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AUTHOR Baker, Richard
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ABSTRACT

A computer-integrated manufacturing (CIM) Phy .cal Modeling Systems Design project was undertaken in a time of rapid change in the industrial, business, technological, training, and educational areas in Australia. A specification of a manufacturing physical modeling system was drawn up. Physical modeling provides a flexibility and configurability that encourages and demands continuous adaptation to change over time and permits demonstration of different manufacturing strategies and their appropriateness for different circumstances. Such adaptation required the involvement, cooperation, and participation among peers and staff of all relevant teaching schools, divisions, and the Technical and Further Education (TAFE) head office. The adoption of the philosophies of total quality management and world class manufacturing encourages the adoption of integrated manufacturing. Emphasis is placed on maintenance with practice in diagnosis, anticipation, prevention, and planning as well as the dynamics of human participation and cooperation in technical systems. (A 23-item bibliography is included. Appendices provide CIM techniques for industry and business, artificial intelligence and expert systems, integrated manufacturing of the future, a list of acronyms, an example of a flexible manufacturing system for training, and descriptions of science and technology equipment for schools.) (CML)

COMPUTER INTEGRATED MANUFACTURING:

PHYSICAL MODELLING SYSTEMS DESIGN

A PERSONAL VIEW

RICHARD BAKER

School of Mechanical Engineering
NSW Department of TAFE

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TO OUR NEVER ENDING QUEST FOR MANUFACTURING EXCELLENCE AND THE CONTINUING EDUCATION NECESSARY TO ACHIEVE IT

PREFACE

While there are occasional references to the New South Wales Department of Technical and Further Education this report was written with TAFE systems Australia wide being seen as the main audience.

This report contains some interesting suggestions on how Integrated Manufacturing ideas, concepts and techniques can be taught and applied on a cost effective basis.

Many of the techniques and items described in this report are not outstandingly new and may appear common sense to many people. However, the challenge is to utilise our ingenuity and listen to our common sense, and to create an environment for using them. In this way educational establishments can provide industry and business with the knowledge and skills it requires in the manufacturing world of the present and future.

Any change, be it revolutionary or not, requires a large amount of energy. I simply hope that this report will provide ways for many people to meet the challenge of Integrated Manufacturing by utilising the conceptual and practical approach of physical modelling systems design.

ACKNOWLEDGEMENTS

This report reflects the contributions of many people with whom I have had long associations. I am indebted to the many who have encouraged and supported me in various ways through my work as well as in completing this report.

I would like to thank trades personnel, engineers, designers, suppliers, students, teachers, employer groups, officers of unions, industry organisations, and officers of the New South Wales Department of Technical and Further Education for their cooperation, advice and genuine constructive comments.

I would especially like to acknowledge the valuable assistance given by Geoff White and Roger Pittaway (from the School of Mechanical Engineering and the CIM Techniques Training Centre at Sydney Technical College). Thanks also go to Titus Gunasekera (School of Mechanical Engineering) and Gary Holborow (School of Engineering Trades and the CIM Techniques Training Centre) from Sydney Technical College for their encouragement and constructive advice.

Appreciation also goes to Robert Ebsary whose idea for using the making of fresh cups of coffee, as a way of simulating several manufacturing operations, was borrowed and modified. Recognition is also acknowledged of the excellent work being done in physical modelling systems design by Barry Roy and his students at Sydney Technical College (School of Mechanical Engineering), some of which is mentioned in this report.

Special mention should be made of the Mechatronics work at Mount Druitt Technical College (School of Mechanical Engineering). Gordon Griffin and his students have built several models and systems which perform just like their industry counterparts and provide valuable training in CIM techniques. Many thanks go to them for their comments and assistance.

Valuable comments on the draft of this report were made by Pat Tucker from the Advanced Technology Education Centre (ATEC) at the Regency College of TAFE, South Australia.

I certainly hope that the voices and energies of the many people I have spoken to during the period of gathering data and compiling this report will somehow be conveyed through this report. Perhaps the best acknowledgement of all, I believe, is for the recommendations, ideas, suggestions, techniques, philosophies, and concepts to be adopted and implemented by TAFE.

CONTENTS

1. *SUMMARY AND OVERVIEW OF PROJECT*

This Computer Integrated Manufacturing (CIM) Physical Modelling Systems Design project was undertaken in a time of rapid change in the Industrial, Business, Technological, Training and Educational arenas, and its formulation has involved new approaches and conceptual change.

The School of Mechanical Engineering, New South Wales Department of Technical and Further Education, and the TAFE National Centre for Research and Development, based in South Australia, commissioned the author to undertake this important research project. The main aim was to prepare a report and specification together with recommendations for functional CIM Physical Modelling Systems Design in the educational environment.

The formulation of this project involves new approaches and conceptual change, and since by its very nature it crosses many traditional boundaries, it is inevitable that controversial issues arise, and need to be dealt with sensitively to avoid destructive conflict.

Recently radical changes have taken place which have greatly strengthened the case for support of the modelling concept. Current multi – skilling discussions, the strengthening Australian Council of Trade Unions (ACTU) emphasis on it covering a broad base, and the provision for a career path in manufacturing, necessitate greater skills in abstraction and generalisation.

The Metal Trades Industry Association (MTIA) has recommended radical change in job categories requiring an increasing need for understanding of the overall context of manufacturing and systemic understanding.

The binding of educational processes to labour market needs, which are in the process of being radically re-evaluated, demands even greater adaptability in the subject matter taught and how it is taught and learned.

It is also an accepted fact that TAFE cannot hope to keep up with the rapidly changing technology by using the latest full scale industrial equipment. The capital cost is prohibitive, even if the processes of logistics and staff retraining could be adequately speeded up.

This report draws up a specification of a manufacturing physical modelling system to prescribe the functionality which will lead to the fulfilment of the broad educational, technological and economic needs identified as relevant to present and perceived future requirements of industry.

We must provide an interactive learning environment where students and staff work together in progressively building up a body of knowledge and understanding of the systems aspects of integrated and flexible manufacturing.

Physical modelling provides a flexibility and configurability which encourages and demands continuous adaption to change over time and permits demonstration of different manufacturing strategies and their appropriateness for different circumstances. Such adaption requires the involvement, cooperation and participation between peers and staff of all relevant teaching schools, divisions and TAFE Head Office.

By physical modelling we can demonstrate the relevant parameters of similarity from a high variety of machines and create systems awareness with simpler machines and richer connectivity. We can allow for different physical layouts and experience their effects whilst providing for a variety of industries to be modelled.

It is important that we impart an understanding of the central role of information transfer in manufacturing and the context of different aspects of manufacturing such as costing, purchasing, design, scheduling, manufacturing resources planning (MRPII), value engineering (VE), just in time production (JIT), total quality management (TQM), etc.

The report encourages the need for inter disciplinary skills on the mechatronics interface with hands on experience. It encourages natural adoption of integrated manufacturing by practicing the philosophies of Total Quality Management (TQM) and World Class Manufacturing (WCM). It places an emphasise on maintenance with practice in diagnosis, anticipation, prevention and planning. It emphasises the dynamics of human participation and cooperation in technical systems. To do this we must help develop communication skills by making it a necessary part of systems engineering and integrated manufacturing.

To summarise the above, it can be seen that the project emphasises the following key concepts:

System, Flexibility, Configurability, Connectivity, Communication, Information, Hands on experience, Control, Abstraction, Integration, Cooperation, Participation, Total Productive Maintenance, Mechatronics and Total Quality Management.

2. RECOMMENDATIONS

This section highlights my recommendations for CIM Physical Modelling Systems Design in TAFE. Reference should be made to the main body of the report for further information, especially to the sections on System Details (12), Machine Specifications (14), Educational CIM PC Software (19), General Specification (22) and Appendix F (30).

2.1 CREATE AN APPROPRIATE IMAGE OF CIM

The primary focus should be on **MANUFACTURING**, rather than computers. Avoidance of the "technology fix" must be foremost in our minds; we can achieve integrated manufacturing without computers. It must be remembered that computers are tools and can only help us achieve our goals if we have the correct mindset. Without this precondition, CIM will always end up as being "Computer Integrated Mayhem".

It is for this reason that I prefer to use the term Integrated Manufacturing (IM) rather than Computer Integrated Manufacturing (CIM). I recommend that TAFE adopt IM as the correct title for its manufacturing courses and thus avoid the wrong emphasis.

Learning to **"Thrive on Manufacturing Excellence, Rather than Manufacturing Chaos"** is our main objective if Australia is to become a World Class Manufacturer. TAFE must, therefore, promote and provide continuing education in **Systems Engineering**. Students must be given the tools for obtaining skills in hydraulics, pneumatics, electronics and controls, Total Quality Management, methods engineering, the ability to cope with a wide range of situations, having a feel for systems and above all be adaptable to change.

If Australia is to survive, as we move towards the year 2000, then our Manufacturing students (engineering, graphic arts, electrical, textile, etc.) must be capable of being multi-skilled in several disciplines. TAFE can provide this service if it conducts the appropriate courses. Topics, such as Mechatronics must be available if we are to obtain our multi-task workforce of the future; our future.

2.2 TOTAL QUALITY MANAGEMENT

It is highly recommended that TQM be presented as a philosophy for not only manufacturing excellence but also for teaching excellence. It should not be presented as a set of techniques but rather as the linking pin towards Integrated Manufacturing.

Evaluation and implementation of Integrated Manufacturing should reflect TQM and TAFE must practice what it preaches. In fact all schools and TAFE's Head Offices around Australia must work towards TQM.

The core subject of all our courses must be a TQM based one as this is important to not only IM courses but all others.

2.3 PROGRAMMING FOR INTEGRATED MANUFACTURING

This should be taught as an overall subject, with principles being applied to CNC machine tools, robots, PLC's, databases, cell interfacing and Automated Guided Vehicles. It is better to produce students that can generalise and build on associations and relationships in a structured way, rather than being proficient in some particular instances of the presently proliferating range of languages, many of which will be obsolete or of little relevance in five to ten year's time.

CNC programming should be feature oriented, parametric and always seeking macro creation. Future IM systems will basically do away with part programming as we now know it, and without an education into the underlying principles of treating functional and process features as objects, creative human input into the production process will tend to be eliminated at great cost.

CAD/CAM systems of the future will do the programming automatically via post processors. This is being done now on many machines and it will not be long before it is standard practice on all equipment.

CAD should also be taught as an interactive tool to enhance the creative design process in all areas. Micro based CAD should be exploited to the full in preference to high powered CAD due to the high costs involved and the urgent need for CAD equipment in TAFE for training right now.

2.4 MODELLING AND SIMULATION

The systematic nature of Manufacturing should be emphasised by the use of simulation modelling which is an important part of teaching the knowledge and application of Integrated Manufacturing techniques. TAFE should invest in systems that provide a demonstration of the basic concepts of multi stage manufacture including all aspects of scheduling, planning, quality and costing.

This report discusses the advantages of utilising physical modelling techniques as a major educational aid. This together with computer simulation would provide the appropriate skills that industry needs to compete in the world market place at a fraction of the cost of traditional methods.

The main reasons for this recommendation are as follows:

* Greater flexibility and configurability are achieved.
* More educational value in several small teaching models than expensive full size machines and equipment.

* Problems and solutions to interfacing can be demonstrated together with the complexity of interconnection of machines and equipment.
* Operational principles of many and diverse equipment configurations and combinations can be shown.
* New techniques can be demonstrated more rapidly and easily.
* Different manufacturing processes can be experimented with by the student who will learn by example and hands on.
* Physical models in conjunction with computer simulation assist in the abstract teaching process.

A physical simulation model makes simplifying assumptions about some aspects of the real world, so that other aspects may be examined. The art of simulation involves careful choice of the dimensions of simplification, and awareness of what has been omitted.

Simulated manufacturing cells and individual equipment can be built using mechatronic principles and techniques. Several examples are explained in this report (refer particularly to Sections 11 & 20).

The central recommendation of this report is that TAFE purchase five complete IM flexible teaching cells complete with a CNC lathe, CNC Mill, robots, visual inspection machine, AGV, conveyors and traverse units from the UK manufacturer (TQ) or similar (refer to Section 14 and Appendix F). These should be located at appropriate colleges which have suitable staff to operate them. Selected teachers from each school involved should be given appropriate training in how to operate the equipment. These teachers would be responsible for passing on their knowledge to other suitable teachers at appropriately conducted staff development sessions.

Small robots (such as TQ's MA2000 and MA3000), CNC machines (such as Spectralight's Lathe and Mill and Roland's CAMM1, CAMM2 and especially the CAMM3 Modelling unit), Lego and Fishertechnik equipment, PLC's, counters and timers, servo, stepper and brake motors, microswitches, photocells, proximity switches, pneumatic valves and solenoids, pressure and flow control switches, train sets, CAD plotters and other suitable electronic components should be purchased to allow for physical models to be constructed. This report includes details on all of these (refer to Section 14 and Appendix F) and it should be remembered that we do not need full scale equipment to teach Integrated Manufacturing.

By providing small "kits" of basic components (electronic, pneumatic, hydraulic, modelling equipment, etc.) with appropriate boards or work tables to build projects students will be able to develop physical models of real world situations. I cannot stress too strongly the importance of hands on development work and student projects as a means of teaching the concepts and techniques of Integrated Manufacturing and Mechatronics. The student projects can be dismantled each year for the construction of new layouts or new projects. In this way many of the components and models can be reused in a different format. Naturally, outstanding models can be kept intact for demonstration purposes.

For the teaching of cell layout, a fixed arrangement is of little use - the layout needs to be changed, and the effects seen and noted. The principles of control are more evident in arrangements of simple elements, than just watching a fixed installation running under controlled conditions. Cellular manufacturing (group technology) principles could be practised showing the link with the different aspects of manufacturing and how it effects product design, process planning, scheduling, costing and plant layout.

To aid in explaining and teaching IM concepts, low cost data communication simulating devices should be developed and constructed. Whilst these devices can be purchased it would be educationally more sound if they were designed and built as student projects. A description of some of these cost effective simulators (developed by dedicated Sydney Technical College teachers) is included in the main body of this report (refer to Section 14.10).

Simulation software is also recommended and several appropriate packages are mentioned in this report. Further research and evaluation is needed by TAFENET and other computer departments in TAFE, in conjunction with the various schools, to select the best packages for each application requirement. However, I would suggest that TAFE purchase several copies of the CIM software package from Delmar Publishers Inc. Each package, described briefly later in this report, contains six modules with the following CIM emulation programs: GENIC, CNCS, MAPT, PC-CADAM2, Micro-CAPP, KK3 and Micro-GEPPS (Refer to Section 19).

The use of wax and paper as physical modelling simulation materials is highly recommended as most maufacturing operations can be demonstrated with them (refer to Section 12).

It is also recommended that appropriate schools, such as Mechanical Engineering, Applied Electricity and Electrical Engineering, work together in developing projects, techniques, interfacing and network protocol connections. It is suggested that it might be worth using teachers from one school to teach in another depending on their areas of expertise. This would be especially advantageous in the smaller colleges conducting Mechatronics, Electronics, Robot Applications, CNC Programming/Application and Integrated Manufacturing courses.

Using the "what if" approach is far preferable to theoretical teaching than individual techniques. An imaginative approach can have a printed circuit board facility simulated one week and a warehouse storage retrieval system the next. Control elements, conveyors, robots, machine tools, injection moulders, presses, cutting devices, label makers, guided vehicles, programmable controllers, assembly and the storage of goods can all be linked together with real experience in interfacing to peer equipment and hierarchical control and coordinating by computer.

The approaches and suggestions outlined in this report provide an exciting possibility for addressing many of the needs identified by industry if Australia is to become a World Class Manufacturing nation. We can produce goods equal to anything currently available in the world today, all we need is the right philosophy, principles, techniques and approach. Physical modelling systems design will certainly put us on this path.

Utility of the approach will be limited only by the creative imagination and the willingness of TAFE to be innovative and carry out what could be a project with world class standing. The dedicated teachers and staff are available, all TAFE has to do is provide the resources and we will be on our way.

It is also strongly recommend that industry be consulted for their support with donated equipment in return for advertising and training of their clients and staff.

2.5 THE LINKING OF INFORMATION

Information transfer is a very important aspect of Integrated Manufacturing. Educational emphasis should be on clearly demonstrating the fundamental nature of information as it enters the system via an order entry facility, through a MRP package, flows from a CAD representation, through a CNC program via a machine tool, and into a finished part.

The necessity for protocols should be demonstrated by the variety of signal types and languages that will be encountered. Students should be familiar with the appropriate terms such as baud rates, ASCII, RS232, bits, bytes, ROM, RAM, EPROM, etc. The integration of control systems should be presented in such a way that the common principles of feedback, Boolean logic, gain, and stability are abstracted by the student. The control systems engineering should encompass hydraulic, pneumatic, mechanical and electronic devices.

TAFE must focus on and adopt MAP (Manufacturing Automation Protocol), the expected world wide industry standard, as a means for the integration of manufacturing systems in our quest for attaining excellence.

An understanding of hierarchical control should be attained by presenting the progressive flow of information needed to produce desired action from the input device, through the machine tool, into the machining cell, the workshop and the company.

2.6 ADAPTING TO THE CHANGING FUTURE ENVIRONMENT

As an ongoing basis it is imperative that TAFE and industry consult at all times to determine changing educational needs. With its students providing a good cross section of industry and business TAFE is well placed to carry out this initiative. By taking this cross section we can define the industries whose needs should be met; the students comprise a committed body of potential information gathers and their employers are motivated to provide the required information.

If staff, students and employers work together we have the potential for providing an excellent educational experience in cooperation. Working together in a TQM manner will go a long way to solving our problems.

TAFE must be active in its role of monitoring developments in industry, with class participation, assignments which require research of trade journals, class group discussions on work experience with new technology and new technology equipment, etc. A major area for ongoing awareness is in the fields of Artificial Intelligence and Expert Systems (refer Appendix B for further information). These technologies are becoming of increasing relevance to manufacturing and their influence should be closely followed.

