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Research and Industrial Interaction

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The paper describes Nanyang Technological University's approach to and the current status of its research and development programme. The different ways in which the NTU has facilitated collaboration with industry in its engineering education and research programmes are also discussed.

INTRODUCTION

LIKE ALL major universities, the Nanyang Technological University (NTU) recognizes that research is the life-blood of a university, creating and nurturing the scholarship which vitalizes the functions of teaching, of disseminating knowledge and learning, and of serving as a national resource centre. Located as it is in a small country with meagre resources and as one of its only two universities, the NTU is well positioned to play a direct role in the training of manpower and in the R&D activities for the economic development of Singapore. This requires that it maintains strong links with industry and that it focuses on 'applied' rather than 'basic' research. Because of the importance of the industrial connection to its teaching and research missions, the NTU has set itself the mandate of being the 'university of industry and business'.

The NTU, as a new university, had the advantage of formulating from scratch the various strategies that it felt would lead to the achievement of its research goals. Broadly, these strategies may be set out as follows:

- Development of R&D excellence in selected areas.
- Development of industry-linked projects and research centres.
- Promotion of inter-school and multidisciplinary research.
- Forging international research links.
- Creation of an on-campus mini science park.

The various research activities within the NTU and the involvement of industry in research and education are considered in the following sections.

R&D CENTRES

The NTU has to date established eight major engineering centres as part of its directed research effort to create centres of excellence in selected technologies. The result of properly thought-through institutional strategy, these centres provide an excellent avenue for co-operation with industry and technology transfer, and for multidisciplinary, inter-school research. The NTU's objectives for participation in technology transfer activities are to enhance the quality of its teaching and research, and to contribute to Singapore's industrial competitiveness and economic development. Hitherto, technology transfer activities at the NTU have not been motivated by a need to generate supplementary revenue for any educational functions.

The eight university-level R&D centres are listed below. For further details, please refer to the Appendix.

GINTIC Institute of Manufacturing Technology (GIMT)

Originally established in 1985 as a CAD/CAM centre in partnership with Grumman International of USA, this centre has since expanded its scope of activity and is now one of the five national research institutes funded by the National Science and Technology Board of Singapore. It maintains extensive linkages with local companies and overseas institutions.

Centre for Graphic and Imaging Technology (CGIT)

Industrial partner:
Silicon Graphics Pte Ltd
Participating schools:
Applied Science—Division of Computer Engineering (host school)
Electrical and Electronic Engineering
Mechanical and Production Engineering

Network Technology Research Centre (NTRC)

Industrial partner:
Digital Equipment Singapore
Participating schools:
Electrical and Electronic Engineering (host school)

Applied Science (Division of Computer Engineering)

Centre for Advanced Construction Studies (CACS)
Industrial partner:
Construction Industry Development Board, Singapore
Participating school:
Civil and Structural Engineering

Centre for Transportation Studies (CTS)
Participating school:
Civil and Structural Engineering

Geotechnical Research Centre (GRC)
Industrial partner:
Public Works Department, Singapore
Participating school:
Civil and Structural Engineering

Robotics Research Centre (RRC)
Participating schools:
Mechanical and Production Engineering (host school)
Applied science (Division of Computer Engineering)
Electrical and Electronic Engineering

Advanced Materials Research Centre (AMRC)
Participating schools:
Applied Science—Division of Materials Engineering (host school)
Mechanical and Production Engineering

The criteria for founding a new centre is that the selected technology must be strategic to the needs of a wide sector of industry and that the NTU must have a strong and proven R&D capability in that particular area—preferably residing in two or more schools. Each new centre is given a start-up grant to ensure that it is sufficiently equipped to support meaningful research work. Subsequent funding is made available on a project-to-project basis from the University's Applied Research Fund and the Ministry of Education's Academic Research Fund.

To promote university–industry alliances, the NTU prefers that the centres are managed jointly with industrial partners. Some centres, such as GIMT, NTRC, CACS and GRC, had industrial partners from the start, whereas CGIT functioned on its own for a couple of years to establish a reputation for itself before co-opting Silicon Graphics, the world leader in computer graphics technology, as a partner. The two most recent centres, RRC and AMRC, are likewise expected to find partners when they are sufficiently well established. CTS works very closely with the Public Works Department, the Civil Aviation Authority of Singapore and the Port of Singapore Authority on projects related to land, air and sea transportation. An industrial partner usually makes a contribution of hardware, software and manpower to the centre. It has to be stressed that such a partnership does not in any way preclude a centre from collaborating or undertaking projects with other companies or organizations.

The benefits to a centre of having the right industrial partner are accessibility to the latest technology, enhanced status and credibility both locally and internationally, and increased participation in technology transfer activities through collaboration with the partner on industrial R&D projects. The industrial partner benefits, in turn, from the greater acceptance of their technology in Singapore and the region due to adoption of these technologies by an established university such as the NTU, the exposure of large numbers of undergraduates and graduates to their technology, and the availability of the centre as a resource for their local and regional projects.

