that it is important to establish strong partnerships with the private sector.

Nevertheless, in spite of the good working relationships established a number of issues were raised which point to the need to strengthen the links between industry and research if R&D is to achieve greater success.

As ASICs demonstrates, the absence of an awareness of one another's capabilities and needs can sometimes lead to projects which may be overly ambitious in their expectations. In this case researchers were not fully aware of the gap between their own expectations and those of their private sector partners. Although their research did lead to a working prototype it nevertheless needed various modifications before it could be marketed, thereby demonstrating that researchers may not always be fully aware of market needs.

In a similar manner, the private firm involved in ASICs was not fully aware of the limitations in R&D capability which exist in Thailand. Although the researchers had previous experience in VLSI design this was not fully applicable to the ASIC project. Moreover, the lack of technical infrastructure in Thailand led to delays which may not have been accounted for when initial expectations were high.

Though initially designed for limited use, LEK also illustrates the gap that can sometimes arise between a researcher's expectations and the needs of the private sector. While LEK has become a useful teaching device within the confines of university engineering labs, its wider applicability has been restricted by the failure to meet the standards of comparable products within the private sector. In order for the LEK software to reach a wider audience and market the need for greater attention to user requirements had to be met.

LEK also illustrates the sometimes poor link between researchers and potential collaborators. The project was initially due solely to the initiative of the researcher and it was only after a number of years that the project received significant funding as well as eventually establishing links with the private sector.

Supply & Demand

Misunderstandings between researchers and the private sector mean that not only are researchers not fully aware of the market demand for any R&D which they may undertake, but that the private sector is not fully aware of the extent of, and limits to, research capabilities in Thailand. These misunderstandings can lead to projects (ASICs) which begin with unrealistic expectations on both sides and it is therefore very important that potential collaborators are fully aware of one another's expectations and limitations when undertaking a project.

One way to achieve better understanding is to make sure that each of the potential collaborators has a stake in a project from the very outset and that there is ongoing communication and feedback between the two groups. As the PC case study illustrates, the strong communication links established between the researchers and the private sector participants meant that the project underwent continual fine tuning to adjust itself to meet the changing demands of the market.

Of the five projects, three (PC, PABX, ASIC) can be said to have been driven by the identification of a specific need within the market identified by members of the private sector in conjunction with researchers. All managed to produce working and marketable prototypes although as we have discussed their attempts to commercialize these results have met with mixed results (for reasons to be discussed in the next section).

LEK is an interesting case because although it was originally intended to serve a fairly limited market (university students) it has since been transferred to a private sector company for further development and eventual marketing. At present the product, in spite of undergoing many transformations, still lags behind other products on the market in terms of its user interface. In this case it could be argued that if the researcher had managed to find private sector collaborators at an earlier stage, the product may have been more marketable than it is at present.

4.7.4 Commercialization

As R&D is often very much a hit and miss affair, especially when dealing with unfamiliar technologies, not all laboratory prototypes will end up as successful commercial products. Nevertheless, being fully aware of the market and of the limitations within the research environment can at least reduce the possibility of failure.

As much of R&D concerns itself with the development of commercial products, our fourth proposition looks at the commercialization of R&D and can be divided into two categories: government policy & institutions, and management. The first seeks to examine the effect of government policies as they relate to R&D promotion as well as the institutional framework for R&D; the second examines the efficiency of project management.

Government Policy & Institutional Support

A number of government policies which inhibit R&D in Thailand include import procedures, tax structures, procurement procedures, quality standards and copyright laws. The case studies indicate that there is a need to revise such policies to make the potential gains from engaging in commercial research more attractive to the private sector.

Lowering import duties on testing equipment, as well as reducing the bureaucracy involved in importing materials and equipment, were listed in many of the case studies as examples of policy revisions which would encourage R&D. The absence of testing equipment means that product quality, which is crucial in the electronics sector, cannot always be guaranteed. On the other hand, cumbersome import procedures only add to the lengthy delays already faced by projects.

Another option, given the cost of testing equipment for small companies, would be to provide testing centers so product quality can be assured, and so as to prevent problems such as those encountered by the makers of the first Thai PC when they could not meet international export standards due to the absence of EMI testing facilities.