It is recommended that TAFE come to terms with the fact that the real need is to learn how to **adapt to change.** Efforts must be towards a moving target which is changing direction and shape on a continuous basis. Being able to adapt to these changes in technology and equipment is what is required if we are to work towards manufacturing excellence in the **"Future Manufacturing Organisation".** Short term solutions and "band aid" temporary repairs are becoming progressively more uncertain approaches for business. As such TAFE must not be tempted to use a stop gap approach, it must look towards the future by utilising the cost effective means of physical modelling systems design, industry cooperation and support, and its own resources available through some dedicated teachers.

3. *PROJECT AIMS*

(a) The principle aim of the project is to draw up a specification of a system for physical modelling of manufacturing in enough detail to prescribe the functionality which will lead to fulfilment of the broad educational, technological and economic needs identified as relevant to present and perceived future operations in business and industry.

(b) The system should provide an interactive learning environment where students and staff participate cooperatively in progressively building up a body of knowledge and understanding of the systems aspects of integrated and flexible manufacturing.

(c) Flexibility and configurability are required, in order to meet the demands of continuous adaption to change, and should permit demonstration of different manufacturing strategies and their appropriateness for different circumstances.

(d) The gaining of multi-disciplined skills in the installation, maintenance and operation of modern integrated manufacturing environments should be sought, with an ongoing awareness of social change and appropriate response to a global competitiveness.

(e) The rate of obsolescence of equipment centred teaching should be reduced by providing an environment for learning abstraction of principles across a variety of equipment, strategies of control, plant layouts, product types and mixes and load profiles.

(f) Understanding of the central role of information transfer in manufacturing should be imparted by experiential learning, as should modern practice of Total Quality Management and Cellular Manufacturing (Group Technology) in a production context.

(g) Interdependences and relationships between materials, processes, machines, humans and time should be demonstrated in a rich context which allows for the "seeing" of situations from differing perspectives and in a variety of contexts.

THE INTENDED OUTCOME IS A FUNCTIONAL SPECIFICATION WHICH WILL LEAD TO A WORLD CLASS SIMULATION FACILITY FOR LEARNING THE MEANING OF MANUFACTURING, WHILST CONTINUOUSLY ADAPTING TO CHANGE, TO COMPETE IN THE WORLD MARKET PLACE.

4. *REASONS FOR THE PROJECT*

It is important to highlight why simulation of integrated manufacturing is a necessity for TAFE and other educational institutions. Consider the following points:

(a) Educational institutions can no longer even hope to keep up with the rapid changes which are taking place in industry, not only in the commonly emphasised technology, but also in the structural and sociological changes which are going to have greater impact. These different aspects are very interdependent, but there is much damage being done by focussing on the technology alone.

A modelling facility allows grounded experience in the totality of a manufacturing environment which is impossible to achieve when subjects are taught separately.

(b) By adopting modelling techniques, educational institutions can overtake change, or at least keep up with it. Different possible approaches to the same set of manufacturing requirements can be explored, with the results that students, industry and teaching staff are all able to undergo a learning experience which can actually influence and shape the way change is taking place.

This requires, however, a significant shift in many entrenched attitudes. These obsolete ways of thinking about skills, categories and training are at present acting as a strong barrier to acceptance of the concepts examined in this project.

(c) Given the very real constraints on capital expenditure, the view that it is necessary to have the latest and greatest leads to a very expensive self fulfilling prophecy of continual obsolescence of equipment.

Modelling by its very nature removes the dependence on the equipment itself, but where there is a fundamental change in equipment which markedly affects the system as a whole, miniature elements can be updated at far less cost than with full scale industrial equipment.

(d) There is an ever decreasing possibility for educational institutions to have the variety of modern equipment to be encountered in industry, and even less hope of being able to demonstrate the variety of mixes of new and old technology which will emerge.

Modelling gives a suitable level of abstraction which can demonstrate the effects of variety, and the systems necessary to incorporate them.

(e) Modern trends towards small lot sizes demand flexibility in the unit equipment to achieve rapid transition from one component to another. All the expensive flexibility of the machine itself has little meaning without the real time context of an interconnected manufacturing system which supplies the needs for this flexibility and the constraints on it. Modelling allows actual execution of process flexibility meeting these needs in a dynamic and real environment.

(f) In order to give concrete meaning to the many control concepts and approaches which are currently being tried out (e.g. JIT, TQM, MRPII, OPT, CAD/CAM, CAE, CIM, etc.), there exists a great need for a facility which can be configured readily to actually run these different philosophies and techniques.

The argument against modelling (that it is not the "real thing") can be reflected back on those who promote this view, by pointing out that their insistence on the "real thing" (e.g. full sized machine tools, actual CNC machining centre, actual wire cutting machine, etc.) precludes experience in the very things necessary for industry to come to grips with World Class Manufacturing and coping with the effects of the information age - understanding of strategies for control systems.

(g) If it is valid to argue for concrete experience in actual CNC machining, it is at least equally valid to argue for concrete experience in execution and implementation of the integrative philosophies of TQM, JIT, Cellular Manufacturing and CIM (in the broadest sense). Modelling is the only practical way to achieve such experience, and leads to an environment which permits the concreting of conceptual skills.

(h) Accompanying the increase in levels of automation and integration, is an increase in participation, decision making and problem solving. Modelling not only permits but encourages the generalisation and abstraction necessary for humans to participate effectively in systems which are tightly integrated by information, thus demanding involvement in symbolic manipulation rather than the emphasis on handling physical things which has prevailed until now.

(i) Modelling permits spending money on a greater number of simple machines connected together in an integrated fashion, thus giving actual experience in, & heightened awareness of, what a system is. There is a crying need for this understanding in industry, and there is a great opportunity for pioneering in this area. Greater enlightenment of staff responsible for training and education would be a most useful by-product.

(j) There is a great deal of experience in the practicalities of connecting elements of automation together. Conveyors, AGVs, robots, machine tools, measuring devices, sensors, actuators, computers, PLCs, CAD/CAM systems etc. require information flow in the form of signals, and a modelled manufacturing environment requires exactly the same control functions as a full scale, "real" factory. The advantage of the modelled environment is that the simpler machines do not detract from the focus on coordination and information flow.

(k) Manufacturing and industrial engineers, technicians and operators need to gain experience and understanding of elements of electricity, electronics and instrumentation. Past training has tended to be exclusively in the mechanical or production skills, but modern industry demands a broader base. Recent developments on the political and labour front have opened the way to removal of the nonsense of demarcation, and job categories are in the melting pot. The proposed development of manufacturing modelling and its application in the teaching of integrated manufacturing will force the pace of multi skilling and provide a test bed and demonstration of the inter disciplinary skills required.

(l) With the greater sophistication of machines, flexible automation and integrated environments, there is a rapidly increasing need for skills in maintenance. This requires an understanding of systems for effective diagnosis, but even more important is the need for knowledge and skills in planned and productive maintenance. This requires "hands on" experience in detecting trends before they become problems, and knowing the pitfalls which are to be avoided.

(m) Integrated manufacturing requires personnel familiar with the coordination of equipment outside the common focus on machine tools and high tech robots, AGVs, etc. Whilst a knowledge of machine tools is an important technical requirement of integrated manufacturing personnel, they also need expertise in many other areas. A modelling facility demonstrates how information and control requirements are common to pumps, boilers, conveyors, bin feeders, ovens, degreasers, mixers, weighing machines, measurement and inspection equipment, test beds, etc., etc.

(n) The problems of scheduling, plant layout, control, maintenance, materials handling, costing, etc. are common to any manufacturing facility, be it for washing machines, shoes, meat pies, computers, gearboxes or underwear. The proposed modelling simulations should emphasise this, and be capable of modelling a diversity of industries.

(o) Integrated environments, the critical role of information transfer, and the struggle for international competitiveness place high demands on personnel for greater cooperation between themselves, and a greater sense of being part of the system, rather than having to contend with it. A modelled working environment provides a system to be part of it.

(p) Technology, structural and social change all demand a greater emphasis and capability in communication. Rather than depending on synthetic exercises, the project provides not only the opportunity, but the necessity for effective communication.

NOTE:

The brief for this report was to specifically investigate and comment on physical modelling techniques for teaching the principles and applications of CIM. However, it is important to remember that learning experiences should be relevant for local industry and business needs. The balance of concept education and industry related training should be designed to meet these needs. Hence, if necessary, an appropriate balance between using suitable simulation techniques, physical modelling and industry compatible machine tools, may be required to suit specific learning tasks and individual needs.

5. *INTRODUCTION*

Today, commerce and industry are geared to new concepts in thinking. Expanding markets, high volume distribution, revolutionary new production methods, and the diversified problems of industry moving into an advanced technological age have created exceptional opportunities for industrial, production and manufacturing engineers.

World Class Manufacturing depends on blended management and requires that everyone help manage the enterprise, that all employees be involved up to their ears in the pursuit of continual and rapid improvement. To achieve world class manufacturing status, Australian companies must change procedures and concepts, which in turn leads to recasting relations among suppliers, purchasers, producers, and customers.

Australian industry will need to seek people who are trained to think broadly, who take pleasure in a sense of accomplishment and pride in a job well done. They require people who are able to grasp the essential elements of a problem, who have learned the practices, principles and theories of industrial engineering and modern management, and who have developed the knowledge and capacity to make decisions, and to manage staff. Such people will turn an organisations into a living, dynamic undertaking.

When built into an effective team inspired with enthusiasm and singleness of purpose, they are the most important fundamental of any organisation.

The efficient industrial engineer/technician requires an understanding not only of the technical aspects of supply, production and marketing, but also the inter-relationships between these and the economic and financial system within the company, the human and administrative aspects of the organisation, the communication of information and ideas within the company, and the economic and social background in which the organisation exists.

AUSTRALIA NEEDS INDUSTRY AND BUSINESS TO ADOPT THE BEST AVAILABLE MANUFACTURING TECHNIQUES, TOGETHER WITH THE PROPER ATTITUDE TO IMPROVEMENT.

6. *THE MEANING OF COMPUTER INTEGRATED MANUFACTURING (CIM)*

Computer Integrated Manufacturing (CIM) is often associated with the application of the most advanced technologies such as complex surface modelling, solids modelling, Computer Numerical Control (CNC) machining, automatic guided vehicles (AGV) etc. While journals and salesmen continue to present these images, the real meaning of CIM will remain obscured.

CIM is a total approach to business management involving the systematic linking of all elements of a manufacturing enterprise. Its successful implementation requires careful strategic planning in order to determine the most appropriate mix of advanced technologies and management techniques. One of the mistakes of many businesses is to install the computer or other advanced technologies and expect integrated manufacturing to follow. This approach is doomed to failure.

In many instances careful analysis may establish that a highly technical solution does not provide the answer. Only with a broad training can staff learn to think clearly and effectively about the business and industrial problems, solve them logically and act decisively. Their management education will teach them how to achieve the results they desire with and through the unified efforts of people.

TAFE can help in this training. However, it must be done in stages, step by step. Utilising a building block approach will help the student understand the principles and techniques of Integrated Manufacturing (IM).

I prefer using the term Integrated Manufacturing instead of Computer Integrated Manufacturing (CIM) as it is more than just the utilisation of a computer or computer devices applied to manufacturing; the human aspect and Total Quality Management (TQM) are just two important aspects to be considered.

Integrated Manufacturing seeks to integrate all aspects of a manufacturing organisation's operation. Hence it is not a particular system, technology or CIM but a long term strategy which, for each organisation, will involve a particular combination of several technologies such as Computer Numerical Control (CNC), Robotics, Computer Aided Design (CAD), Computer Aided Manufacture (CAM), Computer Aided Engineering (CAE), Computer Integrated Manufacturing (CIM), Just In Time (JIT), Total Quality Control (TQC), Optimised Production Technology (OPT), Flexible Manufacturing Systems (FMS), Value Analysis (VA), Manufacturing Resources Planning (MRPII) and Cellular Manufacturing or Group Technology (GT).

.e successful introduction of Integrated Manufacturing ·pends on the skills of the workforce and the way work is ganised. The quality of training and retraining is an important ingredient of success.

One study, which I was involved in, was a proposal to undertake a major program involving the implementation of advanced manufacturing and management technologies. This program was divided into three sub projects:

1. **Integrated Information System.**

   The development and implementation of a computer based integrated information system to support all aspects of the business.

2. **Computer Integration/Automated Interfaces.**

   The development of approaches and policies to ensure that the appropriate level of functional and operational integration between systems occurs.

   The development and implementation of a network of computer based and other electronic devices to facilitate the flow of information between the factory floor and the information system.

3. **Introduction of CAD/CAM/CAE.**

   The phased introduction of CAD/CAM/CAE tools to support the design, development, manufacture and marketing activities of the company.

It was recognised from the onset that the success of these programs would be dependent on the overall level of integration which could be achieved. This underlying philosophy formed the basis of many strategic decisions made during the course of the projects.

TAFE should adopt a similar step by step approach to implementing the teaching of Integrated Manufacturing technologies into course curriculum.

An example of a CIM environment in operation is shown in Figure 1. below.

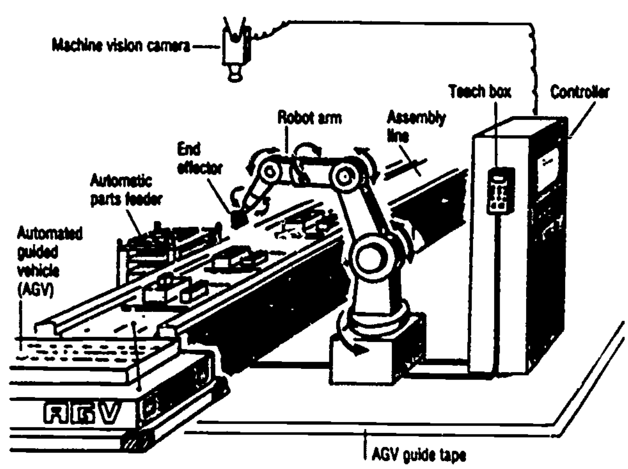


Figure 1. A Typical CIM Environment Operation (CAM)

A diagrammatic layout of a true CIM package, as provided by SSA Services Pty. Ltd. of Neutral Bay, NSW is displayed in Figure 2.

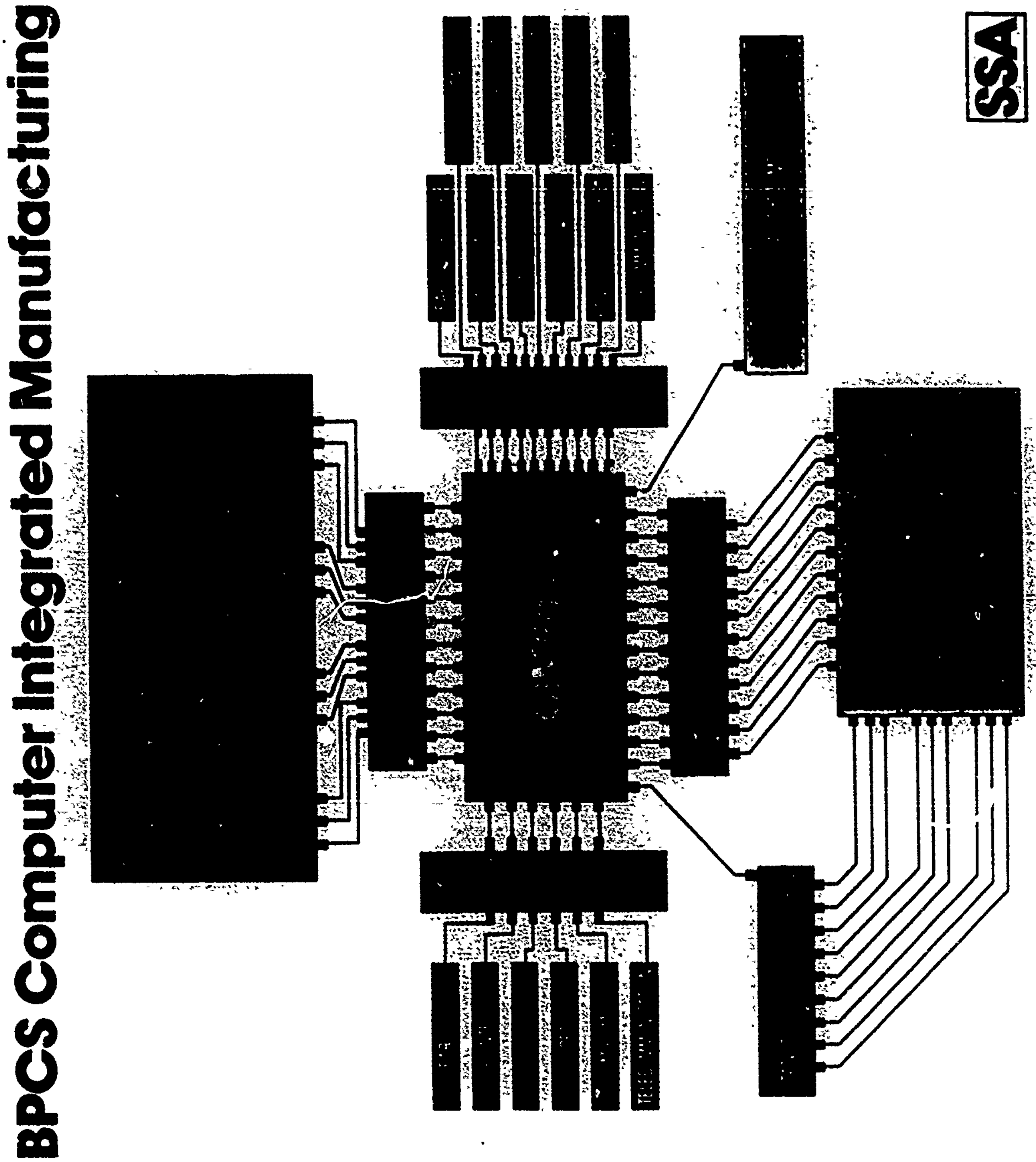


Figure 2. A Typical CIM Operating Package (CIMPath).

7. *COSTS OF QUALITY EDUCATION*

The cost of quality is the cost of not "getting it right" the first time where "getting it right" represents any number of processes or activities which add value. As such it is not merely, as some people incorrectly believe, the cost of scrap and rework but the final cost of a whole range of events triggered by the substandard operation.