Each centre is managed by a team comprising a Director from the host school, a Deputy Director from each of the participating schools and, where applicable, a Co-Director from the industrial partner. An Advisory Committee comprising representatives from the public and private sectors and from the NTU has also been established for each centre. The terms of reference of this committee are (i) to advise on the objectives and general direction of the centre; (ii) to review and evaluate the centre's programmes, research proposals and facilities, and to make suggestions for future development; and (iii) to assist in the liaison with relevant outside bodies.

The full-time staff of a centre include a number of professional officers (engineers with at least Master's degrees) and laboratory technicians to support the research activity and to provide continuity in the operation of the centre. Academic staff, graduate and undergraduate students from the participating schools represent the major users of the centres. Members of the university community feel encouraged to participate in the centres' activities because of the comprehensive centralized facilities available for their academic research and the opportunity to work, often as consultants, on intellectually stimulating, industry-defined problems. The fact that involvement in industry-sponsored R&D activity and contribution to technology transfer work is encouraged and taken into account in the performance appraisal/promotion exercise helps maintain a high level of participation by staff members in the centres. The participating schools take a keen interest in the management, operation and success of a centre because its operating cost is equally shared by them.

As an illustration, CGIT, for example, currently supports eight Ph.D., nine Master's and 48 final-year undergraduate project students from the various schools. More graduate students are expected to join the centre in the near future. Seven large industry-sponsored projects are presently in progress, with three of them requiring between two and four staff from the respective companies to be based full-time in the centre for the duration of the

projects. Each project involves between two and five university staff members, and four of the projects are handled on a consultancy basis.

RESEARCH IN THE SCHOOLS

Apart from the work grouped together in the university-level R&D centres, a large part of the NTU's research activity is carried out in the laboratories and centres of the various schools.

Given that the NTU was established only some 13 years ago and that for a considerable part of this time the university has been preoccupied with the process of building up the teaching facilities and staff recruitment to keep pace with the ever increasing student numbers (the Engineering Schools are still trying to catch up with the desired staff/student ratio), the schools have managed to establish a creditable research record.

To give a flavour of the type and scope of research within the schools, it is perhaps best to mention some specific research projects undertaken in the schools. One example of the type of the NTU's industry-directed research is the multi-million dollar joint project on the design and analysis of tubular joints for offshore structures undertaken by the School of Civil and Structural Engineering (CSE) and the School of Mechanical and Production Engineering (MPE) in collaboration with McDermott Southeast Asia Pte Ltd, ABB Vetco Gray Singapore Pte Ltd, GINTIC Institute of Manufacturing Technology (GIMT) and the National Science and Technology Board. This on-going research has produced useful results on predicting and testing the ultimate capacities of multi-planar tubular joints required in the manufacture of oil rigs.

Another project that has been useful to industry is the joint project between the School of MPE and Singapore's national shipping line, Neptune Orient Lines (NOL), which operates a large fleet of cargo ships and oil tankers. The project successfully developed an emulsified water-in-fuel system for the diesel engines on one of NOL's ships. It involved the modelling, design and testing of the emulsifier, and the redesign of the closed fuel-loop and control system for use with the new emulsifier. Four NTU staff members were aboard the ship on the initial sea-trial to Egypt to ensure that the marine diesel engines performed satisfactorily. Long-term trials have shown that the system can achieve savings of 3% in fuel consumption with no deleterious effect on the engines.

The School of MPE has, since 1985, collaborated with the Mechanical Engineering Laboratory (MEL) of the Agency for Industrial Science and Technology, Ministry of International Trade and Industry (MITI), Japan. The original agreement only provided for collaboration on one project, namely 'Precision Finishing of Free Form Surfaces'. However, on successful conclusion of the project, MEL requested that the collaboration should be extended. This led to the second project on 'Aluminum–Lithium Alloy Composites' and now to an -going third project on 'Development of High Performance Metal Matrix Composites'. This international effort is funded by MITI and includes annual exchange visits by researchers from both sides.

A recent local industrial project involves the collaboration between the School of MPE and GIMT to produce a PC-based software package on quality system documentation to help manufacturers and businesses to systematically develop their quality systems to meet the contractual requirements of the ISO 9000 standards. Sales of this package are going well, with 63% of them to overseas companies. A future package will include specifications for environmental management systems (BS 7750–1002). A Chinese version is also under development.

The Microelectronics Centre of the School of EEE supports a number of academic research and industrial type projects. A successful project related to the industrial sector is the joint effort with Philips Singapore on the design and implementation of an application-specific integrated circuit (ASIC) for the timing, motion and temperature control of some domestic appliances. An improved version of the controller incorporating fuzzy logic techniques is under development. Projects on microelectronic devices and sensors are in progress, with several of them at various stages of application for patents and commercialization. One example is a project with NSTB and several industry partners to design and develop advanced electronic hearing aids, communication headsets, hearing protectors and pre-processors for speech recognition. This project is multidisciplinary in nature, involving microelectronics (VLSI design, micro-machining and ASIC fabrication), computer control (software, analogue and digital signal processing), medicine (physiology and psychology of hearing), mechanical engineering (miniaturization and ergonomic design), and acoustics.