The lack of government incentives was mentioned as another problem which discourages potential commercial R&D in Thailand. These range from the absence of tax relief on the purchase of R&D equipment to the lack of government encouragement of local R&D. The company working on the PABX project suggested that incentives to commercialize local R&D work include some form of government encouragement of "Made in Thailand" products, either through their active promotion and marketing or through purchases by government agencies.

Finally, Thailand's weak copyright laws mean that any potential returns which software developers may expect are likely to be swallowed up by the widespread tendency, both amongst individuals and companies, of purchasing pirated software.

Management

While even the best project management cannot anticipate sudden changes in market demand, a realistic assessment of a project's capabilities and an awareness of the market can serve to diminish the chances of commercial failure. As R&D projects often bring together university/public sector researchers and their counterparts from the private sector, it is important that those managing the project establish an effective understanding between the two sectors.

The active collaboration between researchers and industrialists during the PC project demonstrates how the creation of a good working relationship between the two sectors can lead to successful R&D. In this case, the industrialist had a deep understanding of the microcomputer market and of the potential demand for a Thai computer, and was involved from the very beginning of the process. Using his continual feedback on the market viability of the proposed computer, the researchers were able to adapt their work to market needs and, through the industrialist's connections with overseas suppliers, were able to cut to a minimum the delays which plagued other projects.

The case studies suggest that those who embark on R&D do not always realize that their initial expectations, especially with regards to project timing, may not always be realistic. We have already mentioned the many delays which the projects had to endure due to the low level of R&D infrastructure in Thailand. It could be argued that a realistic assessment of the R&D environment in Thailand beforehand may have at least anticipated some of these delays and thereby led to more realistic timeframes.

As the ASICs project demonstrates, project managers need to be fully aware of their environment and cannot afford to set unrealistic timetables. In this case the project's managers did not fully anticipate the delays that it would face and which ultimately led to the project's failure. Part of the problem was a lack of communication between researchers and the firm involved, which led to a mismatch between the researchers' expectations and those of the private firm. Thus, although the researcher's were able to produce a working prototype, it needed a number time consuming adjustments to make it compatible with market needs. As a result, by the time the product was completed a shift in the market had made it obsolete.

One lesson to learn from these experiences is that it is important to involve the private sector in commercial research. This is not only because the private sector will be more aware of the needs of the market, but also because having invested in a particular project, private companies are likely to make more realistic assessments of the worth of a project, cutting off those which are wasting time and money while willing to invest extra money in promising projects.

The final lesson to be drawn from the case studies is the vital importance of marketing research and market strategies. Adaptive products such as those produced by the PABX and PC projects are in competition with many well-established brand names in what are highly competitive markets. Thus, in order to be successful there needs to be good market analysis undertaken both before and during a project to adapt a potential product to changing market demands. The other important point to be made is the need for high levels of after-sales service in order to make Thai products more competitive.

4.7.5 Short-term & Long-term Gains

The fifth and last proposition, which examines the question of short-term versus long-term gains, arises from the concern that benefits from R&D should not be limited to short-term tangible gains if R&D capabilities are to be developed in an effective manner over the longer term. While there is obviously a place for research that can produce tangible economic benefits, R&D also needs to look to longer term goals, such as the development of knowledge and of human resources, if the sustainability of R&D in Thailand is to be assured.

The five projects that we have been discussing indicate that although both short-term and long-term gains have been achieved, there needs to be a greater emphasis on longer term research, particularly with regards to such strategic research needs as IC, PCB and ASICs design and fabrication capabilities.

Concrete & Indirect Results

We have already mentioned the tangible products which have been developed and the commercial potential of those products. Along with these concrete results, less tangible gains mentioned above include the training of researchers in various technological areas, the diffusion of knowledge to the private sector and the development of links between industry and academia.

We have also suggested that the longer term benefits of researcher training are being lost given the reluctance of younger researchers to work in the public or university sectors, thus making it impossible to develop a longer term core of professional researchers.

Future Needs

One of the points which has been made repeatedly throughout this report is the need to establish longer term R&D goals that will allow for the development of an effective infrastructure base. As the studies have shown, the absence of design and manufacturing capabilities in such strategic technologies as PCBs, ICs, and ASICs can have a serious impact on R&D research.