For example, the costs of quality associated with a drawing office will be far in excess of the cost of re-drafting the design correctly. It includes among other things:

1. The loss of employee productivity due to poor workshop drawings, i.e. the time spent by an employee deciphering a drawing which could otherwise be spent creating wealth.

2. The cost of supervisor time spent managing failure. Often, a managers time is spent "fighting fires" rather than planning future business activities.

3. The cost of delivering products late to market due to the above factors. This includes the cost of lost immediate sales and the cost of lost future sales due to customer dissatisfaction.

I feel that a figure of **AT LEAST 10** times the cost of scrap and rework would be representative of the true cost of quality incurred by an organisation (this applies to TAFE too). This represents a significant cost to the business and should be the prime motivation behind the drive to introduce an integrated manufacturing environment.

If we relate this to teaching then we must get it right too; individual subjects and courses must be structured so as to avoid waste, be integrated, relevant, up to date at all times, follow a logical building block approach and provide students with the knowledge and skills necessary for industry and business to work towards World Class Manufacturing. If TAFE uses simulation methods and the expertise of the dedicated teachers it has in the School of Mechanical Engineering then quality curriculum, without a costly waste of resources, will result.

One of the largest problems is the fact that no where in Australia is there true Integrated Manufacturing, by definition, being carried out. Those companies which say they are practicing IM or CIM are really only using CAD/CAM, FMS or CAE. However, we are working towards the ideal and I look forward to the day when I witness true Integrated Manufacturing in operation.

This report does not have all the answers but should serve as a framework and basis for successive revision and addition to TAFE's approach to providing the philosophies, skills and techniques to assist industry and business become World Class

Manufacturers.

It should be noted that this CIM Physical Modelling System project, although strongly believed to be both of major significance and yet feasible, is set in a time of rapid and expanding change in the Industrial, Business and Educational arenas. Its formulation involves if not new approaches, then certainly different approaches and conceptual change. Since by its very nature it crosses many traditional boundaries, it is inevitable that controversial issues will arise, and need to be dealt with sensitively to avoid destructive conflict. Discussion of these potentially controversial issues will be put aside until when and if they become crucial.

The support of the modelling simulation concept is being strengthened more and more. The joining of the Federal Government's Educational and Training portfolios implied a tighter binding of educational processes to labour market needs which are in the process of being radically altered and re-evaluated, thus demanding even greater adaptability in the subject and course material and how it is taught and learned.

It is an accepted fact that TAFE cannot hope, without industry's help and donations of equipment, to keep up with the rapidly changing technology by using the latest full scale industrial and business machines. The capital expenditure is prohibitive, even if the processes of logistics and teacher retraining could be adequately speeded up.

The strong ACTU emphasis now placed on broad based multi-skilling and multi-functional workers and for the provision of career paths in Manufacturing necessitates greater skills in abstraction and generalisation. Also radical changes in job classifications being recommended by industrial organisations require an increasing need for an understanding of the overall context of manufacturing and the systematic way in which it is changing in line with the current technology.

All of the above indicate a strong need for TAFE to be adaptable to the rapid changes in manufacturing technologies. TAFE has the opportunity to be leaders in Integrated Manufacturing education at a quality level with the building of a CIM centre at Sydney Technical College (now fully operational) and the current construction of the TAFE Technology Centre at Lidcombe. However, I will emphasize again that I am not suggesting that TAFE invest in further Technology Centres, the cost effectiveness is in no way justified. Physical modelling and small training equipment based CIM is the best way for TAFE to teach the principles and techniques of integrated manufacturing in a quality and cost effective manner.

8. *THE INTEGRATED PHYSICAL MODELLING SYSTEM DESIGN*

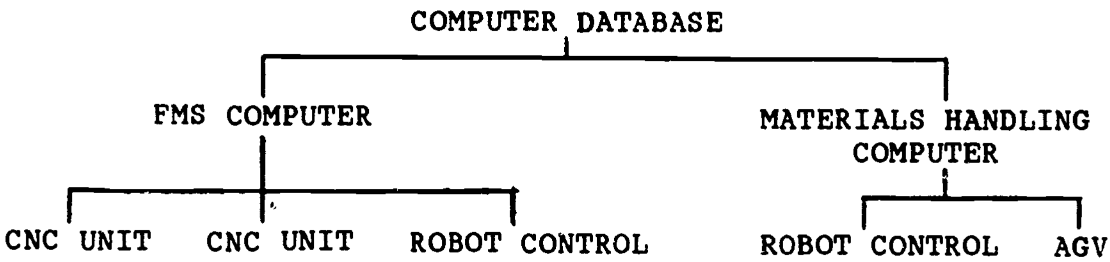
Due to the changing technology and the need for flexibility of both equipment and teaching methods TAFE needs to start out small using smaller machines and equipment together with the use of simulation as a design and teaching tool. If larger full size industrial machines are to be used they will be out of date by the time they have gone through the TAFE administrative approval and purchasing system and are installed (costly equipment rightly has to be justified).

I cannot emphasize too greatly the importance of the need for physical modelling in the educational learning process. In the educational context physical simulation uses a miniature model of the actual system for the testing of software to be used in the actual system.

Physical simulations not only help in the development of manufacturing strategies, but also in the training of operating personnel and the definition of interfaces to the control computer. Configurability to model a given manufacturing environment and flexibility to demonstrate the implications of the different system designs is achieved, whilst maintaining reasonable "real world" identification.

Due to the need to change and update on a regular basis as technology advances TAFE should be ready and able to meet this by using small machines and devices in preference to large and expensive machines which would be hard to justify (from tax-payers funds) replacing as technology alters. Equipment must be flexible!

SMALL CIM FOR TAFE IS IMPORTANT and it must be remembered that Integrated Manufacturing is not just related to metal manufacturing but food, chemical, drugs, woodwork, clothing, plastics, electrical and electronic components, machine tool manufacturing, etc.



An Example of Small CIM

To this should be added the control mechanisms of order entry, JIT, MRPII, TQM, VAM, CAD, VA, GT, etc.

9. *BUILDING APPROACH TO TEACHING INTEGRATED MANUFACTURING*

STEP 1 .... CNC Machine + Manual NC Programming.

STEP 2 .... CNC Machine + CNC Programming.

STEP 3 .... Steps 1 & 2 integrated with a robot to form a manufacturing cell.

STEP 4 .... Integration of several cells via PLC(s) and CAD System.

STEP 5 .... Cells, PLC and CAD System integrated with Computer (Database System - MRP, Schedules, Order Tracking, BOM's, etc.).

It is important that Operations Research techniques be integrated into Integrated Manufacturing especially for simulation and modelling purposes. Research and Development must also be emphasised, especially from the development aspect.

10. AN EXAMPLE OF MODELLING AND DESIGN

As an example of educational training in modelling and design I refer to work undertaken in the Faculty of Design at the University of Technology, Sydney, in the Design Computing Centre at the Balmain campus.

The undergraduates specialise in either fashion and textile design, visual communication design, industrial design, or interior design. The Computing Centre handles all computer-based design subjects. Some are one-semester introductory courses, but the major effort goes into a five-semester strand called a minor study area. Students who choose computing as their minor study area nominate a special interest in desktop publishing, graphics and video, or CAD.

For the last two years CAD courses have been based on AutoCAD, which replaced an older minicomputer-based system, Arcad's GDS.

Most of the CAD students are studying interior design or industrial design, and their interest in CAD is an extension of their classes in architectural or engineering drawing. The students learn draughting as a manual skill on the drawing board, and they also learn modelmaking and rendering presentation drawings as manual skills.

The University of Technology is not in the business of training draughtspersons. The graduates are going to be designers, and the first priority is to give them a clear understanding of the role computers are going to play in their professional lives. In fact that does involve teaching them real CAD operating skills, but that's a byproduct. So, for educational reasons the University does things that aren't necessarily done by people using CAD now to earn a living. They have some freedom to experiment.

Having said that, in fact the primary emphasis to date has been on developing 2D drawing skills. With the GDS system it was necessary to teach students 2D concepts before advancing to the more complex 3D wireframe modelling capabilities of that package.

In the first two years with AutoCAD the University stayed with this philosophy of progression. Students have had to reach the same level of proficiency with AutoCAD that they reach with manual 2D draughting techniques, before exploring 3D concepts. From next year the University is going to change its approach. 2D CAD will be given a lesser emphasis, and students will be introduced to 3D modelling right at the beginning of their minor studies. 3D modelling and 2D drafting will be taught as parallel streams. As a point of interest I would mention that the University is going to switch everything to the Apple Macintosh environment and abandon MS-DOS.

This is because they use 3D modelling as a conceptual tool for designers, quite separate from the use of CAD to produce documentation of a design. Obviously in the overall design process the two can be linked, but they are separate steps. In an integrated CAD/CAM environment the production of drawings is much less important than the development of the design itself, and the use of tools such as FEA and mouldflow analysis.

Mentioning CAD/CAM brings me to the kind of project the students have been working on. There are more industrial design students using CAD than interior designers. The interior designers deal with spaces, like architects, but they also deal with objects such as furniture. The industrial designers deal almost exclusively with objects; designs for products such as tools, appliances, packaging and so on.

Objects tend to be much more complex in form than spaces, and so they present most of the challenges in 3D modelling. The problems in interior design are by and large a subset of those of product design and so, for now, can be left in the background.

Industrial designers aren't mechanical engineers, even though the types of object they deal with can be quite similar. Industrial designers are much more concerned with the human side of product design, which includes the marketing aspects.

What a product designer wants from a CAD system is quite unlike what a mechanical engineer wants. Product designers tend to work on a greater variety of projects, to have more freedom in the shapes they employ, to deal with shorter schedules and smaller budgets, and to put a much greater emphasis on appearance and feel both in their presentations to clients and in the final product itself. The course of an industrial design project is likely to be much less predictable than a mechanical engineering project.

The result is that most industrial design firms in this country don't use CAD much at all. The feeling is that CAD is too expensive, too slow, and too inflexible; the advantages such as editing and repetition of drawings aren't that important for the bulk of industrial design projects. The spread of CAM in Australia has been too slow to create any real pressure on designers to use CAD to maintain integration with industry.

This isn't to say that product designers aren't interested in CAD. Several firms have introduced CAD systems in a small way and their opinions are mainly based on actual experience. I think many if not most industrial designers recognise there is a promise for the future and the only real question is when the right performance will be available at the right price.

It's against that background that the University's students are learning about CAD. In 1988 the senior students undertook several 3D modelling assignments. Typically, they created wireframe models of their own design projects, and then used AutoShade to shade them and prepare perspective views. They've prepared orthogonal engineering drawings from the model inside AutoCAD.

Using macros, students generated complex 3D surfaces based on profiles defined by 2D polylines. The best analogy was found to be a factory or workshop bench, where components can be formed by processes such as extrusion, turning, stretching, and so on. The components can be edited using processes such as trimming, punching, merging, etc, and then re-oriented spatially and fitted together to create complete models.

Apart from their usefulness in modelling product designs there also seems to be some potential for these procedures in medical applications, turning images such as CAT scans and NMR scans into models that can be used, for example, to help with the planning of orthopaedic surgery.

There are several obstacles to overcome in implementing CAD. CAD is competing against a system of documentation and communication that is based on paper drawings, and that system is highly developed and built in to the structure of industry. In manufacturing industry CAD is most efficient as part of CAD/CAM, and people from time to time put forward an ideal of a "paperless design studio" that's conceptually similar to the "paperless office". The "paperless office" idea has sold a lot of fanfold paper. I think the "paperless design studio" might sell a fair few plotters.

My criticism of these concepts is that you can get a tightly integrated "paperless" environment only in a tightly integrated organisation. It could be a small professional elite in, say, the law. It could be an entire company, maybe its contractors as well as with General Motors. It could be just one plant. Outside these islands of paperlessness, we're going to see a need for a universal, flexible medium of information exchange - exactly what paper provides. So for professions that are very open and always dealing with the outside world, such as any of the design professions, there is a lot of pressure to stay with drawings on paper as the main form of output.

That means CAD has to compete as a way of producing plottable results. For anyone with a big project there are still decisive advantages for CAD because you can manage the data in the system to gain all kinds of efficiencies and extra abilities. However, for smaller projects, of the kind that most users of CAD deal with, cost effectiveness is a real issue. It's poor cost effectiveness as a 2D drafting tool that's kept CAD out of all but the top end of the design professions so far.

The potential efficiencies in intelligent use of 3D models could alter that situation. Both presentation renderings and engineering drawings could be derived from the basic database created by the designers. The people actually preparing the drawings don't have to be designers themselves. As a bonus the quality of the final result can improve because the model can be analysed by FEA programs, mould flow programs, and so on, to optimise the design.

11. SOME PROPOSED MODELLING SYSTEMS

11.1 METAL CUTTING, FABRICATION AND PLASTICS

Utilising wax as a raw material, melted down to form billets and castings, we can simulate forming operations to produce plate, rod, film, etc. Machining operations, under numeric control, can be carried out as can joining, assembly and simple packaging tasks.

Assembly could include incorporation of electric devices to give "live" finished products, which are then used in the production environment, or reclaimed, reduced in size, and recycled. The recovery and recycling becomes an additional complete process, feeding raw material to the prime manufacturing cycle.

Materials handling with robots and conveyors should be emphasised along with the necessary controls and information flow.

A good proposal would be for a simulated flexible manufacturing cell utilising small CNC machines, robots, simulated AGV and simulated storage system. This can be carried out using physical modelling techniques as follows:

A small teaching robot loads a training CNC Lathe with a billet of wax material. The CNC Lathe is programmed away from the cell with the program being down loaded from a remote PC Compatible Computer via a CAD/CAM program. The turning operations are carried out and the robot removes the part and places it on the simulated AGV (a model train system with locomotive and flat top truck).

The AGV train conveys the part to a CNC Mill or Drilling Machine where the same robot removes it from the AGV train and places into the machine for the next stage of the simulated manufacture. The robot then loads the CNC lathe again to start the cycle again.

Once again the CNC Mill or Drill is programmed remotely utilising a CAD/CAM package. When the machining is completed the robot removes the part and places it back on the AGV train which conveys it to a packaging and storage area.

Another small robot removes the part and places it into a small plastic container. When two parts are loaded into the container the robot then picks it up and places onto the simulated storage system (model pallet racking). The AGV train meanwhile has travelled back to the first work station (CNC Lathe).

The robots are controlled by microcomputers and their individual control modules. The CNC machines are linked to a remote IBM PC Compatible Computer via the appropriate interfaces and post processors. The AGV train is controlled by a Programmable Logic Controller (PLC) and appropriate electronic logic devices.

The cell discussed is based on the work of 1989 Stage 4 students in the Associate Diploma of Control Engineering at Sydney Technical College and their enthusiastic teacher, Barry Roy. Figure 3. shows a diagrammatic layout of the cell.

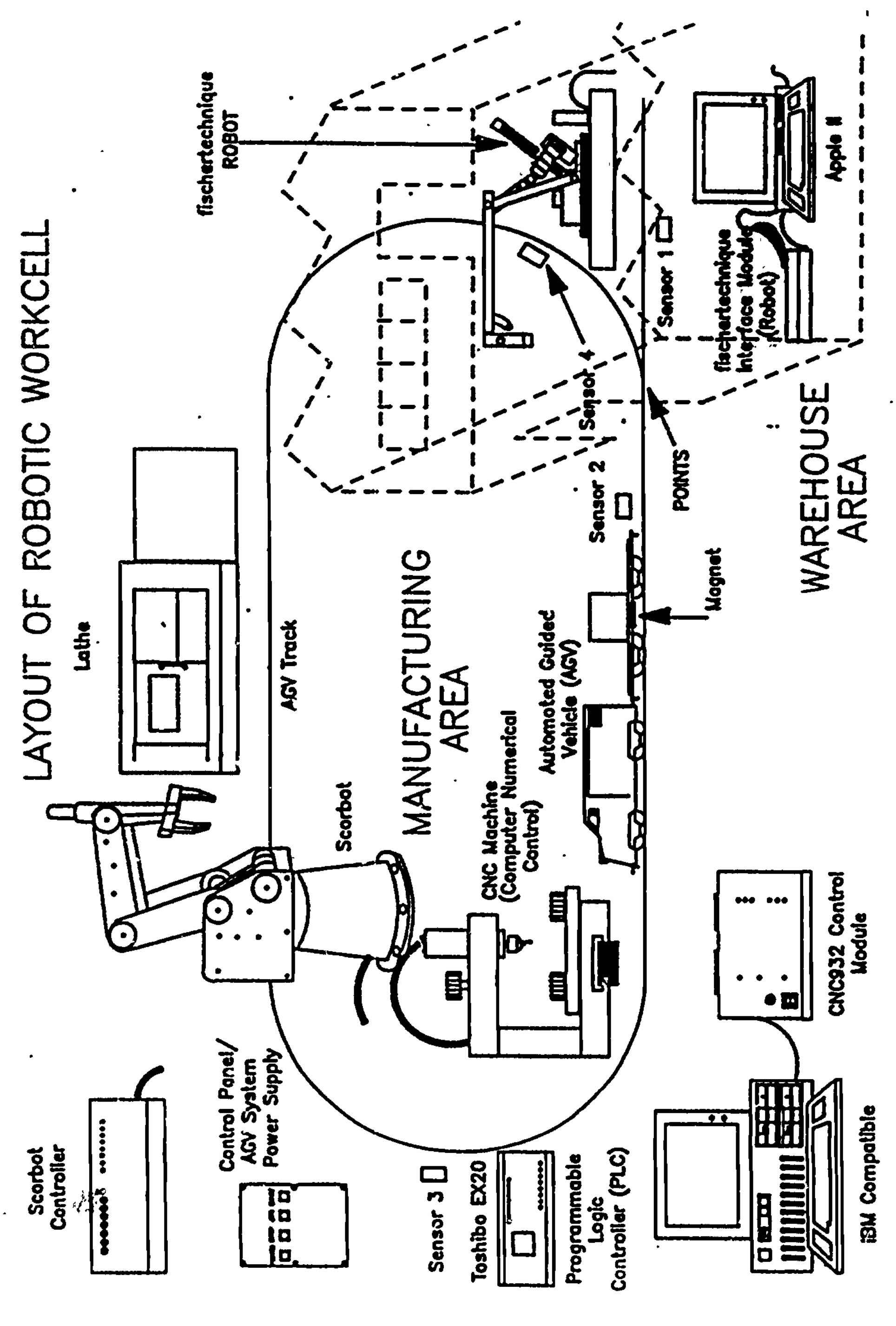


Figure 3. A Typical Physical Modelling System

Figure 4. shows the complete physical model of the cell and Figure 5. is a detail of a Fishertechnik model robot loading the model AGV (model train).