Another such multidisciplinary project at the Microelectronics Centre is research work on the development of an optical waveguide immunosensor, which is being carried out in collaboration with a local biotechnology company. Immunodiagnostic testing for a large number of antibody- or antigen-related diseases such as AIDS and drug abuse is a routine procedure which is done daily in centralized labs. The basic aspects involving the characterization and optimization of the sensor are carried out in the NTU, while the company concentrates on developing the sensor into a marketable product.

The Parallel Processing Research Laboratory, in the School of Applied Science, for example, has the following on-going collaborative projects: implementation of a real-time restoration system for old archived films or video material with the Cambridge University Engineering Department; development of a three-dimensional real-time

ultrasound imaging system with Singapore General Hospital; and the realization of a parallel picture archival and communication system based on MIMD-distributed memory architecture with the National University Hospital.

Many other smaller industrial projects of this nature have been completed, ranging from radar reflection studies for Singapore's Changi Airport, electromagnetic interference studies for the Mass Rapid Transit system, transport studies for road traffic, geotechnical problems for high-rise buildings, electronic road pricing techniques, medical imaging systems, wire bonding imaging, advanced fibre reinforced thermoplastics, thin-film gas sensors for use with domestic LPG cookers, design of underground granite caverns for storage, transportation and other uses, software development for commercial applications, design and development of a total replacement knee prosthesis, etc.

MINI SCIENCE PARK—THE INNOVATION CENTRE

As another of its strategies to have close interaction with industry, the NTU established the Innovation Centre in 1987 to encourage firms to locate their R&D operations in an on-campus mini science park so that they could benefit from the easy access to specialized manpower in the form of graduate students and university researchers, and state-of-the-art facilities in the various laboratories and centres of the university. In turn, such interaction would complement and augment NTU's research capacity.

A total space of 2500 m^2, comprising unit sizes ranging from 32 to 220 m^2 and leased at nominal rents on three-year tenancy agreements was made available to the Innovation Centre. The Centre, however, did not quite live up to expectations in its early years. Small local start-up companies formed the majority of tenants and, for economic survival, they focused primarily on short-term developmental types of projects leading to quick commercialization. Such projects, however, were not amenable to the involvement of NTU staff. Also, it was assumed that success would be assured once the companies and the NTU's Industrial Liaison Unit had worked out the tenancy details. It soon became clear that the people actually doing the R&D work needed to be convinced about the benefits of collaboration before the actual interchange of knowledge could take place.

In 1990, when the initial three-year tenancy agreements were coming to an end, a Selection Committee comprising the Director of the Centre and the deans of the schools was formed to tighten the selection process so that only companies with *bona fide* credentials were allowed in. Also, various mechanisms were put in place to improve tenant–university relations and to encourage collaboration. One such mechanism is the 'adoption' of companies by schools in order to maintain close interaction between the residents and the university community. The aim is to foster an environment that can facilitate working-level, people-to-people collaboration.

The Centre currently hosts 15 tenants (95% occupancy), including local start-up companies, such as Falcom Consultancy set up by three recent computer engineering graduates from the NTU; established local companies, such as Wearnes Technology and ACMA Technologies; to multinational companies, such as AT&T Consumer Products and Digital Equipment. Research and development activities in areas such as structural repair materials and techniques, automated guided vehicles, machine vision technology, PC hardware and software, multimedia and networking products, RF antennae, and disk drive technology have been successfully carried out jointly by the NTU and the companies. The following are some of the commercialized products and processes:

- A new technique by L&M Repairs Technology Pte Ltd to lift sunken concrete surfaces by injection of polyurethane chemicals through predrilled holes in the concrete slabs. The invention cuts time and cost by more than 90% compared with conventional methods.
- A pen-based Chinese hand-writing recognition and inputting device by Wearnes Technology Pte Ltd. At present it has a vocabulary of almost 7000 Chinese characters, which is adequate for most applications.
- A portable acupuncture device using a low-power helium neon laser by Acoustical Services Pte Ltd.
- The first locally designed notebook computer by Dyna-Mech Electronics Pte Ltd.
- An interactive multimedia CD-ROM title on Chinese cooking by Wearnes Technology Pte Ltd.
- The PROL—Programmable Lighting System for machine vision applications by Vital Technology Pte Ltd.

The demand from prospective tenants has been such that an additional space of 4000 m^2 will be made available in 1995 to accommodate more R&D companies.

R&D AGREEMENTS

The NTU has established formal joint R&D programmes with a number of local organizations, such as the Singapore Telecoms, the Ministry of Defence, the Telecommunication Authority of Singapore, the Port of Singapore Authority, and the National Computer Board. The intention of the programmes is to undertake joint R&D in projects which are consistent with the policies and objectives of the external organisations. In each case a research fund with equal contributions from the two parties is set up to fund the project work.