As those working on the PC project realized, if R&D is to continue to develop competitive products while also moving to higher technology areas, there is an urgent need to engage in more basic research in such areas as digital and integrated circuit design so that Thailand can further develop its R&D capabilities. While the economic benefits which short-term R&D can bring cannot be denied, the case studies have also shown that to ignore longer term needs will eventually lead to the demise of any local electronics capabilities.

4.7.6 Conclusion

In spite of the efforts of the researchers and the positive results which many of the projects produced, there still remain many environmental factors which inhibit the R&D process in Thailand and which will have to be tackled if the full benefits from R&D are to be realized. This holds especially true in the field of electronics, where the rapid pace of technological change necessitates R&D which is efficient and hence, timely. The many delays which the R&D projects we have been discussing suffered were for some a crucial factor in determining the project's success or failure.

We have mentioned some of the factors which make R&D in Thailand less efficient than it might otherwise be, and which include shortages of manpower, inadequate technical facilities and supporting industries, lack of government incentives for R&D and poor project management. The existence of these and other constraints will make it very difficult for Thailand to catch up in the technological race, especially as many of the countries with which she will be competing do not face the same constraints.

To change the R&D environment and thereby reduce and/or eliminate some of these problems a number of policies need to be adopted, and it is the purpose of the final chapter of this report to outline some of the policies whose adoption may best contribute to the development of R&D capacity in Thailand.

CHAPTER 5 LESSONS LEARNED AND POLICY IMPLICATIONS

The purpose of this chapter is to draw some lessons from the case studies investigated in Chapter 4 and to outline the policy implications of those lessons. The chapter is divided into three main parts: an overview of the case studies, lessons learned from the case studies, and their policy implications. Before embarking on this task, it is worth mentioning that although the lessons learned are merely drawn from five case studies, they nevertheless indicate that there are a number of key factors which affect R&D performance in Thailand, at least in the electronics sector.

5.1 CASE OVERVIEW

To recapitulate, the five case studies selected aim to cover all product ranges of the electronics spectrum including hardware (computers and telecommunications), software, and components. In addition, they have been selected to cover a wide range of R&D goals, with some being clearly market oriented while others focused more on the accumulation of knowledge. Finally, all the case studies were chosen because they were able to provide good material for analyzing the positive and negative aspects of electronics R&D in Thailand.

- Personal Computers (PCs)

The PC project set out to produce an industrial prototype of a 32 bit microcomputer and can be categorized as reverse engineering type of research. The project selected a very reasonable topic and scope of work which had potential commercial value, and began with the very modest goal of making a simple modification to an available schematic diagram; as a result the product was both technically and commercially successful. However, although the result was a PC 386-SX model it has at present ceased to yield benefit to the local computer manufacturing firm involved, as the knowledge and experience gained from the project have evolved to the higher plane of engineering workstations.

- Private Automatic Branch Exchanges (PABXs)

The PABX project is part of a larger NECTEC effort to develop office automation equipment such as cordless telephones, key telephones, and facsimiles. The analogue PABX, capable of handling 250 lines of communication and expandable to 400 lines, was the first product completed in 1991 and has since been commercialized by a local telephone manufacturer (and is, in fact, a modification and scaled-down of another PABX project funded by a R&D funding agency). This project again indicates the calibre of Thai researchers as well as demonstrating the benefits which the knowledge gained from one project to another can bring.

- Application Specific Integrated Circuits (ASICs)

The ASIC project aimed to design an integrated circuit to meet a particular purpose. In this case the project sought to apply VLSI design to an ASIC chip which would depict the Thai language on 16 bit micro-computers by designing an ASIC chip to put on a monochrome graphic computer card. It was a rather ambitious and innovative project for Thai researchers, although it was both technically feasible and economically sound. Unfortunately, the prototype which was developed was not marketable due to a change in the market which rendered it obsolete.

- Linear Electronic Circuit (LEK 6.0)

LEK 6.0 is a software package for the analysis and design of arbitrary electronic circuits. It can be classified as an electronic design automation product. For the past 10 years, it has evolved through several versions, gradually improving its performance and user interface. At present, the package has been licensed to a software company in Thailand for further development and marketing. Nevertheless, no further effort to reach the market is expected as the software was not originally developed for commercial purposes and is not applicable to professional uses.