Figure 4. A FMS Physical Model.

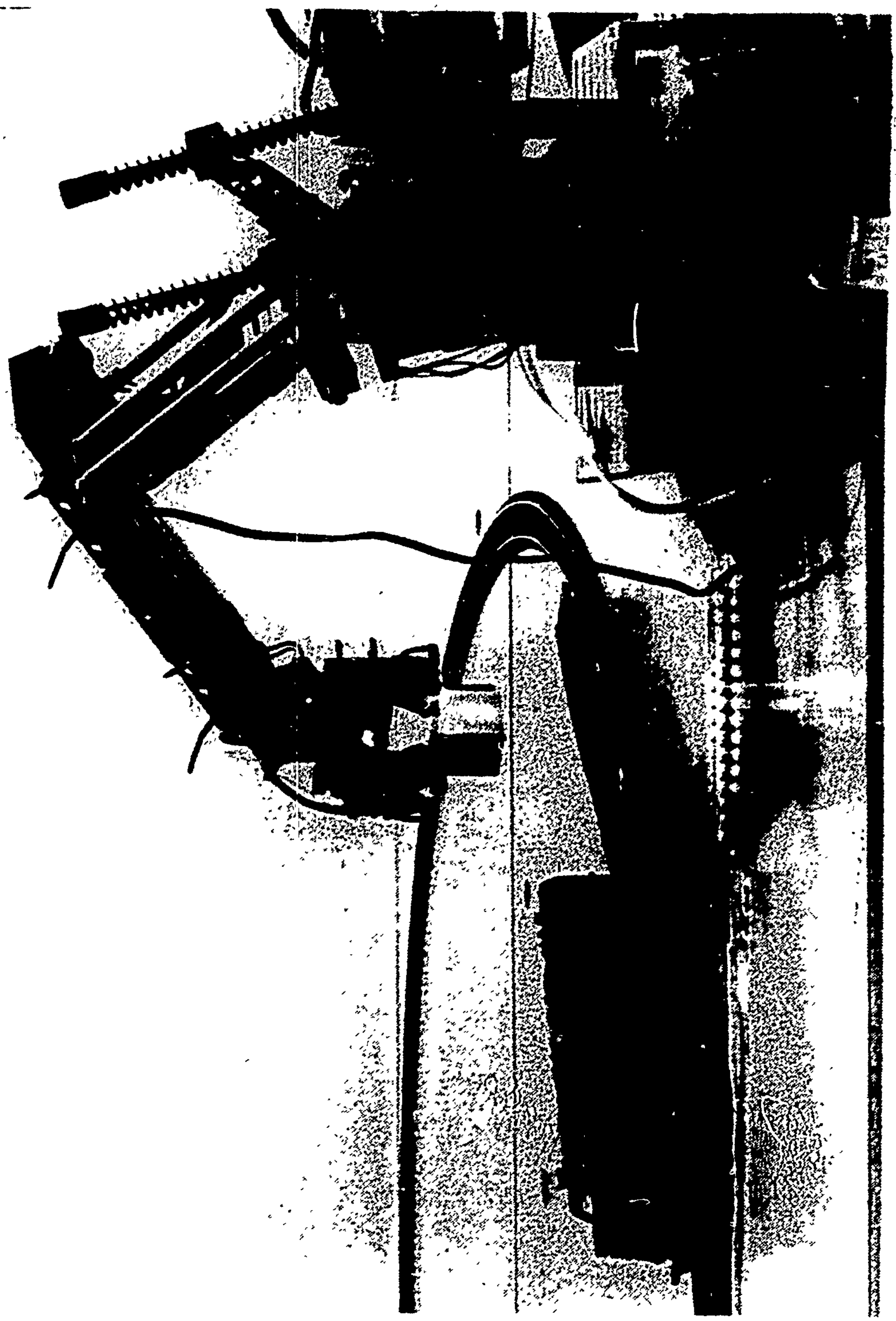


Figure 5. Model Robot Loading a Model AGV System.

The scope of this arrangement is very flexible and can be altered very easily to simulate different product manufacture and different operations. For example, the storage robot can be linked to the AGV train to transfer loaded containers to a delivery truck for simulated shipment to a customer.

Utilisation of electronic Lego and Fischertechnik modelling devices can be put to good use in the teaching of integrated manufacturing and mechatronics. This type of equipment, being modular, allows for models to be constructed and altered easily or dismantled completely to start another model.

The interaction of both digital and analog data, involved in flexible manufacturing cells, can be effectively simulated using a low cost data communication simulator and associated software. This software graphically simulates the operation of robots, CNC machines, AGV's, conveyors and other cell equipment together with the appropriate input/output signals. The unit is interfaced with a PC via an appropriate card and allows for testing student knowledge by reprogramming the system to produce faults for correction.

A similar device can be utilised for the training of Programmable Logic Controller (PLC) interfacing and programming. This is done via microswitches and coloured Light Emitting Diodes (LED's) after connection to a PC slot.

The building block approach lends itself very well to the education process and allows for many varied models (such as plotters, robots, storage systems and conveyor systems) to be constructed and interfaced with electronic devices. This allows students to learn the skills and techniques of integrated manufacturing and mechatronics and then to apply them in producing simulated working models of real life industrial equipment and systems.

11.2 ELECTRONICS, COMPUTING AND CONTROL

Emphasis should be on the use of equipment, diagnosis and testing, with the actual manufacture (not explicitly electrical) subsumed in the above. Staff and students with electrical backgrounds should gain experience in planning, inventory, scheduling and Total Quality Control with small electronic modules which give a familiar context.

A wide use of sensors, transducers, displays, controllers and micro computers emphasises the ubiquitous role of electronics in Integrated Manufacture, and gives mechanically trained people some relevant hands-on experience with diagnosing, using simple construction of electronic and electric devices.

Deliberate use of battery powered miniature tools involves a considerable involvement in electrical measurement and energy management.

11.3 FOOD AND PROCESS ENGINEERING

Creative use of household and kitchen devices could be used to give some idea of process engineering and liquid processing. Making coffee, tea, toast, simulated cakes and desserts gives an appreciation of the complexities we take for granted and introduces chemical processing via a washing machine cleaning off the wax, in this case "crockery", produced in the wax works, and testing the effluent for pollution. The use of heat processes and their control would also be a feature.

A typical simulated process engineering operation (making cups of coffee), based on ideas from Robert Ebsary of Knowledge Systems, could be as follows:

Enough coffee beans for a batch order, say 1 to 6 cups, are dispensed from a gravity hopper, with a solenoid actuated cut off, into a small container on a weigh scale, with feedback to the solenoid when presetting plus lag correction are reached. A robot picks up the container of coffee beans and empties them into a coffee grinder with the fineness setting controllable via a servo, with interlocked on/off on the grinder motor via a relay. The ground coffee is collected in a fine mesh nylon filter/funnel.

Hot water is held at boiling point, with a thermostat in a small urn, which needs fairly frequent, but irregular filling from a solenoid on the fresh water line. The fresh water line has an auxiliary heater switched in to cope with the step thermal load of cold water. Level switches on the urn could provide low and high alarms and cutouts, as well as the normal fill instigation signal, and interlocks would ensure that coffee is not made with non boiling water.

The filter funnel is placed on the coffee pot by the robot, where it is kept hot on a hotplate with thermostatic control. A programmed cycle of coffee grounds wetting is commenced and is followed by a controlled flow rate and cut off for the number of cups, which is achieved with a solenoid driven by a small integrating flow meter.

A challenging task then follows for the robot to pour from the pot into the "batch" of cups, presented on a rotary table indexing in synch with the filling motion. The batch of cups is taken away on a conveyor, and the robot reloads the batch tray with empty cups.

The filter/funnel is emptied by the robot with a programmed "thump" into the waste bin, and the filter is then sent via the conveyor for washing at a sink.

Addition of sugar or non sugar additives, either by snipping open paper sachets, or vibratory feed, could be included as too could the addition of milk by puncturing small UHT containers. Dispensing milk from cartons or bottles would probably be very difficult but not impossible. This could be looked at and adopted at a later date.

As can be seen there is plenty of room for growth and adaption.

11.4 PRINTING, PUBLISHING AND OFFICE AUTOMATION

Normally viewed as a service industry, the printed page could be used, in a radical way, as a simulated manufacturing process. An infinite variety of products could be designed, set up, made and inspected utilising desk top publishing equipment with micro computers, printers, plotters and scanners as production devices.

Output can range from class notes and diagrams for student use, through the obvious potential for cutting and folding shapes, to the use of graphics and text on the printed page as a symbolic representation of parameters in any physical item imaginable.

11.5 TEXTILES

Although limited in its scope, it would be possible to simulate, in a sewing machine, another form of Numeric Control. Taking waste cotton material we could make cleaning cloths and simple miniature bags and ties for materials, the continuing role for workers in handling the complexity of floppy materials can be shown. Washing and drying of the cloths under process demand provides extra integration into the overall scheme.

11.6 MODEL RAILWAY AND SLOT CAR SYSTEMS

Model railway and slot car systems are excellent to simulate the real thing. These could be built to simulate an actual railway goods yard or railway port facility or city road system.

This important tool of simulated manufacturing makes no claims of relevance to railway engineering or road planning, but uses the railway as a metaphor for an information carrier, with great possibilities for quite complex programming and problem solving if needs be. Industrial logic and sequence control techniques can be used for scheduling routes via point changes, feedback control of locomotive speed, fail safe logic for collision avoidance, message passing via signals, etc.

Queuing, scheduling and sequencing problem solving can all be simulated. The factors involved in running a railway to a timetable, or having goods loaded in a shunting yard and despatched to a destination, are similar to those in running a manufacturing facility.

There is probably no better way to create complexity and richness of dependencies in a manner which allows quick changeover to an entirely different abstract structure in which to achieve a task. A quick addition of an extra siding, or the requirement that the train or slot car must deliver one parcel to a certain destination before some other, creates new situations to be catered.

As well as this, the railway trucks can be used to carry wax tokens, manufactured as mentioned in a previous suggested simulation, which symbolise job allocation and completion, test results, material requests, etc. Pieces of paper with bar codes, and even simple active electronic circuits provide vast scope for relevant learning.

Another use for the railway, slot car approach, is that it could be used for simulating cash flow and cost of production statistics, by transporting tokens around the cycle from cost centres, to invoicing, and cash receipt.

Incremental development of the size of the system is easily attained, without having to change what already exists, and there is little danger of "becoming obsolete", since the problems, solutions and learning experiences are ubiquitous across time, and are not dependent on the present level of technology involved.

11.7 PHARMACEUTICAL PRODUCTS

Filling and labelling machines for liquid, tablet and capsule manufacture. This too allows for all the tools and techniques of integrated manufacturing and mechatronics to be tested. The order can be enter, product scheduled, produced, packaged, labelled and stored awaiting distribution.

11.8 CONSTRUCTION AND ARCHITECTURE

Plant and Facility layout simulation using the microcomputer and suitable scaled models to design, draw and produce a proposed new factory, warehouse or office building complete with the internal layout of equipment required. Perhaps a security or alarm system complete with video display could be incorporated.

Once again using the appropriate electronic components, controllers, etc. in conjunction with a model (a doll's house could be used) could be used to simulate the real thing. You do not necessarily need full size equipment to teach and test student abilities, skills and knowledge of mechatronic devices and their application in an integrated environment.

11.9 BANKING AND FINANCIAL

The set up of a simulated automated teller machine network and/or cheque verification system. Again all the techniques and skills could be taught and tested using simulation methods.

11.10 MATERIALS HANDLING AND STORAGE

Another choice could be the use of a small Automated Stacker/Retrieval System for the storage and retrieval of a range of components. Utilising a group or team approach the participants would be required to program the system to stack and retrieve items in the best, most economical order utilising a sales movement schedule. A simulation program can be used to compare the layout of each team of participants with the best solution.

Each team would have to install all coding recognition devices to perform the stacking and retrieval function in accordance with their program. Safety features must also be included in the design of the system program.

System bugs can be introduced by the supervising staff at various stages to check the fault finding skills of each team and items can be recoded or moved to confuse the teams in locating items.

Changes can be requested to suit new forecast sales or new orders and the participants' skills and knowledge would be required in altering the system program and layout to suit the changed schedule requirements.

11.11 OTHER EXAMPLES

There are a host of other examples available and only a few have been suggested here for discussion and thought. It is important that the teaching of Integrated Manufacturing contain appropriate testing and assessment of skills and techniques learnt by providing a project.

SMALL CIM IS AN IMPORTANT TRAINING TOOL and it must be remembered that Integrated Manufacturing is not just related to metal manufacturing but food, chemical, drugs, woodwork, clothing, plastics, electrical and electronic components, machine tool manufacturing, etc.

A simple product could be produced from the order to despatch to the customer. For example a flanged coupling or universal joint could be ideal to test the skills of each team of participants through each stage of the project. The team should consist of a maximum of two to three people with mechanical, industrial, manufacturing and electrical engineering skills together with programming knowledge.

The order must be entered into the computer manufacturing database program to set the production schedule process into operation. Due to time restraints the MRP software can be pre-loaded with the product database, B.O.M.'s etc. Drawings can also be pre-loaded for the same reasons. However, the interface between each operation must be understood by the participants as errors can be introduced to test them.

The team must next use the CAD/CAM interface to produce suitable CNC programs which must be down loaded automatically to the appropriate machines. Program errors could be introduced, at rest break times, to test the fault finding skills of the team both before producing product and during manufacture.

The set up of each machine and interface is the responsibility of the team and they must work to the design of their flexible manufacturing program. Robots and/or AGV's will convey the product from machine to machine or cell to cell. Robots must also be used to place and remove the product form each stage of manufacture. All individual cells and machines must be linked by the Manufacturing Automation Protocol (MAP).

The suggested finish of the project could be the packaging of the product, by robot, into containers or boxes, through a labelling machine and finally into a simulated storage area awaiting delivery to the customer. All documentation (works orders, routing and operations schedules, delivery dockets and invoices, etc.) should also be produced.

For the testing of flexibility skills it may be possible (subject to time restraints) to produce another similar sized product which is suitably different to test the skills of integrated manufacturing.

The quantity of product produced will be decided by the length of the project. Producing a required quantity of the product can be part of the test of the teams ability to work to time constraints as would be experienced in most industrial enterprises.

11.111 A Tool for the Mind

Perhaps the simplest way to regard Integrated Manufacturing is as a tool for the mind rather than a tool just for the hands. It extends our mental abilities, makes the creative part of design work faster and more visual, allows us, in fact, to see what we are thinking. To this extent it may even enable us to extend our imaginations into areas never ventured before. This is not an overstatement, but make no mistake Integrated Manufacturing is, after all, a tool, and only as good as the people who use it.

12. *SYSTEM DETAILS*

12.1 MATERIAL SELECTION

Initial thoughts were that thermoplastic should be the preferred material. This was based mainly on the grounds of recycling being possible, elimination of the waste disposal problem, and cut the costs of material purchases. Different colours could be used for visual effectiveness and to represent different materials (grey for cast iron, silver for aluminium, brown for bronze, etc.).

An alternative material could be paper as it yields a very rich variety achievable at low cost and with quicker start up time. This medium would require, however, a greater degree of symbolic abstraction at the outset, and it was decided that the abstractions of miniaturisation and plastic material would be enough to contend with, so thermoplastic was maintained as the preferred material.

Subsequent thinking, however, reintroduced Paper in conjunction with Thermoplastic, for direct capabilities such as labels. This would then meet one of the project's goals of extensibility, in that symbolic representation could gradually be introduced. It also allows for modelling the Printing, Graphic Arts and Publishing industries. Various experiments and time have served to make the concept more acceptable, and its utilisation is now strongly recommended.

Foam plastic was examined, but its mechanical properties are poor, and it requires recovery processes such as solvent distillation, so was ruled out. PVC was eliminated for reasons of toxicity and instability of product when recycled. Polypropylene has very desirable engineering properties, but requires high processing temperatures. Impact Grade Polystyrene then became the recommended material.

Material selection was seen to be the first necessary decision to be "frozen", and was performed in conjunction with the selection of processes for production of basic shapes and recovery methods, as well as the range of unit processes which can be carried out.

On examination of available equipment, it was found that extruding and injection moulding machines were too expensive (of the order of $60,000) and too heavy (greater than 1 tonne), thus "unfreezing" the material selection, and looking for other alternatives.

When examining smaller compact milling machines (such as the Roland CAMM3 discussed later), the use of modelling wax arose, and some experiments were conducted. With some reservations on strength in bending, it was found to be eminently suitable, with quite a sharp melting point of approximately 190 degrees Celsius. This allowed for atmospheric melting in baths, and gravity casting, which did away with the pressure moulding problems of thermoplastic.

My recommendation for the main material is **wax**. However, use should be made of **paper** for many simulation models. Research and testing indicates both can be used successfully, so both materials are recommended with wax being used for a larger percentage.

Wax could assist in the simulation of the following manufacturing operations:

(a) Extrusion.
(b) Vacuum forming and moulding.
(c) NC drilling, turning and milling.
(d) Hot air cutting, guillotine, punch and nibble.
(e) Hot air welding.
(f) Breaking into granules.
(g) Packaging of granules for recycling.

The advantages are full recyclability, reasonably easy material break up and a close approach to "concreteness" (the real thing). The main disadvantages are complexity in some dies with slow feedback to design modification and the danger of losing system focus.