For example, the collaboration with the National Computer Board (NCB) was initiated in late 1993 with a three-year budget of S$500,000. The NCB is a statutory board under the Ministry of Finance entrusted with the development of information technology in Singapore. In 1991 the NCB unveiled the IT2000 masterplan which aims to develop Singapore into an intelligent island, where IT will be pervasive in every aspect of the society by the 21st century. The national information infrastructure to be deployed for this purpose needs the kind of technology which is still evolving or has yet to be realized. Numerous institutions and companies, both local and multinational, are participating in the development of the infrastructure. It was in this context that the R&D collaboration with the NCB programme was initiated. To date ten joint projects have been commissioned.

Under these agreements, funding is only provided for equipment; research manpower, if needed, is provided by the engineering school that initiated the project. Academic staff have been very supportive of these programmes because of the opportunity they provide to work on real-world problems with practising engineers. Rarely, if ever, have reasons of secrecy or proprietary rights been invoked to stop a member of staff from publishing the results of such work. Also, as mentioned earlier, the NTU takes a positive view of such participation by its staff.

In addition to these university-level agreements, there are also a number of school-level agreements with external organizations. Examples of such arrangements are those between the School of Electrical and Electronic Engineering and Schlumberger Asia Pacific, Thomson Consumer Electronics Asia, Rahmonics, Northern Telecom Asia and Racal Electronics.

INTERNATIONAL RESEARCH LINKS

The NTU maintains a large web of formal and informal links with overseas institutions for the purpose of research collaboration and exchange of staff. Some of these links will be mentioned here to give an idea of the range and scope of work undertaken. The Microelectronics Centre has joint projects with the Thin Film Laboratory of Cambridge University for research on diamond-like carbon devices and silicon carbide devices. The projects involve exchange of staff who work on the fabrication and measurements of these devices at the NTU and Cambridge. In fact, all the engineering schools are involved in formal research collaboration programmes with the Cambridge University Engineering Department and the various engineering departments of Imperial College, London.

The School of MPE, as mentioned in a preceding section, has a long-standing collaboration with the Mechanical Engineering Laboratory in Japan. It is jointly involved with Strathclyde University in a project on analysis and design of horizontal pressure vessels funded by the Commission of European Communities. The School also has collaborative projects with Tsinghua University and Huazhong University of Science and Technology of China, and Instron Corporation, USA. The School of CSE has joint projects with the Japan Public Works Research Institute, Kyoto University's Department of Environment and Sanitary Engineering, the Institute of Industrial Science of University of Tokyo, and the Department of Civil Engineering of Stanford University.

GIMT has on-going projects with Ecole Nationale Supérieure Des Mines de Paris, the Steinbeis Transfer Centre of Germany, Rensselaer Polytechnic Institute's Center for Manufacturing Productivity and Technology Transfer, University of Illinois's Knowledge-based Engineering Systems Research Laboratory, Nanjing University, Xian Jiatong University, Tsinghua University, and the University of West Virginia's Concurrent Engineering Research Center.

Many mutually fruitful results of collaborative work have been derived from these linkages, and this international dimension has been particularly useful in promoting the general enhancement of research at NTU.

RESEARCH FUNDING AND MANPOWER

The NTU's Applied Research Fund (ARF) is the main source of funding for research projects with values of less than S$250,000, a category into which the bulk of academic project proposals fall. Projects that need larger sums are submitted to the Ministry of Education for funding. For research proposals that are industry driven or commercially relevant, the appropriate source is the Research and Development Fund administered by the National Science and Technology Board (NSTB).

Project proposals are vetted separately by the heads of divisions and the deans of schools before they are forwarded for review by the Research Coordinating Committee chaired by the Director of Research, with senior academics from the various schools as members. The recommendations of the Committee are then submitted for the consideration of and final approval by the Applied Research Fund Allocation Committee chaired by the President of the NTU, with members coming from industry.

There are currently 332 ARF projects on-going, with a total value of about S$20 million.

The values of on-going projects financed through other sources are as follows:

- *Joint collaboration*
  - Number of projects 30
  - Contribution by external party S$3.2 million
  - Contribution by NTU S$2.5 million
- *Ministry of Finance R&D projects (now funded and administered by NSTB)*
  - Number of projects 8
  - Total Funding S$12.1 million

- *Research and Development Assistance Scheme of the NSTB*

Number of projects	3
Total funding	S$845,000

Catering for higher degree research students has, until recently, been difficult because we could not get enough Singaporean graduates to stay on for higher degrees. This was mainly due to the very good job market for engineers. This situation caused a significant slowdown in the development of our research programmes until a few years ago. In recent years, the NTU has mounted recruitment missions to neighbouring countries, and these efforts have helped to increase the number of research students. Also, as a result of the NSTB's initiatives to increase private-sector R&D activity, there has been a marked improvement in the number of Singaporeans wishing to pursue higher degrees in research owing to the perceived increase in demand by industry for qualified R&D people.