- Medium Scale Integration Fabrication (MSI fabs)

This project is part of a series of university research projects on semiconductor technology which have already produced discrete devices such as diodes, transistors, MOSFET, thyristors, etc. The project aims to fabricate 10 micron ruled ICs by using MOS technology and mask fabrication and alignment in Thailand. With equipment suitable for discrete device fabrication, the research team succeeded in producing medium scale ICs having electrical characteristics comparable to ICs available in the market some years ago. Although the prototype was never meant to be commercially applicable, substantial knowledge, experience, skills and, very importantly, confidence were gained.

5.2 LESSONS LEARNED

Surprisingly, case studies which cover a wide range of products and research goals do nevertheless point to a number of common lessons which can be gleaned from the experiences of electronics R&D in Thailand. Examining the lessons learned we can break them down into four areas:

1. the research capabilities of Thai researchers,
2. the relevancy of R&D to industrial needs,
3. the commercialization of R&D and short-term gains,
4. the adequacy of R&D infrastructure,

a) Capability of Thai researchers

Despite working in an unfavorable and constrained environment, Thai researchers are by and large able to complete their R&D projects. Questions usually arise following the completion of projects as to what should be expected from them. Lessons learned from the case studies point out that this largely depends upon the research topics selected and the equipment, personnel, and technical services available. Evidence shows that Thai researchers could somehow find substitutes to partially offset their shortcomings stemming from lack of proper equipment, shortage of technical personnel, or inadequacy of technical services. Of course, they could, by no means, overcome the problems of insufficient infrastructure in the country. However, topic selection is a more decisive factor in determining the efficiency of a research project, and hence the potential for the utilization of research. Modest research topics (such as reversing engineering of foreign products against originally designed products starting from scratch) seemed to yield better results in terms of the learning curve and commercialization of R&D results.

b) Relevancy of R&D to industrial needs

Lessons from case studies suggest that industrial needs are not always clear. Industrial firms muddle through in setting up their directions and goals as the government has never provided specific targets and convincing plans which the industry can follow. Consequently, the research community can hardly anticipate industrial needs.

Nevertheless, the case studies show that in order to make R&D projects relevant to industrial needs, topic selection and private sector participation are essential. Research topics selected in close consultation with the participation of private firms tend to end up with higher utilization of research results for the simple reason that they are better able to meet industrial needs. Consultation between researchers and users throughout the R&D process, from topic selection and project execution to launching of a marketable product, make them feel mutually benefit. Projects carried out by university researchers alone tend to be commercially abortive despite having commercial objectives in mind.

c) Commercialization of R&D and short-term gains

Commercialization of R&D results is closely related to the relevancy of R&D to industrial needs. If the final products match industrial demands, chances for commercialization are high, as are short-term gains. Nevertheless, the case studies indicate that commercialization of R&D results requires more than simple topic selection, and private sector participation. It has to be well managed to keep up with moving windows of opportunity, particularly in the a fast-changing technology area like electronics. This is because along with the process of product development, starting from the conception of research ideas to market introduction, the fine tuning and adjustment of research prototypes to meet market demands is always needed. This surely cannot be realized without strong technical services such as product testing and technical information, a supporting industry that can produce such items as reliable and cost-competitive PCBs, and, very importantly, an industrial environment with beneficial tax structures, customs procedures, and suppliers of parts and components.

d) Adequacy of technological infrastructure

Needless to say, inadequate technological infrastructure is the bone of R&D performance. Lessons show that projects which can secure the support of qualified and reliable manpower, including knowledgeable and experienced researchers and supportive research assistants, tend to be completed much faster and more efficiently than those of which cannot secure such support.

Technical services such as standards, testing, training, information, and consultancy a also raised again and again as non-supportive factors for R&D. This holds true for supporting industries such as PCB production as well as for the supply of other parts and components. Inadequate technological infrastructure clearly leads to projects spending more time, effort, and resources than would otherwise be necessary. As we have mentioned, although Thai researchers could somehow cope with the unfavorable and limited technological infrastructure, their research results are as a result less than they could be. As a result, expectations from outside the researcher community are barely met and frustrations within the researcher community remain.

5.3 POLICY IMPLICATIONS

If R&D performance in Thailand is to be improved, the lessons we have outlined above indicate that a number of government policy and market mechanisms are required to change.

5.3.1 Topic Selection

First of all, topics selected for R&D projects should be agreed to by all concerned parties; namely, academics, industrialists, and government agencies. This is to make use of each party's knowledge and experience and to make sure that each party has a stake in the project; this is a critical point in determining the success of R&D projects. In the case of Thailand it is recommended that the government agency (the project funder), the private firm (the product manufacturer), and the university (the researcher) be involved.