Paper, in both plain and coloured A4 sheets could be used to simulate the following operations:

(a) 2D cutting and machining (drawing with different colours on plotters).
(b) NC cutting with a laser.
(c) Transfer with vacuum cups on a robot.
(d) Guillotine, punch and nibble.
(e) Folding.
(f) Staple and glue.
(g) Optical inspection.
(h) Assembly.
(i) Block manufacture (shred, wet mix with bonding agent, compression mould, cure and machine into shapes).

The advantages of paper utilisation are low cost of work centres and material, quick to implement and gain earlier understanding of principles and techniques involved. Other advantages are the richness of variety and complexity obtained symbolically with an infinite capacity for change.

The major disadvantages of using paper are that it is subject to "toy world" criticism and that only partial recyclability is possible (i.e. there is always a demand for sheet paper).

13. *RANGE OF UNIT PROCESSES*

13.1 *PRODUCTION OF BASIC SHAPES*

In conjunction with checking for recovery methods, selection of the methods for production of basic shapes was fundamental. Extrusion was examined with a view to producing tubes and sheet as primitive building blocks, with variety introduced by cutting and fabrication, but investigation showed there was far greater choice of machines available by the use of Injection Moulding, which becomes the recommended primary process.

Production of these shapes can not only model "in house" production processes (as when a plastic kitchenware factory is modelled), but can model the purchase of components such as small sheets, rods, and sections for fabrication, as well as castings and forgings for machining. Thus a project aim of configurability is achieved by redrawing the "factory" boundary, and creating a sub system which can be used to model supplier to customer relationships.

13.2 *MACHINING*

It is stressed at the outset that the intent of the project is not to provide facilities for learning in depth skills for a certain type of machine, but to acquire an understanding of systems. Consequently, it is recommended that resources not to be channelled into complexity in the machine if such complexity does not contribute strongly to variety and interdependence in the system. This point cannot be over emphasised, because the writer is very aware of pressures to allocate resources to "high tech" full size machines which are then used in a restrictive "old world" context.

With the above argument in mind, requirements for this project are best met with the simplest machines which will allow for Direct Numeric Control (DNC). One is tempted to recommend drilling, but that would detract considerably from process flexibility, one of the more visible of the project aims. Turning and combined Milling, Drilling and Boring are recommended, without the expense (and distracting) feature of continuous curve generation.

13.3 *FORMING*

Desirable process complexity can be introduced with the heat variable in Vacuum Forming, with the interdependence of residence time, vacuum capacity, and temperature. Heat supply can be via electric lamps or hot air. Opportunities for an exercise in quick die change techniques arise, as well as awareness for payoffs for a number of cavities in relationship to cost and just in time principles. Such a facility will produce, in addition to orthodox industrial mouldings, applications such as simulated pastry shells for meat pies.

For production of angle sections, Bending can be performed using hot air dies, and the use of impact polystyrene allows for Cold Forming. with the possibility of Coining, Embossing, and even a simulated forging, using robot manipulation.

14. MACHINE SPECIFICATIONS

14.1 INTRODUCTION

Current perceptions on the scope of CIM in industry lead to the belief that any proposal should incorporate NC machine tools and robots in order to establish credibility. Consequently, the first recommendations are in line with this perception, in the hope that an awareness of the possibilities of different approaches will evolve.

14.2 MILLING MACHINE

Prime constraints here are minimal size, weight and cost, whilst providing CNC control for flexibility of small lot production. A survey of equipment currently available indicates that for around $20,000, we could obtain machines which fall within the following preliminary guidelines:

* Weight 60 Kg.
* Size 700 mm cube.
* Minimum 2.5 axis under NC, with full 3 axis control.
* Additional 4th. axis useful for circular table, or (more importantly), to simulate pallet change.
* Provision for feedback sensing probes.
* Travel (on all axes) approximately 150 mm.
* Spindle speed variable under program control to approximately 7,000 rpm.
* Spindle power approximately 100 watts.
* Programming can be performed both at the machine and off line (from remote microcomputer).
* Full access can be obtained to controls for custom interfacing.
* Interface and circuit diagrams to be available for integration into networks.
* Program protocols and signal codes to be available for custom program configuration and future high level program development.
* RS232 interface connection available.

It seems that costs practically double with provision for automatic tool change devices. Although this is a desirable complexity, the abstract principles involved can be obtained far more economically on a lathe, so it is omitted as a definite requirement on the milling machine.

The ability to interlock cycles with clamping and loading is stressed.

Provision should be made for vacuum removal of swarf for recovery and recycling.

Existing interface and post processor for communication with commonly available CAD/CAM packages (such as AutoCAD, VersaCAD, Quickdraw, CadKey, AutoCAM, SmartCAM, MasterCAM) is essential.

Smaller compact mills are available for training CNC mill operations. These are around $9,000 to $10,000 (educational price) and utilise standard industry G & M programming codes and provide interfacing facilities to most CAD/CAM software packages. Specifications are as follows:

* Weight 45 Kg.
* Size 560 mm long, 560 mm wide, 650 mm high.
* Table to spindle dimension 205 mm, throat 90 mm.
* Instantaneous X and Z axis position readout on computer display.
* X axis travel 230 mm, Y axis travel 130 mm, Z axis travel 140 - 160 mm.
* Spindle bore 9.5 mm.
* Spindle speed variable to 2,000 rpm.
* Spindle power 370 watts.
* Feed rates 2.5 to 239 mm/min.
* Programming can be performed both at the machine and off line (from remote microcomputer).
* Full step and half step resolution.
* Robot interface available
* RS232 interface connection available.

14.3 LATHE

Compactness, weight, cost and CNC control are also emphasised here. For approximately $25,000, lathes are available which fall within the following guidelines:

* Weight 250 Kg.
* Size 1,000 mm long, 650 mm wide, 800 mm high.
* Full X and Z continuous Numeric Control.
* Swing 50 mm over cross slide, 150 mm over bed.
* Spindle speed variable to 3,000 rpm.
* Spindle power 400 watts.
* Tailstock available.
* 6 position tool change turret under program control.
* Ability to take preset tooling.
* Programming can be performed both at the machine and off line (from remote microcomputer).
* Full access can be obtained to controls for custom interfacing.
* Interface and circuit diagrams to be available for integration into networks.
* Program protocols and signal codes to be available for custom program configuration and future high level program development.
* RS232 interface connection available.

Provision should be made for vacuum removal of swarf for recovery and recycling.

Smaller and more compact training CNC lathes are available for around $8,000 to $9,000 (educational prices). These use industry standard G and M programming codes and can be converted to milling operations with an appropriate conversion kit. Specifications are as follows:

* Weight 45 Kg.
* Size 635 mm long, 546 mm wide, 600 mm high.
* Instantaneous X and Z axis position readout on computer display.
* Swing 32 mm over cross slide, 90 mm over bed.
* Distance between centres 205 mm.
* Spindle bore 10 mm, spindle taper No. 1 Morse Taper.
* Spindle speed variable to 2,000 rpm.
* Spindle power 370 watts.
* Feed rates 2.5 to 230 mm/min.
* Tailstock available.
* 4 tool Programming capability.
* Programming can be performed both at the machine and off line (from remote microcomputer).
* Full step and half step resolution.
* Direct robot interfacing capability.
* Milling interface connection.
* RS232 interface connection available.

14.4 ROBOTS

A fully flexible, six axis industrial quality robot has been located for approximately $20,000, and could be used at different times for machine loading, pouring of wax into moulds, assembly, conveyor unloading, stacking, deburring, simulated welding, etc.

A problem arises however, in the fact that detailed programming of complex robotic paths may well distract from the prime intent of the exercise, i.e. to impart an understanding of integrated systems as systems.

At this stage there are good reasons for a more humble configuration of robotic use. It may be preferable to utilise the educational or simple "pick and place" type. These are closer to $5,000 in cost, thereby allowing two or three to be involved in performing different functions simultaneously in different parts of the complete production process (manufacturing cell with integration of several operations and equipment).

Conventional robotic handling devices are inherently flexible and ideal for most machine loading applications. In an FMS cell, however, it is very likely that a robot will be required to service a number of machines and peripheral devices. The operating envelope of the robot can, therefore, become the limiting factor when considering a multi machine cell.

The solution is to introduce an additional axis by adding a servo controlled traverse device which provides a further 1.7 metres of reach to the robot, giving an overall operating envelope of over 3 metres. The traverse unit can be used in overhead or gantry configurations in situations where floor space is a constraint.

Other "do it yourself" robotic devices are available (such as Lego and Fischertechnik units) which are very adaptable to various simulations. These robots are relatively inexpensive and are excellent for teaching the principles of robotics. With their modular facilities they are easily converted to all types of robots (gantry, pick and place, loading and unloading, etc.).

14.5 AUTOMATED GUIDED VEHICLE

Industry has recognised the need for improved productivity and has closely examined all areas to which automation can be applied.

Whilst robotic handling devices have been successfully used within production cells themselves it is only relatively recently that the effect of improving material flow on a macro scale has been realised.

The ability to transport stock from raw material stores to a given production cell and later to either a second cell or to finished stores is now relatively straightforward using Automated Guided Vehicles (AGV's) programmed to carry out material delivery tasks in line with production requirements. This flexibility is essential in a true flexible manufacturing system. AGV's also find use in automated warehousing for finished stock retrieval and as mobile work stations.

From an education and training viewpoint it is impractical for teaching staff to consider the use of full scale AGV systems. Both cost and space rule out this possibility.

However, there is an excellent working AGV with a lift capacity of up to 25 Kg which has been specifically designed for educational and training purposes. Its scale and facilities make it ideal for integration to CIM systems.

The vehicle is programmed by the "mission method" in that it receives information about its tasks from a ground station with which a host computer is communicating. Simple graphics are used to plan the AGV route and any interaction with other devices that may be necessary during its mission.

On completion of its mission, the AGV, automatically docks with its base station to recharge its batteries and await further mission instructions from the host computer.

An off line programming package is available which allows a class of students to develop routes remotely from the AGV prior to down loading to the host computer and to the AGV itself.

Any number of AGV routes can be compiled and stacked in the host computer. This facility, together with the off line programming capability, is a key factor in providing a system which is genuinely flexible and integrated with the overall system. The following basic requirements are desired:

* Flexibility of material handling.
* Stand alone or part of a CIM system.
* Small and compact.
* Off line programming capability.
* On board computer or microprocessor.
* 25 Kg. Lifting capability.
* Passive metal guidance tape laid on floor (no embedded floor wires) for ease of relocating routes.
* Automatic docking and recharging facilities.

14.6 INDEXING CAROUSEL

In a true flexible manufacturing cell there has to be provision for buffer storage of the components as they pass through the various machining and inspection operations. These can take many forms, from simple magazine arrangements to complex storage systems.

There is available a carousel which has been designed to represent many of the features of the more complex industrial systems. It consists of a rotary 6 station indexing carousel which utilises optical sensors for component recognition. The unit can be interfaced to a robot or to a standard PLC. Signals are used to index the carousel in either direction.

From an educational point of view the concepts of logic control via either robot I/O or PLC optical sensing and integration with other devices can be effectively taught with this carousel device.

14.7 VISION AND AUTOMATIC INSPECTION SYSTEMS

The use of vision systems in industrial applications is increasing rapidly. Machine vision is used for the checking of products for quality, accuracy and completeness as well as providing a valuable sensor for robots, automated guided vehicles and other robotic systems.

The technologies involved in vision systems should be of great interest to educators of integrated manufacturing as it represents a combination of opto electronics, electronics, computing, and mechanical technologies.

A small teaching vision system has been sourced which not only teaches the concepts of machine vision but also can be used as a working model in a CIM environment. The system is based on an industrial unit utilising a solid state camera which captures the image of the component being inspected.

The stored image is processed by the on board microprocessor and the data compared with that relating to a previously stored image. In this mode of use outputs are communicated to an associated robot which takes appropriate action. The vision system can also be used as a control sensor to provide feedback data for robot control functions.

In recent years the nature and emphasis of inspection and quality control has changed significantly. No longer is it viewed as "a last in the line" process to catch out of tolerance components. Today inspection takes place continuously throughout the production stages.

Accumulated data is used as a control element to take corrective action when a process is found to be drifting out of limits. This latter technique, referred to as statistical process control is now virtually the norm in manufacturing industries around the world.

There is a small modular Automatic Inspection System available for educational purposes which simulates basic industrial equipment. The modular concept means that automatic inspection stations can take several forms from stand alone single measurement devices to fully integrated systems with a number of measurement inputs interfaced to robot handling devices and via a multiplexer interface to a host computer for data processing.

SPC software packages, available for receiving data via an RS232 serial link and via menu control, can produce control charts, histograms, process capability, and other data related to the performance of the manufacturing process.

14.8 ENGRAVING MACHINE

As a more economic alternative to the above selection of equipment, whilst still retaining some association with cutting machine tools, a small engraving machine has been identified for under $10,000. Numeric control is limited to two axes, but basic notions of DNC and information transfer can be demonstrated with downloadable programs and fonts.

Opportunities for quality control by measurement are limited, as is the desirable binding of conformity of size tolerances with ensuring successful (or otherwise) fits for assembly operations, which would have to be carried out elsewhere in the production process. Some degree of symbolising and abstraction could be attained by representing part features and parameters by engraved messages and patterns.

Some aspects of the CAD to CAM link can be experienced, and the command set is identical with that for driving plotters. This gives the opportunity for easy future extension into more symbolic representations and the ensuring understanding of systems at a higher level.

The engraving system utilises existing software with drivers written for standard plotters and by simply typing your name or scanning a photograph the system quickly and efficiently converts it into an engraved reproduction. The system is easy to use, lightweight and compatible with almost all types of microcomputers.

The engraving bed is 200 mm x 140 mm with full clearance on front and sides for oversize sheets. The sign length is governed only by the available material and engraving can be done to a maximum depth of 5 mm.

14.9 PLASTIC FILM CUTTER

A plastic film cutter, costing about $10,000, could be used. It is similar to the engraving machine, but cuts adhesive Vinyl film as used in the Sign Writing industry. A huge variety of shapes, messages, logos, etc. could be generated in many colours, and tool wear monitoring and prediction, could be an important parameter, with links to Quality Control strongly demonstrable.

The necessity for manual skills in "weeding" the unwanted material from the cut patterns would provide desirable experience of integration of humans in with the automated environment. Some aspects of CAD/CAM could readily be executed, with quick and visually attractive feedback for effort put in. Opportunities emerge for experiential learning with elements of graphic design, optimum use of material through nesting and layout, and opportunistic scheduling using Cellular Manufacturing (Group Technology) principles.

A disadvantages of this suggestion is the non reuse of materials and consequent ongoing costs and supply of new materials. The actual cost is not very great however, and the supply problem could be turned to great advantage by making generation and placement of material orders part of the operational task.

Opportunities for Total Quality Control exercises in timeliness of order placement and delivery, appropriate minimal order quantities, order integrity, etc., become readily achievable.

14.10 CIM SIMULATOR

This simulation device teaches the concepts of CIM utilising low cost data communication techniques. The unit and software costs around $450 - $500.

The interaction of both digital and analog data, involved in flexible manufacturing cells can be effectively simulated using a prototype "Cimulator" (trade name) and associated software which graphically simulates actions of machines and input/output signals.

Obviously, if these signals are handled on the machines in the real full size cell by students, damage to both machines and work in progress may result. However, by utilising the capabilities of a "Cimulator" no damage to the equipment is involved if a student makes a mistake in the sequence of operation. Students can learn the logic involved in interfacing several machines in a manufacturing environment without actually touching the full size units.

The "Cimulator" was developed by highly motivated teachers of the School's of Mechanical Engineering and Engineering Trades at Sydney Technical College. It consists of an interface card which plugs into any IBM or compatible PC slot, a control box which consists of LED's (Light Emitting Diodes) and buttons to allow simulation at the touch of a button. An appropriate on screen software display explains what steps to take and a graphical representation of a typical FMS cell in operation is shown.

The software instructs the student for each appropriate step to take in simulating the operation of a cell. Program errors can be introduced for the student to solve and correct without causing any damage if he or she makes a mistake.

14.11 PLC TRAINER BOARD

The same data communication concepts, as for the "Cimulator", can be extended to teaching programmable logic controller (PLC) operation and programming by the use of a simple PLC trainer board.

This PLC trainer board, developed by the same Sydney Technical College team who produced the "Cimulator", plugs into any commercially available PLC. The inputs to the PLC are simulated by microswitches and ouputs are displayed using appropriately coloured LED's.

This board allows students to become familiar with the logic and programming of PLC's and how they are interfaced to operate other devices and equipment. It is a cost effective (around $200) way to teach the principles of PLC's and how they can assist the CIM environment.

15. *EDUCATIONAL INTEGRATED MANUFACTURING EQUIPMENT*

Generally the cost of providing education and training for Integrated manufacturing technologies is prohibitively high and is out of date by the time it has been installed in an educational institution. Full industry standard equipment is not designed for training and is very expensive, both to purchase and maintain.

Whilst new Integrated Manufacturing and Mechatronics courses are being developed which integrate the previously compartmentalised disciplines the availability of suitable "hands on" equipment has lagged far behind this.

Suitable cost effective equipment and systems have been sourced which are suitable for all levels of education and training in Integrated Manufacturing and Advanced Manufacturing Technology.

The located system, British in origin with an Australian agent, is excellent for teaching and providing the necessary skills for the operation of full fledged large industrial equipment at a fraction of the previous cost levels.

The system can be built up using various modules which are expandable, give industrial realism and are safe to operate. Flexible maufacturing cells can be designed and configured to exactly fulfil current industrial needs. The modular concept allows for on going development in a planned and logical manner.

At the entry level, for example, a single CNC machine can be integrated with a small robot to form a basic cell. This combination of a CNC machine tool and a robot is the logical first step towards a fully integrated CIM training system. Expansion of the work cell at a later date may include the addition of further machines, an AGV, an inspection station, or integration of a CAD/CAM system: all of these options and many more are possible.

The scale of the specially adapted machine tools and robots ensures industrial realism without the disadvantages of the high capital and maintenance costs associated with full scale industrial systems.

The linking or integration of the machine and robot can be achieved in two ways, either by utilisation of the powerful robot software and its associated interface to supervise the functions of the machine tool, or by the use of a separate programmable logic controller (PLC). Either way, the training capability and effectiveness of the cell can be further enhanced by the addition of off line programming and CAD/CAM packages.