At present, there are about 400 higher degree research students, of which 42% are from Singapore, 26% from China, 22% from Malaysia and 10% from India and other countries. The ratio of Master's to Ph.D. students is approximately 2:1.

In the last three years, we have supplemented our research manpower by a Post-Doctoral Fellowship scheme, funded by the NSTB, that allows the NTU to bring in promising young Ph.D.s from established overseas universities to work on selected research projects. Some 50 such persons are now in service in the schools and centres. After a tenure of not more than three years, they are assisted to find alternative employment, preferably with local industry. Some of them are absorbed into the academic staff establishment.

CONSULTANCY SERVICES

The NTU encourages its staff to undertake consultancy work for industry so that, apart from the direct professional service rendered to a company, staff become aware of the special problems facing Singapore and its neighbouring countries. This, in turn, enables staff to use these problems as examples in the various courses and projects in the undergraduate programmes. In this way students will be better prepared to deal with such situations after they graduate.

Companies generally approach staff members, who are known to them through previous engagements or who have the required expertise, with proposals of consultancy work. Staff are not permitted to solicit such work. When the details have been finalized, the staff member is required to submit an application to his or her Head of Division, who comments on the nature of work, period and time involved, remuneration, use of university facilities, involvement of non-academic staff (typically laboratory technicians), and on-going consultancies and then forwards the form to the Dean. The Dean will give permission for the consultancy to be undertaken, provided the work has the requisite technical merit to warrant the services of an NTU staff member and the other guidelines set by the University are satisfied. A staff member is permitted to spend a maximum of 10 hours per week on consulting work, is required to give an undertaking that there will be no conflict of interest, and is allowed to retain a total remuneration of up to a maximum of 60% of his/her annual salary from such services. If university equipment is used, a charge is levied based on the current price of the equipment and the duration of use.

In 1992, for example, 255 staff members were involved in consultancy work with a total value of $2.3 million. The corresponding figures for 1993 were 270 staff members and a total value of $2.5 million.

UNDERGRADUATE TRAINING—INDUSTRIAL LINKS

The following sections describe the ways in which the NTU makes use of its industry connection to ensure that, in addition to academic qualities, its engineering courses adequately prepare graduates for successful careers in industry.

New courses

The NTU places top priority in relating its professional courses to the requirements of industry and business. This pragmatic approach begins before a new course is introduced. The Nanyang Technological Institute (the forerunner of the NTU) itself was established in 1981 with the three engineering schools (civil, mechanical, and electrical) because a manpower survey indicated a dire shortage of engineering graduates. Since then the NTU regularly consults industry, through surveys and dialogue sessions, before any new course is introduced. This ensures that it produces the right number of graduates with skills that industry can use.

Advisory committees

Each academic school, and in some cases each division within a school, has an Advisory Committee with membership drawn from industrialists, business leaders, senior government officers and academic staff. This Committee, with a membership term of two years, represents a very important link with industry. The Committee meets on a regular basis to discuss matters such as course material, industrial attachment, staff recruitment, course validation, research activities, laboratory facilities, graduate employment, updating of curriculum to meet changing demands, etc. The schools value the input and feedback provided by the external committee members, and the NTU administration deems the meetings important enough to require that the proceedings are reported to the NTU Council.

Table 1. Number of industry-sponsored student projects

School	Number of Industry Sponsored Student Projects (1993-94)
Civil & Structural Engineering	13
Electrical & Electronic Engineering	70
Mechanical & Production Engineering	45
Applied Science	10

Final-year student projects

All final-year students undertake a major project which offers a scope to develop their initiative, creativity, design and problem-solving capabilities. The projects are substantial enough to warrant a scheduled time allocation of 10 hours per week over the academic year. Students are required to document their work and report their findings in formal reports, and give oral presentations at the conclusion of their projects. Besides projects submitted by the academic staff, industrial organizations are invited to submit proposals for industry-linked projects through the NTU's Industrial Liaison Unit, Innovation Centre, or directly to the school. In such cases, the project students are supervised jointly by teaching staff and qualified personnel from industry, and the results of the projects are made available to the companies. The NTU encourages such projects because they involve students and their lecturers in real-world projects of immediate value to companies. Table 1 lists the number of industry-sponsored projects for the academic year 1993/94.

Industrial attachment

Another significant linkage to industry is provided through student participation. Every engineering student is required to complete a six-month industrial attachment (IA) as part of their undergraduate training. This provides the students with invaluable exposure to the production, engineering and management problems of the real world, and awareness of constraints that are placed upon the professional by physical, financial and human resources. Equally important is the opportunity it provides to develop the social, technical and communication skills needed to work effectively as part of a team. The student's performance during the attachment is assessed by his or her academic and industrial supervisors, and a grade is awarded.