In Thailand, university researchers, who are highly knowledgeable, can contribute a great deal to technology monitoring and prototype production. Industrialists have their strengths in the areas of manufacturing and marketing and therefore their contributions can be most valuable for commercializing R&D results. With their participation, practical solutions to project management and product marketing can be expected. On the government side, funding and coordinating should be its two main tasks, as private firms and university researchers are not able to fund R&D projects entirely by themselves and often need help in seeking out R&D projects with potential commercial returns.

What is significant about the case studies is that they demonstrate that R&D projects initiated with the consensus of all concerned parties not only end up with both technically feasible and economically sound projects, but also with committed parties, each of whom has its own stake in the project. Success, be it in the form of short-term economic gains, commercialization of R&D, or concrete results from R&D projects, is therefore more easily achieved when the researchers, manufacturers, and the funders all have a strong stake in the success of a project.

5.3.2 Private Sector Participation

The studies indicate that private sector participation in R&D projects right from the onset should be required. This will inject commercial aspects into R&D projects which are presently largely carried out by university researchers. Private firms are prepared to spend more money than expected on projects that show good potential and are also more willing to terminate bad projects which waste effort, time, and resources; in other words, they are flexible enough to use resources in a productive way if they are allowed to share in the risks and benefits of a project.

The case studies reveal that for R&D projects aiming at commercial success, private sector participation is required throughout the R&D process. Starting from topic selection, private firms do not want to be involved in a non-commercial project for which effort and resources are required. Moreover, they will not want projects delayed as this greatly affects marketing activities (plans, preparations, and executions) and, more importantly, market opportunities. Furthermore they will not hesitate to close projects down instead of wasting money, while also not hesitating to push promising projects which lack resources till the end.

Private sector participation can therefore offset a number of the shortcomings from which R&D projects carried out by university researchers alone often suffer. These include the failure to match final prototypes to changing market conditions, and the overestimation of university researchers (who tend to lock themselves in the labs and have little concern for the market) of their own capabilities.

5.3.3 Project Management

The management of R&D projects should be strongly emphasized. This is to increase not only the possibility of commercialization of R&D results, but also to make better us of the time, effort, and resources involved. Project management is required right from topic selection through to project execution and market introduction as it is often good project management which makes the difference between success and failure.

As it is clear that project management is one of the weaknesses of Thai researchers, funders of R&D projects need to therefore play a greater part in this area. This does not mean, however, that funders should intervene and deal with routine operations and the decision making process. Rather, it means that they should be involved in topic selection, the formation of the research team (including the private sector where appropriate), project direction, and the design of measurable objectives at the beginning of the project. Following these initial steps funders should turn their attention to the monitoring of project performance by evaluating the results which have been achieved against the time and resources spent, by assisting in removal of unexpected impediments, and by being prepared to provide more resources to or to terminate projects, or even to change a project's direction.

The case studies also show that strong leadership (providing vision and securing funding) alone is not a guarantee of R&D success. In particular, for large commercially oriented projects, apart from private sector participation and strong leadership, detailed studies on market opportunities, technology trends, and capability assessments are needed right from the outset, as well as studies which continually monitor and predict market and technology trends.

5.3.4 Technological Infrastructure

Basic technological infrastructure such as technical manpower and services needs to be assured before money is spent on R&D projects. This will provide a knowledge base and indispensable services to researchers, and hence improve the technical and/or economic success of R&D in Thailand.

The case studies make it rather clear that if technological infrastructure in Thailand were better than it actually is, the projects would have spent less time, effort, and resources than they did, and would have achieved better results. Insufficient technical manpower is the most serious problem R&D faces, followed by the lack of technical services, including product testing, technical information (standards and specification) on equipment and components, and manpower training for both basic technical and research skills. As the case studies indicate, the lack of all of these technical services exacerbates the endeavors of researchers in the country. Without removing some of the impediments mentioned above, the rate and direction of R&D activity in Thailand will not advance even if huge amounts of money are provided and private firms are fully committed on R&D. That is to say, a positive combination of careful topic selection, abundant private participation, and good project management can hardly advance the country's R&D performance if the technological infrastructure is not put in place.