16. *MODEL ROBOTS AS TEACHING AIDS FOR ELECTROMECHANICAL ENGINEERING*

The use of model robots offers supplemental instructions to the mechanics of motors, gear trains, power, leverage and force. At the same time, they provide hands on experience in the electronics of external sensors and control methods. Robotic training aids are available for all levels of education from public schools, through colleges to universities. It is not surprising that the production of robotic training aids also now exceeds that of commercial industrial robots.

16.1 *SOME AVAILABLE TYPES*

One of the first robot training aids was the Turtle robot, produced by Terrapin Inc., and shown in Figure 6. It was designed for computer control via a ten conductor umbilical cable: eight conductors connecting to the computers parallel I/O port and two to furnish power to the Turtle's electronic circuits and motors. It could be computer programmed to seek out a clear path through a complex maze. Its clear plastic dome served as an obstacle contact sensor, and each blind path encountered a contact sensor signal that would be relayed back to the computer to be stored as an error path.

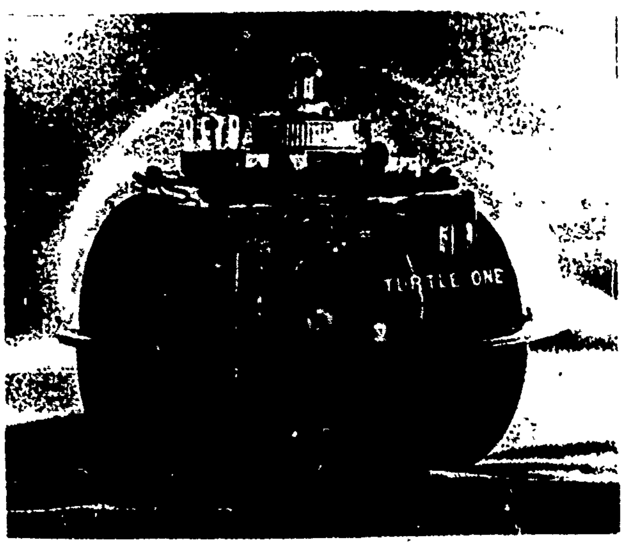


Figure 6. Original "Turtle" (TM) Robot.

Distance was calibrated by the number of revolutions of each wheel and also stored in the computer's memory. In this manner the Turtle could be run into the maze to locate and remember each turn error on its first try. Then, having thus located the maze's error paths, on its second try the Turtle could complete its passage through the maze error free. Once the Turtle had mastered the maze, it could be placed on a sheet of paper and, with its on board solenoid activated ball point pen, available only as a kit, it also provided students with firsthand experience in the assembly of electronic components onto a printed circuit board.

Most training aid robots serve multiple purposes of demonstrating motor driven devices, control of motors and control methods. A number of simple model robots, available through H & R Corporation in Philadelphia, Pennsylvania, USA, demonstrate electronic motor control, gear trains and control by infrared radiation or sound.

Figure 7. shows a Line Tracer robot, which has the capability of following a black line drawn on the floor or a large sheet of paper. The method of control is an IR LED transmitter and two IR receiver photodiodes. If the IR transmitter is centred on the black line, both wheels are driven forward. If the IR transmitter is off the black line, only one wheel receives forward driving power and the robot circles around the black line until it again centres with the line. The assembly of the kit provides the student with hands on experience in the assembly of motor driven gear trains and small component assembly with machine screws and nuts.

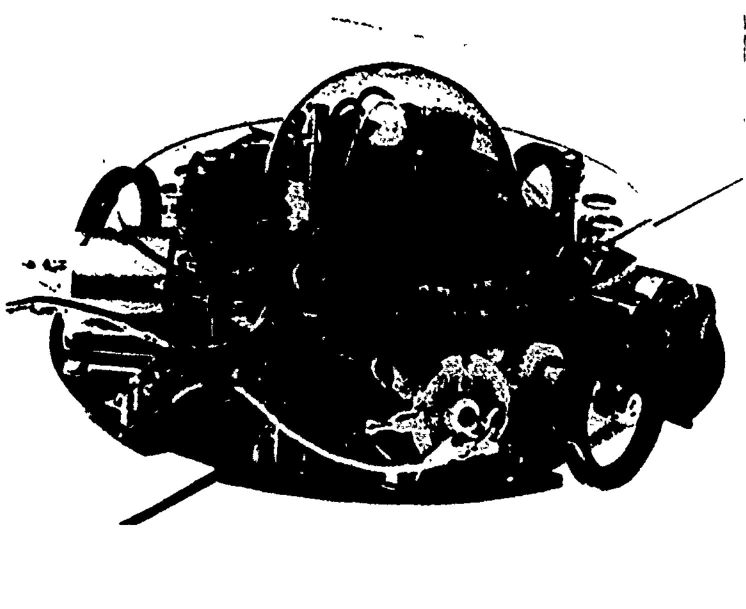


Figure 7. Infrared Radiation Controlled "Line Tracer" Robot.

A sound activated robot, the Piper Mouse, is shown in Figure 8. The sound from a whistle causes the robot to move forward until it receives a second whistle signal which causes the robot to stop. A third whistle signal causes the robot to turn clockwise; a fourth, counter clockwise; and it stops on the fifth signal. Like the line tracer robot, the whistle controlled robot provides the student with hands on experience in small assembly and motor driven gear trains.

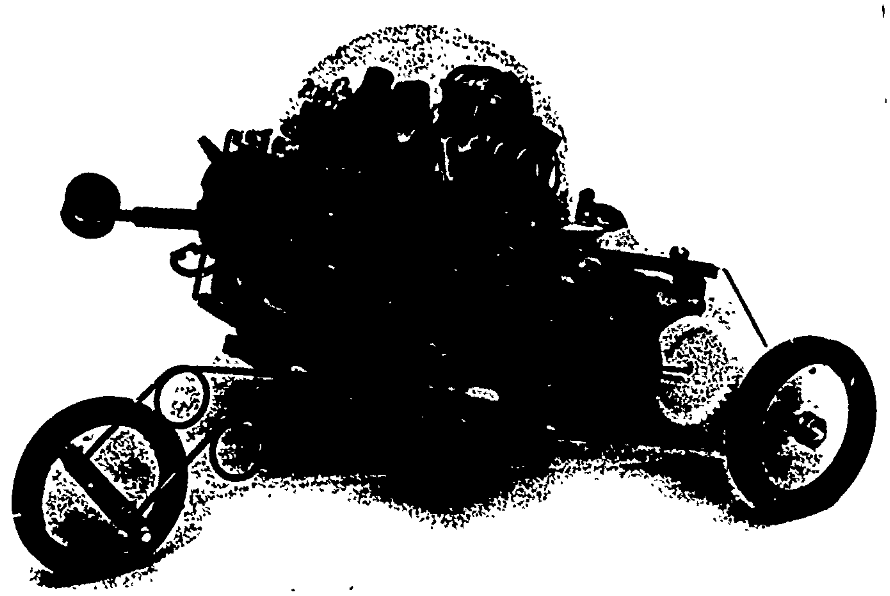


Figure 8. Sound Activated & Controlled Robot, "Piper Mouse".

Figure 9. is called the Space Invader Robot. Its six moving legs enable it to climb over obstacles that would stop the two wheeled driven robots shown in Figures 2 and 3. It runs continuously once the power is switched on. Should it encounter an obstacle, its IR sensor causes the drive motors to turn the robot continuously until the IR sensor indicates a clear forward path.

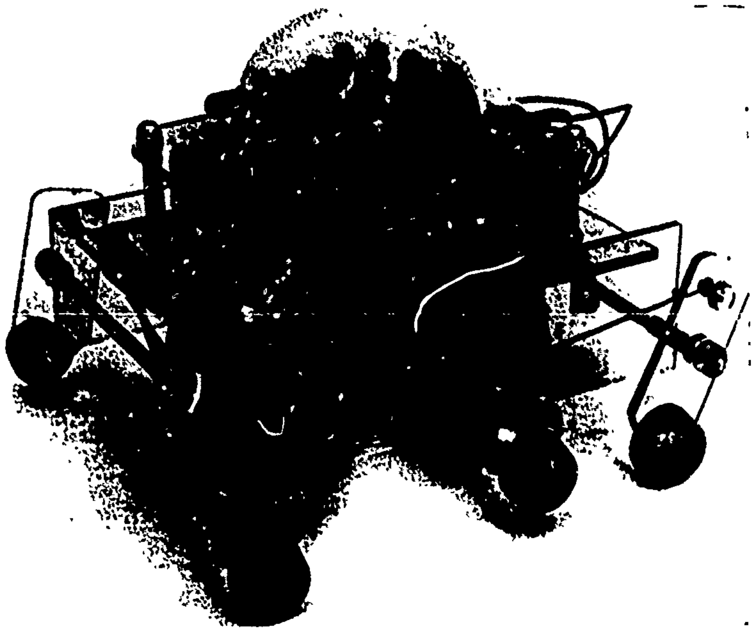


Figure 9. "Space Invader" Infrared Obstacle Detector Robot.

Figure 10. shows a programmable 4K RAM robot, Memocon, that is programmed via a seven function teach pendant or via a parallel I/O port of a microcomputer. All four robots in this series are approximately 125 mm round (or square) and none over 90 mm high. Movement speeds are low enough to conduct laboratory experiments on the average size bench.

Figure 10. Programmable 4K RAM Robot, "Memocon".

Another step up the ladder of teaching aid robot evolution, we find the computer controlled robot RBX5 shown in Figure 11. RBX5's microcomputer is the National Semiconductor INS8073 with 8K RAM expandable to 16K. Its program language is Tiny BASIC Robot Control Language. Available software includes Alpha and Beta programs that enable RBX5 to learn from its experience. Optional software is packaged as plug in modules which are plugged into a panel on RBX5's back. RBX5 measures 330 mm in diameter and 610 mm tall, which provides ample interior room for additional user electronics, interfaces and control functions. Interfacing to a computer is via an RS232 serial port. RBX5's basic external sensors include eight tactile sensors extending around the middle of its body, an LED edge detecting sensor located under its skirt at the front castor and sonar for obstacle detection up to 11 metres.

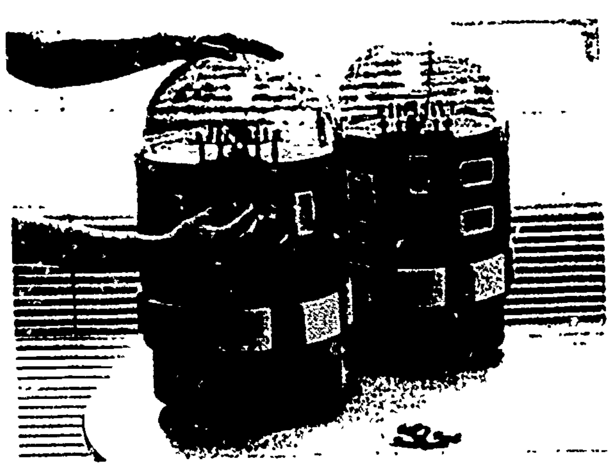


Figure 11. RBX5 Robot.

While the teaching aid robots mentioned are fully capable of demonstrating a limited number of electromechanical principles, they fall short in providing sufficient technical literature and tie in demonstrations for all technical college courses. A better approach would be to design a totally different type of robot as a means not only of teaching electromechanical principles but to provide ongoing projects that would offer the students hands on experience in robot design and fabrication for a period of at least a year or preferably two to three years of their course.

16.2 DESIGNING A TEACHING AID ROBOT

Student project robots do not have to follow the designs of motion picture or television robots. Whatever, the design, it should incorporate as many mechanical engineering principles as possible and the electronics for control or interface to a computer.

The three basic sections of any robot are the wheel support base, the superstructure and the manipulator. Each section must be designed within the weight limits of the driving motors and the space required for on board power and controlling electronic circuits. Internal accessibility to motors and electronic circuits is as important as structure integrity and strength design considerations. The design should stress functional simplicity, which is the approach of using minimum components to accomplish the end results. Since the three sections form an integral unit, a concept drawing should be made incorporating the final size, appearance and functions of the robot before any detailed designs can be started. Figure 12. shows a typical radio control transmitter for controlling the movements for servo motors and the robot functions that each servo motor activates.

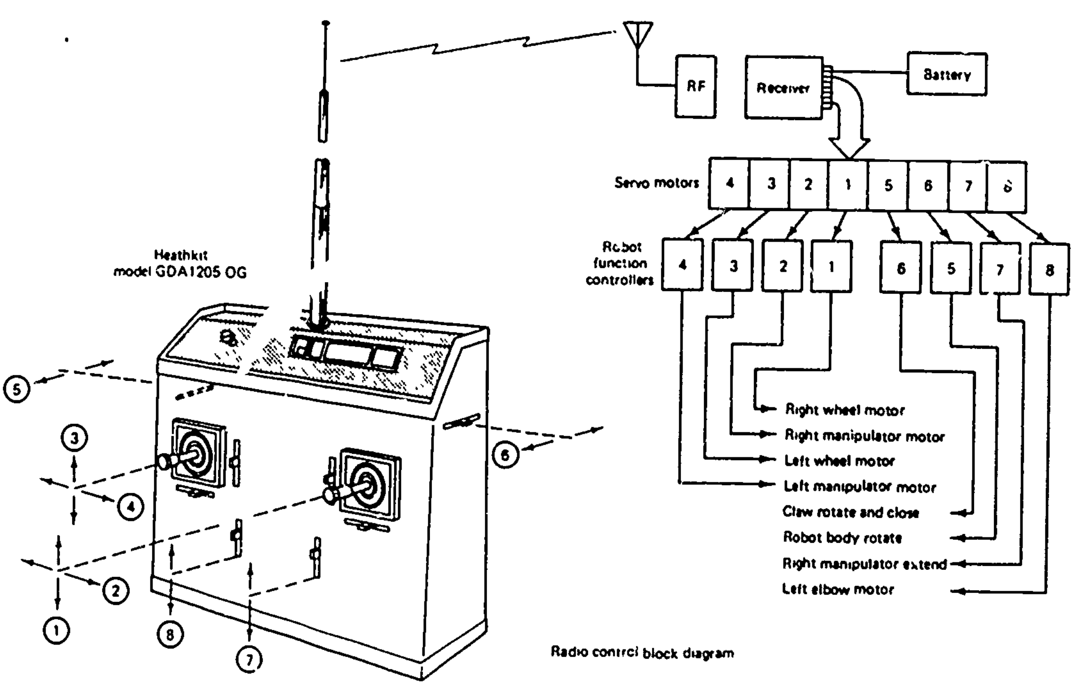


Figure 12. Typical Robot Control Transmitter.

17. *SIMULATION IN MANUFACTURING*

Whilst this report is related to physical modelling it is important, from a teaching point of view, that TAFE work with simulation modelling techniques as well. There are various software packages that can be utilised to assist in decision making and problem solving.

The use of simulation to design and "optimise" manufacturing and warehousing systems continues to increase at a rapid pace. However, there is a common impression that simulation is largely a complicated exercise in computer programming. Thus, in many simulation "studies" the major emphasis is on simulation software selection (see later section for details) and on model "coding".

In fact, I believe that simulation modelling is a sophisticated systems analysis activity, and that model coding represents only 30% to 40% of the total effort in a typical sound simulation study. Careful attention must also be paid to such activities as problem formulation, data and information collection (e.g. control logic for material handling equipment), probabilistic modelling of a system randomness such as machine breakdowns, developing a model which is both valid and credible, and the statistical design and analysis of simulation experiments.

If these important project activities are ignored, there is a likelihood that the model will produce erroneous results, or the study's conclusions will not be used in the decision making process (even if they are correct).

The pitfalls to avoid are broken down into four categories: the model development process, the selection and use of simulation software, the modelling of system randomness, and the design and analysis of simulation experiments.

17.1 *MODELLING AND VALIDATION*

Developing a simulation model of a complex manufacturing system requires a certain amount of skill and experience in order to manage the overall project effectively and also to decide what elements of the real system should be included in the model.

The following pitfalls refer to the process of building and validating a simulation model.

* **Pitfall 1: Failure to have a well defined set of objectives.**

A number of organisations embark on simulation studies without a clear statement of project goals. This is partly due to a lack of understanding of simulation and the types of simulation and of the types of information that it can provide.

I strongly believe that every simulation project should begin with a definitive specification of overall objectives and also of the particular manufacturing issues to be addressed by the model. Simulation models are not universally valid, and the appropriate level of model detail can be addressed only when a precise statement of goals is available.

It is also important to identify significant performance measures (e.g. throughput or machine utilisations), since a model may be capable of providing an accurate estimate of one measure, but not another. (See Pitfall 9 for an example). Project goals should be set at an initial meeting which includes managers and all key personnel.

* Pitfall 2: Inappropriate level of model detail.

In general, there should not be a one to one correspondence between every element of the model and every element of the corresponding system. A model should have just enough detail to address correctly the manufacturing issues identified during project formulation, and for the model to be credible. If the model is not detailed enough, any conclusions drawn from the simulation study will be doubtful validity.

Conversely, if the model has unnecessary detail or if the basic entity (or "part") moving through the model is too "small", the model execution time or memory requirements may be excessive, particularly on a microcomputer. To overcome this chose the basic part as a box or packet rather than an individual item to ensure reasonable computer execution times.

* Pitfall 3: Failure to interact with management on a regular basis.

It is very important to interact with the manager and other key personnel on a regular basis throughout the entire study. This helps ensure that the correct problem is being solved and that the manager's interest in the project is being maintained. More importantly, the model becomes more credible, since the manager understands and accepts its assumptions. (In fact, it is desirable to have the manager and other "important" people "sign off" on key assumptions.) This enhanced credibility will increase the likelihood of the model's results actually being used for decision making.

* Pitfall 4: Insufficient simulation and statistics training.

Since model "coding" typically represents less than 50% of the work for a sound simulation study, it is necessary for the analyst to have a fair amount of expertise in areas other than the use of a simulation package. In particular, the analyst needs to have formal training in simulation methodology, including validation techniques, selection of input probability distributions, and interpretation of simulation output data.