The NTU's Industrial Liaison Unit is responsible for making arrangements for the IA places. The list of places offered by industry is then submitted to the respective schools, whose academic staff visit every company/organization to evaluate their training programmes. Students are finally assigned to those companies that offer training programmes judged to offer sufficient scope and depth. Industry, in recognition of the value of such attachments to the training of undergraduates, has always responded positively to the attachment programme. Table 2 shows the kind of response that the NTU has received for its IA programme.

The other benefit of the IA scheme is that it provides an excellent opportunity for the academic staff of the schools to interact with industry during the course of their regular bimonthly visits to the companies to check on students' progress.

Table 2. Placement of industrial attachment students

School	Year	No. of IA Placements	
		Required	Offered
Civil & Structural Engineering	1991	139	255
	1992	176	220
	1993	144	256
	1994	207	250
Electrical & Electronic Engineering	1991	553	698
	1992	546	553
	1993	605	632
	1994	603	691
Mechanical & Production Engineering	1991	397	515
	1992	424	457
	1993	455	515
	1994	434	487
Applied Science (Division of Computer Engineering)	1991	149	298
	1992	224	267
	1993	277	319
	1994	298	354
Applied Science (Division of Materials Engineering)	1993	37	40
	1994	55	58

Adjunct staff scheme

To strengthen further the industry connection to the undergraduate programmes, an adjunct staff scheme allows experts from industry to participate in the teaching, typically for up to 8 hours/week. In addition, they also participate in the supervision of final-year student projects. This scheme has been very successful in bringing an industrial perspective into our classrooms and laboratories.

CONCLUSION

In its short 13-year history, the NTU has established a creditable research base and will continue to enhance and expand the scope of its research activities. In order to ensure that its research activities are relevant to the technological and economic development of Singapore, the NTU has focused on applied research and has put in place a successful programme of interaction with industry. Academic staff are encouraged to participate in industrial consultancy and sponsored research. Links with a number of reputable overseas institutions have been established for the purpose of research collaboration and staff exchange. The industry connection is also extensively used in ensuring that the NTU's engineering education programmes are in tune with the needs of the profession.

APPENDIX: R&D CENTRES

NTU–CIDB Centre for Advanced Construction Studies

This Centre was established in 1989 in partnership with the Construction Industry Development Board (CIDB) of Singapore. The objectives of the centre are to undertake R&D in areas related to construction technology and management, financing and marketing. In addition to its operations simulation laboratory, accelerated weathering chamber, construction management software and a resource library, the Centre has access to the facilities of a number of laboratories within the School of Civil and Structural Engineering. The centre has undertaken industry-sponsored R&D work in areas such as diagnosis of buildings, curtain walls, high-pressure waterjets for concrete repair, computer modelling of construction projects, risk evaluation modelling and build–operate–transfer projects.

The centre also conducts a two-year part-time M.Sc. course in international construction management aimed at senior executives in the construction industry, and organizes regular seminars for construction professionals.

Centre for Transportation Studies (CTS)

This Centre was set up to conduct research into transportation issues relevant to Singapore and the surrounding region. It has been involved in a number of projects sponsored by government agencies and industry. Some such projects are (i) speed–flow relationships for traffic in restricted zones, (ii) driver behaviour in the central expressway tunnels, (iii) road pricing systems, (iv) trip and parking generation of major land use developments in Singapore, (v) evaluation of effectiveness of speed cameras on driver behaviour, (vi) feasibility of telecommuting to reduce traffic congestion in Singapore, (vii) analysis tools for the study of aircraft and passenger movements at airports, and (viii) computer simulation models for the major components of an airport system.

The CTS also conducts regular intensive short courses for the Singapore Aviation Academy of the Civil Aviation Authority of Singapore and the Singapore Port Institute of the Port of Singapore Authority.

NTU–SILICON GRAPHICS Centre for Graphics and Imaging Technology (CGIT)

In 1989, the NTU set up the Computer Graphics Centre (CGC) in response to growing demand from staff from the various schools for R&D facilities in the rapidly advancing field of visual computing. The Centre, with excellent state-of-the-art three-dimensional graphics and image-processing facilities, was extensively used for staff and graduate student research projects and undergraduate final-year projects. In 1992, the NTU felt that the CGC had the resources, expertise and proven research capability to play a larger role in co-operative R&D with industry, especially when computer graphics is finding increased industrial applications due to powerful three-dimensional graphics workstations becoming more affordable. Experience with other centres at the NTU had shown that the most expedient way of enhancing links with the business community is to form a strategic alliance with a key company/organization in a given technological discipline. In this context, the NTU considered Silicon Graphics, the world's premium provider of computer graphics hardware and software, as the most appropriate partner for the centre. Coincidentally, Silicon Graphics happened to be looking for an appropriate site for a technology centre in Singapore as part of their decision to establish, in collaboration with educational establishments, centres in some selected countries, to enhance their R&D outside the USA. After a detailed evaluation of various establishments, they chose the NTU because of its expertise in the technology and established record of successful links with industry and business. With the formation of the partnership, the CGC was renamed the Centre of Graphics and Imaging Technology (CGIT).