These subjects in turn require a solid grounding in statistics and probabilistic modeling. This knowledge is required regardless of the simulation package used. Furthermore, the necessary training is usually not provided by seminars on a particular simulation product, but is available in university courses and in private short courses specifically on simulation techniques.

17.2 SIMULATION/ANIMATION SOFTWARE

The selection of an appropriate simulation package can have a big impact on the ultimate validity of the model and on the timeliness with which the project is completed.

* Pitfall 5: Inappropriate simulation software.

If the simulation package used for the study doesn't have sufficient modelling flexibility, the manufacturing system of interest will have to be approximated, resulting in a model of unknown accuracy. Thus, model results may not provide a reliable indication of actual system performance. It is also desirable for a simulation package to have a user friendly environment which promotes rapid model development, and for the software to be usable by people without a high level of programming expertise.

* Pitfall 6: Misuse of animation.

Animation is certainly a powerful tool for communicating the essence of a simulation model to management, and in some cases it can aid in the debugging and validation process. However, the persuasive nature of a high quality animation can sometimes promote a false sense of security about the goodness of the model.

In particular, since only part of the model's logic can be portrayed in an animation, it is not possible to assess model correctness solely on the basis of the animation. Also, the efficacy of a particular manufacturing system design cannot be determined, in general, by watching the animation for a "short" amount of time. Rather, a careful statistical analysis of the simulation output data must be performed.

17.3 MODELLING SYSTEM RANDOMNESS

Most manufacturing systems contain one or more (input) sources of the randomness (random variables). Processing times of jobs at a machine, assembly times, machine running times before breakdown, machine repair times, set up times, and the outcomes of inspecting jobs (e.g. good, rework, or scrap) are possible examples of random variables in a manufacturing system.

Furthermore, in order to model the system correctly, each random variable must be represented by an appropriate probability distribution in the simulation model.

* **Pitfall 7: Replacing a distribution by its mean.**

Simulation analysts sometimes represent a random variable in a simulation model by its postulated mean value, rather than using the corresponding probability distribution itself. This practice may be due to either a lack of definitive data on which to base an intelligent distribution selection or a misunderstanding of the impact of randomness on system performance measures.

* **Pitfall 8. Using the wrong probability distribution.**

We have seen that it is generally necessary to model each source of system randomness by a probability distribution. However, it is also important to use the "correct" distribution.

* **Pitfall 9: Incorrect modelling of machine times.**

The largest source of randomness in many manufacturing systems is that associated with machine breakdowns (or down times).

17.4 EXPERIMENTAL DESIGN/ANALYSIS

One of the most important (and often neglected) aspects of a simulation study is the design and analysis of simulation experiments. Since random samples from the input probability distributions "drive" a simulation model through time, simulation output data (e.g. daily throughputs) are also random. Thus, output results must be interpreted carefully.

* **Pitfall 10: Misinterpretation of simulation results.**

Suppose that a manufacturing system operates 16 hours a day and that we would like to estimate the mean (or expected) daily throughput. If we run the simulation only one time, the value of the throughput from the simulation output is only one observation from a probability distribution whose mean is the desired expected daily output. (This is absolutely no different from trying to estimate the mean of a population in classical statistics with only one data point). Furthermore, this single observed value of throughput may differ from the expected daily throughput by a large amount.

* **Pitfall 11: Failure to account for the warm up period.**

When simulating manufacturing systems, we are often interested in the long run behaviour of the system; i.e., its behaviour when operating in a "normal" manner. (In the above example we were interested only in the behaviour of the system over a 16 hour day). On the other hand, simulations of manufacturing systems often begin with the system in an empty and idle (or some other unrepresentative) state.

This results in the output data from the beginning of the simulation not being representative of the desired "normal" behaviour of the system. Therefore, simulations are often run for a certain amount of time, the warm up period, before the output data are actually used to estimate the desired measures of performance. Use of these warm up period data would bias the output results.

18. *SIMULATION SOFTWARE FOR MANUFACTURING APPLICATIONS*

There has been a dramatic increase in the use of simulation for manufacturing analyses during the past few years. This has been caused by the greater complexity of automated systems, reduced computing costs brought about by microcomputers and engineering workstations, improvements in simulation software which have reduced model development time, and the availability of graphical animation which has resulted in greater understanding and use of simulation by engineering managers.

Increased interest in simulation has, in turn, led to an explosion in the number of simulation packages with a strong orientation toward manufacturing problems, with more than 25 such products now being available. As a result, a person trying to select simulation software for his/her organisation or for particular application is now faced with a bewildering variety of choices in terms of technical capabilities, ease of use, and cost.

The situation is exacerbated by frequent changes or additions to existing software and by the regular introduction of entirely new simulation products. A person new to the field of simulation modeling could literally spend three or more months carefully evaluating software for a particular simulation project.

There is an unfortunate impression that simulation is largely a complicated exercise in computer programming. Thus, in many simulation "studies" a significant amount of the effort is spent on "coding" the simulation model in a simulation package and, also, possibly, in selecting the software in the first place.

As mentioned earlier model coding represents only 30 to 40% of the total required work in a typical simulation study. Most of the other tasks (problem formulation, data and information collection) are, for the most part, not performed by existing simulation software, regardless of how easy these products are to use. Thus, it is incumbent on the simulation developer or user to have a fair amount of expertise in *simulation methodology* per se, in addition to the use of one or more simulation products. Many universities offer courses which cover the important simulation project activities. TAFE has to become more involved in this area as well by providing education, training and application skills in simulation modelling software use. This is especially important in Integrated Manufacturing and Industrial Engineering Courses. The use of simulation software should go hand in hand with physical simulation modelling.

18.1 *TYPES OF SIMULATION SOFTWARE*

There are two major categories of software for simulating manufacturing or warehousing systems. A general all purpose simulation language is a simulation package which is general in nature (e.g. it could be used for modelling computer or communication systems), but may have special features for manufacturing such as workstations or material handling modules. There is one simulation language, AutoMod II, which is specifically directed toward material handling and manufacturing problems. A model is developed in a simulation language by writing a program using the language's modelling constructs.

The major strength of simulation languages is the ability of many of them to model almost any kind of manufacturing system, regardless of the complexity of the system's material handling equipment or control logic. Possible drawbacks of simulation languages are the need for programming expertise and the possibly long coding with modelling complex manufacturing systems.

A manufacturing simulator is a computer package that allows one to simulate a system contained in a specific class of manufacturing systems with little or no programming. For example, STARCELL is a simulator oriented toward manufacturing cells.

The particular system of interest (in the domain of the package) is typically selected for simulation by the use of menus or graphics, without the need for programming. The major advantage of a simulator is that the "program" development time may be considerably less than that for a simulation language. This may be very important, due to the tight time constraints in many manufacturing environments.

Another advantage is that most simulators have modelling constructs specifically related to the components of a manufacturing system, which is particularly desirable for production personnel. Also, people without programming experience or who use simulation only occasionally (e.g. a manufacturing engineer) often prefer simulators because of their ease of use.

The major drawback of many simulators is that they are limited to modelling only those manufacturing configurations allowed by their standard features. This difficulty can be largely overcome if the simulator has the ability to "drop down" into a lower level language (e.g. FORTRAN) to program complicated decision logic. (Most of the model would still be developed using menus and graphics).
Note that a complex model developed in a simulation language by an analyst can be made more accessible to manufacturing personnel by adding a flexible, menu driven "front end" and also tailored output reports. The front end allows one to make a certain set of modifications to the model without programming. TAFE needs to teach these skills and show students how simulation programs can be made more user friendly and adaptable to suit any requirement.

There are two major types of manufacturing analyses for which simulation is used. In high level analysis, the system is modelled at an aggregate level and details of the operating or control logic are not included. (A high level analysis is often performed in the initial phases of manufacturing system design, since detailed system information is not then available).

Typical objectives are determining the required numbers of machines and material handling equipment, evaluating the effect of a change in product volume or mix, and determining storage requirements for work in process. Manufacturing simulators are often used for high level analyses, but a language could be used as well.

A detailed analysis is performed to fine tune or "optimise" the performance of the system, and the corresponding simulation models typically represent operating or control logic in considerable detail. Most analyses of this type are done for existing systems, because of the need for a precise system description.

An example of a detailed analysis would be determining the best operating strategy for a complicated conveyor system. Many detailed analyses are done using a simulation language because of the need to model complex decision logic, which may be unique to the system being studied. In some cases simulators can also be used, particularly if they have the ability to drop down to a lower level language.

In addition to the two types of manufacturing analyses discussed above, simulation is increasingly being used to support daily scheduling decisions on the shop floor. FACTOR and InterFaSE are scheduling orientated manufacturing simulators with utilities for accessing the necessary manufacturing databases.

18.2 DESIRABLE FEATURES

There are six groups of specific features that, in my opinion, are important for simulation software to be used in the analysis of manufacturing systems.

18.21 General Features: One of the most important features is modelling flexibility, because no two manufacturing systems are exactly the same. If the simulation package doesn't have the necessary capabilities for a particular application, then the system must be approximated resulting in a model with unknown accuracy. For a simulator, it is desirable for parts (or entries) to have general attributes (e.g. part number, due date, etc.), which can be appropriately changed.

Ease of model development is another very important feature, due to the short time frame for many manufacturing analyses. The accuracy and speed of the modelling process will be increased if the package has good debugging aids, such as an interactive debugger and on line help facilities.

Fast model execution speed is particularly important when the simulation model is to be run on a microcomputer (PC). For a simulation model of a food manufacturing plant it took seven hours to emulate two weeks of production on a relatively fast 16 Megahertz (MHz) PC.

The maximum model size allowed by the simulation package may be an important factor when the model is to be executed on a PC. For some packages, the maximum model size will become less important since some vendors are beginning to offer extended model sizes on the OS/2 operating system.

It is also desirable for software to be compatible across computer classes. Thus, for example, a model could be developed on a PC and executed on a minicomputer or mainframe.

18.22 Animation: This has become a widely accepted part of the simulation of manufacturing systems. It is particularly useful for communicating the essence of a simulation model (or of simulation itself) to managers or other manufacturing personnel, which greatly increases the model's credibility.

For systems with complex logic, animation may also be useful for "program" debugging, for model validation, and for suggesting new control strategies. Desirable animation features include ease of development, user creation of high resolution icons (using bit mapped graphics), and smooth movement of icons across the computer screen.

18.23 Statistical Capabilities: Since almost all manufacturing systems exhibit random behaviour, it is imperative for a simulation package to contain good statistical capabilities and for them to be actually used. In general, each source of randomness (e.g. processing times, machine operating times, machine repair times, etc.) needs to be modelled by a probability distribution, not just its mean.

A simulation package should contain a wide variety of standard distributions (e.g. exponential, gamma, and triangular), should be able to use distributions based on observed shop floor data, and should contain a multiple stream random number generator to facilitate the comparison of alternative system designs.

Since random samples from the input probability distributions "drive" a simulation model through time, simulation output data (e.g. daily throughputs) are also random, and appropriate statistical techniques must be used to design and interpret the simulation runs. A simulation package should contain a command to make independent replications of the model automatically, with each replication using different random numbers, starting in the same initial state, and resetting the statistics to "zero".

It is also desirable to have the ability to specify a warm up period (at the end of which output statistics are reset to zero) and to construct a confidence interval for a desired measure of performance (e.g. mean daily throughput) in order to determine the statistical accuracy of the simulation results.

18.24 Material Handling Modules: These are an important part of most modern manufacturing systems and, furthermore, are often difficult to model. Therefore, the availability of flexible, easy to use modules for modelling transporters (e.g. forklift trucks), AGV's (including contention for guide paths), conveyors (both transport and accumulating), AS/RS, cranes, and robots can significantly reduce model development time. It should be noted, however, that the existing material handling modules in some simulation packages may not always be sufficient due to the great diversity of available material handling systems.

18.25 Customer Support: Most users of simulation software require some level of on going support from the vendor. This can be in the form of general software training or may be in providing technical support for specific modelling problems encountered by the user. Good documentation including numerous detailed examples, is important for software use as well as initial installation.

18.26 Output Reports: It is desirable for a simulation package to provide time saving standard reports for commonly occurring performance statistics (e.g. utilisations, queue sizes, and throughput), but also to allow tailored reports to be developed easily. (For example, standard reports are often not suitable for management presentations).

Furthermore, it is often of interest to obtain high quality graphical displays (e.g. histograms or time plots of important variables) and to have access to the individual model output observations (rather than just the summary statistics) so that additional analyses can be performed.

I have discussed types of simulation software and have given a detailed list of features to consider when choosing software for a particular application. However, the choice of a simulation package may still be a difficult decision due to the proliferation of simulation products and their widely varying capabilities and prices. I recommend that potential users, such as TAFE, consider the following activities when making decisions:

1. Carefully determine the types of manufacturing issues that you want to address by simulation, paying particular attention to the required level of model detail.

2. Develop a short list of candidate simulation packages based on your requirements in item 1 above, on features of the available software, and on cost considerations.

3. Talk to several users of each product on your list (these may be hard for TAFE to locate easily) to get independent assessments of software strengths and

weaknesses.

4. If possible, get a months free trial (there should be educational demonstration disks available, if not, most suppliers are willing to give educational institutions copies to view) of each product to see how it perfc⁻ms on applications of particular interest to TAFE.

It should be noted that there is no simulation package which is completely convenient and appropriate for all manufacturing applications. Tnus, organisations that do a large amount of simulation may want to consider several simulation packages, which are used for different types of analyses by people with different backgrounds. TAFE needs to view several and obtain advice from appropriate teachers as to course requirements.

Following are brief details on some simulation software packages which should be investigated by TAFE for suitability.

18.3 SIMULATION LANGUAGES

Product	Vendor	Approx Price (US$)
AutoModII	Auto Simulations Inc.	48,000
CADmotion	Simulation Software Systems Inc.	4,900
GPSS/PC	Minuteman Software	1,500 - 2,000
INSIGHT	SysTech Inc.	1,900
PCModel	Simulation Software Systems Inc.	3,900
RESQ	IBM Corporation	7,500
SIMAN/Cinema	Systems Modelling Corp.	1,900 - 28,000
SIMPLE_1	Sierra Simulations & Software	750
SIMSCRIPT II.5	CACI Products Co.	13,500 - 16,500
SLAM II	Pritsker Corporation	25,000 - 75,000
SLAMSYSTEM	Pritsker Corporation	18,000

18.4 MANUFACTURING SIMULATORS

Product	Vendor	Approx. Price (US$)
FACTOR	Pritsker Corporation	35,000 - 250,000
HEIRTSS	HEI Corporation	1,500
InterFaSE	Auto Simulations Inc.	60,000
MAST	CMS Research Inc.	9,500 - 11,900
MIC-SIM	Integrated Systems Technologies Inc.	450 - 1,750
Micro SAINT	Micro Analysis and Design	1,500 - 2,800
PROMOD	Production Modelling Corporation	1,500 - 2,800
SIMFACTORY	CACI Products Co.	15,000 - 16,500
STARCELL	H.J. Steudel & Associates	3,500
WITNESS	ISTEL Inc.	25,000
XCELL+	Pritsker Corporation	8,000

Of the simulation languages I would suggest that PCModel, SIMAN/Cinema and SLAMSYSTEM be further investigated. For Manufacturing Simulators Micro SAINT, PROMOD, SIMFACTORY and STARCELL should be suitable. All of these recommended packages run on IBM PC's or PC Compatibles.

19. *EDUCATIONAL CIM PC SOFTWARE*

There are several simple CIM programs that are available which convert a PC into a work station environment. These work station environs will range from a NC machine to an APT work station to a CAD/CAM work station to a Computer Aided Process Planning work station. The software for emulating an NC machine is capable of emulating the tool path both graphically as well as controlling a physical machine.

One development of major significance is that of graphical and scaled iconic models of flexible manufacturing equipment. These iconic models can be described as "miniature physical models which can emulate most of the machine tool characteristics, motion control features and software requirements of full scale flexible manufacturing equipment". The graphical models range from the line graphics on a plotter or monitor to animation on a graphics terminal.

These models can be used to construct a safe and inexpensive environment for the instruction of: NC programming, motion control and other CAD/CAM applications. Using graphic and iconic components, design and motion control problems, as well as Flexible Manufacturing systems can be analysed and refined without having to incur a major manufacturing expense.

This report will focus on one package which has been selected from the many available as suitable for educational purposes in TAFE.

The researched package consists of a CIM student workbook and six modules of PC software. It is available from Delmar Publishers Inc., is titled "Computer Integrated Manufacturing Software and Student Manual", and is written by Richard A. Wysk, Tien-Chien Chang and Hsu-Pin Wang. This package is highly recommended for TAFE to purchase as it is reasonably priced and provides a good simulation of industrial based CIM.

The six software modules are as follows:

Disk 1	**GENERIC**
Disk 2	**CNCS**
Disk 3	**MAPT**
Disk 4	**PC-CADAM2**
Disk 5	**KK3 and Micro-CAPP**
Disk 6	**Micro-GEPPS**

Most of the CAM principles required of today's technicians and engineers are embedded in the software. Following is a brief description of the six modules:

19.1 *GENIC - A GENERIC NC SIMULATOR*

GENIC is a generic emulator for CNC machining centres, milling machines and drilling machines. GENIC is capable of emulating several different kinds of NC part programming formats such as standard word address, tab sequential and fixed block formats.

GENIC can not only emulate standard NC part programming formats, but it can also emulate specific NC words and formats for particular machining centres which currently exist in the market. Examples of these machines include: the Cincinnati Milacron T-10, Pratt and Whitney Horizon V, the Bridgeport Series I and the Bridgeport Series I with an Allen-Bradley controller. Instructions for each of these machines have been installed as part of GENIC, however, a large variety of machines can also be emulated using GENIC by simply describing the machine programming features.

GENIC requires the user to furnish a data file as part of the program input. The data file should contain a complete NC part program in a format installed in GENIC. The data file can be created using any ASCII text editor or word processor. Word processors provide a friendly user environment, and if ASCII files can be created directly from them, an efficient person-machine system results.