The strategic partnership with Silicon Graphics has not only opened the door to leading-edge visual technology but enhanced the Centre's credibility with the industrial community. This has led to a very healthy growth in the number of co-operative projects with industry and in consultancy-type pro-

jects. The CGIT has appointed full-time professional officers, largely from its pool of research assistants who had graduated with a higher degree, to cope with the increased activity with industry. It also regularly conducts joint training courses with Silicon Graphics for industry personnel. In view of CGIT's facilities and expertise, for example, a Paris-based company especially requested the Centre to help it conduct training in the application of three-dimensional graphics software for animation, industrial design and data visualization.

An Advisory Committee for the Centre, comprising of members from the public and private sectors, sets the general directions, evaluates progress, makes proposals for future developments, and assists in the liaisons with external bodies.

NTU–DIGITAL Network Technology Research Centre (NTRC)

The Centre was established jointly with Digital Equipment Singapore in 1991 to undertake applied R&D, prototyping and system integration work in computer networking and communication technologies.

The development that spurred the setting up of the Centre was the Singapore Government's adoption of the IT2000 Masterplan, which seeks to develop Singapore into an 'intelligent island'. A key component of this plan, an advanced national information infrastructure (NII), has to be evolved and deployed. However, considerable technological advances have to be made in computer networking and communications before the NII can be fully deployed. The success of IT2000 will need the synergistic collaboration of many multinational and local companies and R&D institutions. In this context, the NTRC is able to harness the on-campus R&D expertise and Digital's know-how and capabilities in networking and system integration to participate actively in a number of projects with the National Computer Board, the architect of the IT2000 plan.

The NTRC has also engaged in co-operative projects with other organizations, such as Singapore Telecom, the Telecommunications Authority of Singapore, Mindef, Northern Telecom and Motorola.

An Advisory Committee, similar to the one for the CGIT, assists in the operation of the Centre.

GINTIC Institute of Manufacturing Technology

In 1985, the then Nanyang Technological Institute (NTI) signed a five-year agreement with Grumman International of USA to set up the Grumman International/NTI CAD/CAM Centre or GINTIC for short. In its five years of existence, the GINTIC established itself as the key CAD/CAM technology transfer centre in Singapore. When the agreement with Grumman ended in 1990, the NTU upgraded the Centre to the GINTIC Institute of Computer-Integrated Manufacturing (CIM) and soon after that it was designated as a national research institute (there are five such national institutes) and funded by the National Science and Technology Board. In 1991, the Institute of Manufacturing Technology (MT) was set up at the NTU to undertake research in manufacturing processes and automation technology. Following a rationalization exercise, the CIM and MT institutes were merged in January 1993 to form the GINTIC Institute of Manufacturing Technology (GIMT).

The goal of the GIMT is to undertake research in computer-integrated manufacturing, manufacturing processes and automation that supports industry by providing specialized manpower, technology, knowledge and infrastructure. It also engages in R&D programmes in pre-competitive technologies to build expertise which industry can draw upon at a later stage.

The GIMT has a staff strength of about 200 and an annual budget of S$30 million. It has collaborated with more than 150 companies and has also engaged in manpower training through part-time M.Sc. programmes in computer-integrated manufacturing and precision engineering, and supervision of full-time higher degree research candidates. Some of the larger projects it has undertaken include the $3 million joint project with Siemen Nixdorf, the Construction Industry Development Board and the Public Works Department to develop a concurrent engineering framework for large engineering works, the $2.4 million project with the National University Hospital to use CAD/CAM technology in the design and manufacture of a prosthetic implant for knee joints with a large bend angle, and the $8 million joint project with EXCEL Machine Tools and the Huazhong University of Science and Technology, China, to develop a range of laser machines.

The GIMT is planning to set up a holding company to spin-off its innovations and to invest in high-technology ventures strategic to Singapore's manufacturing industry.

A Management Board, with majority of membership drawn from industry, oversees the operations of the GIMT. An International Advisory Panel comprising of seven leading experts in the appropriate technologies from various countries advise the GIMT on its R&D programmes and their relevance to current and future needs of industry.

Robotics Research Centre

The Centre was formally established in May 1994 with a start-up fund of S$1.68 million. It is jointly managed and funded by the School of Applied Science (SAS), the School of Mechanical and Production Engineering (MPE), and the School of Electrical and Electronic Engineering (EEE).

The Robotics Research Centre aims to consolidate, focus and accelerate robotic research activities within the NTU by making available a centralized and conducive environment equipped with state-of-the-art facilities.

The Centre will vigorously promote postgraduate research with Ph.D. and M.Eng. research projects in the area of robotics. In order to maintain industrial relevance, collaborative projects with industry will be promoted along with the provision of consultancy services.

The Centre is organized into support groups consisting of disciplines relevant to the many robotics-related programmes. The support groups are mechanical engineering design, electrical engineering design, multi-body and flexible structure dynamics, actuators and motion control, sensors, machine intelligence and vision, and robot programming and task scheduling. The following five specific projects are currently in progress.

- Three-dimensional real-time vision system for robotic guidance
- Three-dimensional ultrasound-guided surgical robot
- Automated guided vehicles for a hospital environment
- Parallel robots
- Service robots

Although the Centre is in the early phase of development, it has begun to establish industrial and research affiliations. It is currently formulating a number of research proposals with appropriate industrial parties and has established collaboration with overseas institutes on some of the projects. In the area of three-dimensional vision, the Centre is collaborating with INRIA of France and NLPA of China, and the medical robot is being developed jointly with Imperial College, London. LIRMM of Montpellier is collaborating on the AGV development. The service robot project has local industrial collaborators.

Advanced Materials Research Centre

This Centre, established in May 1994, is a joint effort of the Schools of Applied Science, and Mechanical and Production Engineering with the purpose of co-ordinating and focusing the research activities of the two schools in the areas of advanced materials and advanced materials processing.

The centre has identified the following as its main areas for research:

- Special engineering ceramics
- Special engineering polymers
- Composite materials
- Metal casting
- Welding and brazing
- Coatings technology
- Metal and ceramic powder processing technology

About 30 research staff from the two schools are involved in the Centre's activities. It is equipped with a wide range of the latest equipment for materials research (scanning electron microscope, X-ray diffractometer, HIP furnace, thermal spray coating unit, plasma nitriding unit, CHNS analyser, quantitative image analyser, hot stage polarizing microscope, differential scanning calorimeter, dynamic mechanical analyser, differential thermal analyser, thermogravimetric analyser, capillary rheometer, torque rheometer, chemical vapour deposition system, controlled atmosphere furnace, and a wide range of mechanical testing equipment). Plans are under way to procure a transmission electron microscope, a Raman spectrometer, thin a film deposition system, a sinter-HIP furnace, and welding and casting facilities. The total value of the equipment obtained by pooling of existing resources within the two schools and from the start-up grant will be in the region of S$10 million

Principal research activities at the moment are in the areas of metal-matrix and polymer composites, speciality polymers for biomedical applications, chemical vapour deposition, metal and ceramic powder processing, thermal spray coatings, and corrosion. Under way soon will be activities in the areas of casting and welding.

Geotechnical Research Centre

The Centre was established in 1994 as a joint effort between the School of Civil and Structural Engineering and the Public Works Department of Singapore. The main objective of the Centre is to serve as a focal point to spearhead R&D in geotechnical engineering with emphasis on the creation of space through land reclamation, construction of tall buildings and underground space utilization. Other areas of interest include unsaturated soil mechanics, field and laboratory testing, soil dynamics, neural networks and numerical modelling of soil structure interaction problems. The Centre also serves as a repository of the vast experience and knowledge gained from past projects and future developments.

The key staff comprises academic members from the NTU and engineers from the PWD. The Centre shares the teaching and research facilities with the Division of Geotechnics and Surveying, which includes three laboratories, one workshop and an experiment station The three laboratories are Soil Mechanics, Engineering Geology and Geotechnics Research, which cover a floor space of 1000 m^2. The workshop has a floor space of 500 m^2 and houses a triaxial rock testing apparatus, *in situ* testing and field monitoring equipment. The experimental station has a test trench measuring 14 m × 3 m × 3.5 m deep, fitted with a 10–tonne overhead crane and a reaction system. It can be used for large-scale model testing in clay and sand.

Professor **Harcharan Singh** is the Dean of the School of Applied Science and the Head of the Division of Computing Systems. His research interests centre on image processing and computer vision. He received an M.Sc. degree from Queen's University, Belfast in 1965 and a Ph.D. from the National University of Singapore in 1982. He was an academic staff member with the Department of Electrical Engineering, National University of Singapore for 18 years and moved to the NTU in 1988 to set up the School of Applied Science.

Professor **Tan Hong Siang** received his bachelor's, master's and doctoral degrees in electrical engineering from Imperial College of Science and Technology, London, Massachusetts Institute of Technology and McGill University. He worked at the British Post Office Engineering Department's Research Station, London, on the design of slow-wave structures for low-noise amplifiers for satellite communications. He joined the University of Malaya in Kuala Lumpur in 1966 and was appointed to the Chair of Electrical Engineering in 1973, a position he held until 1991 when he joined the NTU as Professor and Head of the Division of Electronic Engineering. He holds concurrently the posts of Director of the Microelectronics Centre and NTU Director of Research. His research interests are radar scattering, microwave propagation models for cellular radios, and diamond thin films. Among the awards he has obtained are the Siemens Premium and Medal, a Royal Society Rutherford Scholarship, and a King George V Fellowship. He is a Fellow of the Institution of Electrical Engineers, London.