19.2 CNCS - A CNC MACHINE SIMULATOR

This CNC machine simulator runs on a IBM PC or PC compatible computers and uses colour graphics to simulate the cutter motion. The user can either plot the cutter path, the cutter path with the image of a cutter, or real time animation of cutter motion.

Raw material can be defined interactive on the screen and the cutter path shown cutting through the raw material. The principles of CNC programming can be learned without using actual machines. Part programs can also be prepared and verified by CNCS before the real machining takes place.

CNCS consists of three major parts: screen editor, syntax check facility and simulator. The screen editor can handle part programs up to 600 blocks. On line help menus are provided. These menus can be displayed by pressing appropriate function keys. Help menus include editor key help, part program data format help, G code and M code help. Part programs can be prepared and edited using the editor. The syntax check facility checks the user's part program syntax. It prompts the user for every syntactic error encountered. When a program is free of syntactic error, it can be simulated graphically on the screen using the simulator. The verified part program can be punched on paper using the simulator.

In order to allow users to tailor CNCS to their own CNC installation, a program INSTALL can be used to change the part program format. CNCS checks the user part program format according to the installation data. The structure of the CNCS system is shown in Figure 13.

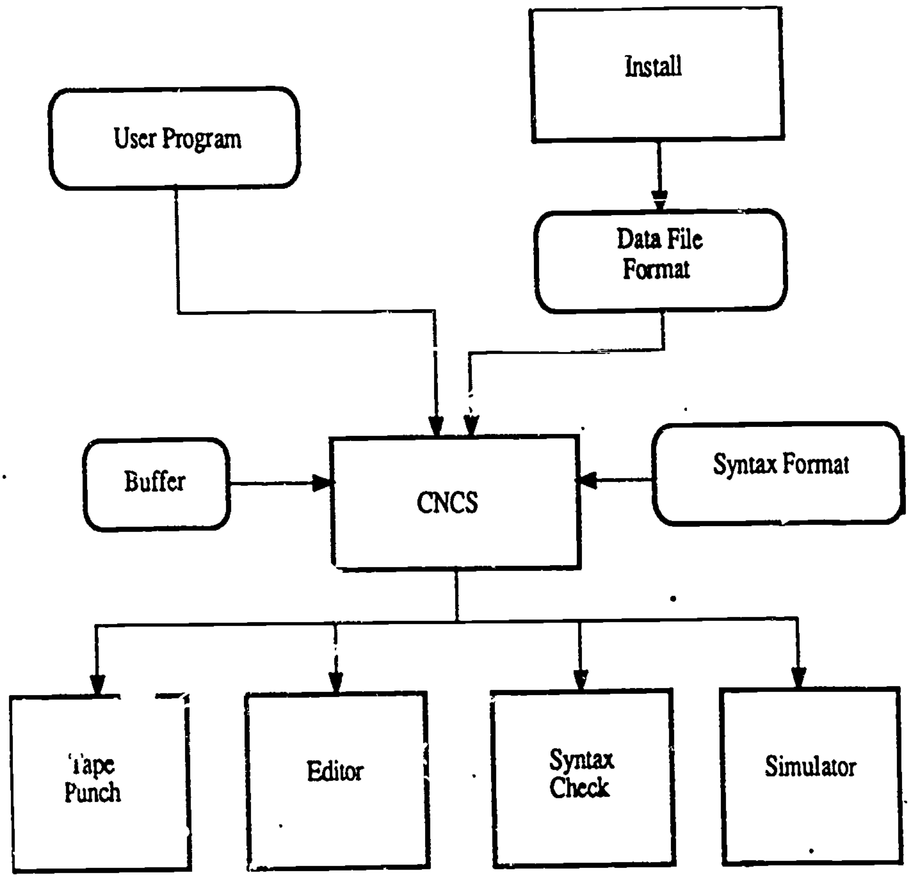


Figure 13. CNCS Program Structure.

19.3 MAPT (Micro-APT) SYSTEM

MAPT is a combination of a text editor, a subset of the APT (Automatic Programming Tool) processor and a real time colour graphics NC machine simulator which runs on an IBM PC or PC compatible microcomputer. It is a computer aided part programming system which generates instructions for Numerically Controlled (NC) machine tools.

Using the MAPT language, a manufacturing engineering student specifies the geometry of a part to be machined, the motion of the tool (cutter) and the operations involved in producing the part. The MAPT system translates these instructions into numerical information which guides the machine tool to produce the part. Tool centre offset is automatically calculated and the current version of MAPT is capable of 3 axis programming.

MAPT is an interpreter language and the user can compile (MAPT actually interprets) a MAPT source program line by line. The final cutter location (CL) and error messages are printed out as the program compiles. The CL data can be plotted with user defined geometries to verify the program. Paper tape or paper tape format data are generated by post processors for the target NC machine. The CL data currently generated by MAPT is non standard.

MAPT also contains a built in screen editor with help facility. The user can get on line assistance on both editor commands and MAPT language syntax. A user program can be created, compiled, edited and then compiled again without leaving the MAPT processor. A built in graphic package allows the user to verify a program and can also simulate cutting in real time with colour graphics and sound.

Several functions such as zooming, grid on/off, single step, etc. are available. For TAFE colleges where an NC machine is not available, this option can allow students to learn NC programming without a machine.

19.4 THE PC-CADAM SYSTEM

This allows the user to interactively create 2D part drawings easily using a PC. Moreover, when incorporated with GENIC or MAPT, mentioned previously, it is possible to graphically validate the NC codes created by PC-CADAM by emulating the cutter path on the screen. NC codes may further be used to control a physical machining process, either through GENIC to run a miniature CNC machine or a full size NC machine.

19.5 THE KK3 CLASSIFICATION AND CODING SYSTEM

Cellular Manufacturing or Group Technology (GT) is a techniques and philosophy to increase productivity by grouping a variety of parts having similarities of shape, dimension and/or process route. The basis of most GT applications is a classification and coding system. A coding system describes the basic characteristics of the part with respect to the part geometrical shape and/or process route (set up, inspection and measurement). By gathering parts with the same (or similar) code number and grouping them into a group cell (which may be processed by a computer), its design, process planning, manufacturing, cost estimation and material requirements planning (MRP) are made more systematic.

KK3 is an ideal classification and coding system which, in its computerised form, presents several advantages:

(a) It significantly reduces error. The computer will not make mistakes due to visual or manual error and fatigue.

(b) It decreases the time spent on coding parts. Tutorials and queries appear on the screen instantly, eliminating the need to turn pages or look up coding rules.

(c) It reduces the amount of manual processing of a code number. The computer generates the number and permanently retains it in the data base without any human intervention.

Interactive coding of parts is quite easy using the computerised KK3 system. The user simply responds to queries with Y (yes) or N (no), or a number according to work piece drawings. The current status of the coding process is displayed at the upper right corner of the user's screen.

19.6 MIRCO-CAPP SYSTEM

This is a microcomputer based program for assisting those individuals who are responsible for generating manufacturing process plans for the fabrication of discrete parts.

Classically, a printed copy of an ordered sequence of manufacturing operations accompanies each production run of a part through the production shop, operation by operation, work station by work station. It is the responsibility of process planners to generate a routing sheet describing the sequence of operations. A reasonable production sequence for the fabrication of each part is extremely important in today's manufacturing environment. However, generating such an operation sheet is not an easy job especially for a process planner who works without the help of adequate computer software.

Micro-CAPP provides a means of reducing the individual's workload generally required for a process planner to function productively. It is a vehicle for standardising and streamlining production methods by reducing individual decision making from the process planning function to the extent possible. Micro-CAPP also provides a means of storing process plans for each part for the convenience of later retrieval any time needed.

Micro-CAPP is an interactive software program. In other words, the user communicates with the computer and invokes the execution of various Micro-CAPP functions in a real time mode. The communication medium used is a video display terminal with a keyboard. Once initilised, the application program of Micro-CAPP remains in an immediately executable state until the Micro-CAPP session is terminated.

19.7 MICRO-GEPPS PROCESS PLANNING SYSTEM

This is a microcomputer based generative process planning system. It is not a full scale generative program but was designed for educational purposes only. It was intentionally developed to be used as part of classroom material for instructing Manufacturing Systems and Process Engineering courses.

Micro-GEPPS was specifically developed to generate manufacturing process plans for those parts which might be:

(a) completely coded using the KK3 coding scheme, and
(b) fabricated by using a CNC lathe.

In other words, a part may not be planned using Micro-GEPPS if its geometric complexity is beyond the description capability of KK3, or it is non rotational.

20. *SIMULATING CELL ACTIVITIES IN THE CIM ENVIRONMENT*

Interest in Computer Integrated Manufacturing (CIM) has been steadily increasing as many industries consider automation and CIM a necessity to compete in the market place. By definition, the CIM environment requires high level control of production processes and operation. An important key to the successful implementation of CIM is integration, as the interactions between shop floor planning, control, and resource allocation must be integrated during both planning and operational phases.

A manufacturing cell, in which machine centres are dedicated to the production of similar parts grouped in families via cellular manufacturing, simplifies planning and control. This is because each cell can be treated as a semi independent sub system, similar to "the factory within a factory" concept. As a result, the work cell design allows the production system to be more responsive to product changes, thus making the system more market oriented.

The work cell concept also simplifies the problem of controlling automatic robotic material handling systems by limiting their range and versatility requirements. Furthermore, the work cell approach reduces total machine set up time, thus making Just In Time strategies possible. Work cell structures also improve process quality by allowing a transfer of diagnostic knowledge between similar operations on different parts.

To analyse the design or operational strategies of a cellular manufacturing system, it is necessary to build a physical or mathematical prototype of it. Physical experimentation within the system itself often is too disruptive and costly, and is sometimes not feasible if the work cell is in the design stage. Mean value analysis and network queuing theory provide rough cut analysis for cell design questions but fail to give the detailed time history needed to examine decisions made on a day to day basis. For these reasons, discrete event computer simulation is an attractive alternative.

Computer simulation estimates the cell model's system characteristics for specific operating conditions by accumulating statistical data on it over a period of time. Simulations also enable the user to maintain stricter control over the experimental environment than can be done within the actual system.

Cell simulation is the process of developing a model of a work cell, encoding the model into a computer language, and then utilising the computerised model to analyse the behaviour of the work cell over time.

The model is first expressed in narrative form, and then as a computer code. When the code is run, it traces the movement of each individual part from its arrival in the work cell through the various work centres on its route to the exit.

Individual operations are characterised by a processing time (per part) and a possible set up time.

A work centre will be either idle, due to a momentary lack of work or a "problem" such as unscheduled maintenance, or it will be busy. A run may consist of tracing the flow for thousands of individual parts, in which case various performance measures, such as throughput times for each part type, utilisation of each work centre, number of each part type, utilisation at each station, number of each part type that was delinquent to due date, scrap rates, and work in process at each work centre, can be accumulated.

Obviously, a variety of information is required to develop a cell simulation. Specifically, any factor that influences set up and processing times, arrival times, routing, and management of queues at each work centre can affect the performance measures. Some of this information is "data", such as the processing and set up times and the routes, but other information deals with loading and cell management.

Cell loading involves selecting the sequence of jobs to run, choosing certain jobs to be loaded and run simultaneously, and choosing the batch and transfer lot sizes. These are parameters in the simulation and can be adjusted by the user to identify "good" values. Cell management involves rules applied at the work centres which assign priorities to jobs in the queue. A first come first served rule is a typical default value, but can give very poor due date performance under certain conditions. Thus a simulation can incorporate various management schemes that the user can adjust. By allowing the user to evaluate cell performance under various data, loading, and management factors, cell simulation is a powerful management tool.

Several studies have investigated the use of simulation for long or short term decision making. The study of scheduling algorithms and their effect on shop floor performance is usually pursued using simulation models, and some work also has used simulation to develop expert systems for shop floor control. In addition, simulation can be used to decide upon appropriate control strategy when certain transient events occur.

In the past, simulation often was frowned upon for manufacturing analysis because of problems associated with programming complexity. Several recent developments, however, make it much more convenient to implement manufacturing systems, and especially cell simulations. They are as follows:

1. Data collected routinely by the CIM system can be converted into data needed by a typical simulation.

2. Syntax free (menu driven) simulation languages have been developed which greatly reduce programming complexity.

3. Animation, typical in most simulation languages, can

enhance the decision maker's understanding of the time dependent system behaviour.

4. Cell activities are confined in their scale and range, thus models need not consider the interactive complexities of the entire production system.

5. Developments in future CIM systems may make it possible to automatically restructure and augment simulation models and databases with minimal human interaction.

In two distinct cases, simulation provides useful information about work cell characteristics. The first is during the design process of a work cell or an individual product. Simulation allows the user to look at an "optimal" choice which can be made with reference to the desired performance characteristics, such as throughput time or average waiting time. Simulation accounts for the probabilistic nature of the manufacturing process and outputs both transient (short term or daily) and steady state (long term or monthly) solutions to performance questions.

In this case, simulation provides a high level of integration to a CIM system. Suppose a designer wants to estimate the various production requirements for a conceptualised part. The part may be conceptualised, designed, and represented in a product database of the CIM system. This design then flows to a process planning module (computer or human), where various routes are hypothesised, given the constraints of the current system. In its most developed stage, simulation then would access part information from the product database, routing information from the process planning module and other higher level information, such as expected demand, current machine layouts, and performance characteristics, to provide the user with information which may be synthesized into estimates of cost, equipment, personnel, and time requirements for the given conceptualised part.

The other case in which work cell simulation provides useful information to a CIM system is in the management of a work cell during transient, destabilising phenomena. Some examples of such sporadic and/or catastrophic events include machine breakdown, worker or material shortage, critical short term increases in demand, sudden decreases in process/product quality, or the introduction of a new part into the work cell.

These events could possibly decrease or paralyze work cell efficiency. In the event of these types of occurrences, a factory manager could first manipulate the simulation database to emulate the event, and then simulate various managerial schemes, such as different loading patterns, alternative routings, additional labour or emergency equipment, and varying transfer lot sizes, to determine the optimal decision.

In each of these cases, there is a subtle way in which simulation can point to the information needs for integrated operation. Since the operation of a simulation traces the movement of each part, it follows that at every point in time, the location of every part, the length of every queue, and the available capacity at every work centre is known by the simulation. This information may not be used to control or manage the flow for a particular model, but it could be utilised to develop more responsive management decisions.

Thus a simulation contains more real time information than is known by any single source in a typical manufacturing setting, and so it may be used as a test bed for management strategies that depend upon cell status information that may not be available. In this way, a simulation can serve as a framework to test certain information structures in CIM.

The use of cellular manufacturing techniques is an important part of CIM. Cells simplify the planning and control of the CIM system, and make the company more efficient and responsive. Simulating cell activities can be useful to both the cell designer and the factory manager, and simulation can be used to derive the time dependent behaviour of the cell, thus making it an efficient decision making tool.

Due to its usefulness in predicting cell behaviour, simulation will eventually become an integral part of the CIM environment.

21. A PROPOSED SIMULATION STUDENT PROJECT ON CAD/CAM INTEGRATION

21.1 ABSTRACT

The integration of CAD (Computer-Aided Design) and CAM (Computer-Aided Manufacturing) has benefited many large companies who could afford the system. The existence of a completely integrated and affordable system of CAD and CAM on a micro-computer is still a dream to come true for many smaller companies. However, the decreasing cost of microelectronic devices has resulted in the feasibility of low cost CAD/CAM systems on an economic scale more likely in the very near future.

This proposed simulation example presents this integration by means of a pilot study on gear shaft design. Not only is this example an excellent and affordable teaching project it is also suitable for a small company to enter CIM in a relatively small way without spending huge amounts of money.

The project is carried out on a PC and makes use of a CAD package (AutoCAD) and a CAM package (Lathe Productivity Package).

The project consists of three main phases. Phase one involves an interactive design analysis and drafting in 2D and 3D of the designed shaft. The second phase consists of the process planning routine which calculates the speed and feed rate of the turning operation. Information regarding the tools used is also determined here. The last phase is the manufacturing phase. Simulation of the manufacturing process could be viewed using the Lathe Productivity Package. At the same time, NC codes for the manufacturing operations could be retrieved to be subsequently transferred to a controller which drives the CNC lathe.

A decent CAD/CAM system similar to that described in this example costs in the vicinity of $25,000, which is much cheaper and easier to maintain than larger systems and appeals more to small and medium sized companies.

21.2 INTRODUCTION

Computer aided design (CAD) and computer aided manufacturing (CAM) systems have existed separately for a number of years. The activities within CAD have been centred around analysis and optimising particular designs. Finite element is an example of this. Within CAM, the data processing capabilities of computers have been exploited for production scheduling and inventory control and the mathematical capabilities have been exploited for aiding the production of Numerical Control (NC) codes. Thus in the past, CAD and CAM have been developed separately within the design and production functions of the companies, each function seeking to exploit computers in its own way.

In recent years, the use of integrated CAD and CAM systems has increased substantially. Unfortunately the cost of such systems has put them out of the reach of many small manufacturing companies. While the larger companies who could afford the system enjoy the harvest resulting from such integration, small to medium sized companies could only "sit and watch".

This example proposes a PC-based integration of CAD and CAM. An attempt is made at presenting the basic concepts of such integration and the way integration can be implemented using personal computers by means of a case study on shaft design and manufacture.

21.3 CAD, CAM AND CAPP

21.31 Definition of CAD

CAD or Computer Aided Design can be defined as any design activity that involves the effective use of the computer to create, modify or document an engineering design. The scope of CAD ranges from the analysis and optimisation of the design to the final presentation of the product design in drawing forms.

21.32 Definition of CAM

CAM or Computer Aided Manufacturing is defined as the effective use of computer technology in the planning, management and control of the manufacturing function. The applications of CAM can be divided into two broad categories namely:

(1) Manufacturing planning
(2) Manufacturing control

CAM applications for manufacturing planning are those in which the computer is used to support the production function, but there is no direct connection between the computer and the process. Some production activities include cost estimation, computer aided process planning (CAPP), computer assisted NC part programming and production and inventory planning.

Manufacturing control is mainly concerned with managing and controlling the physical operations in the factory to implement the manufacturing plans. Included in the control function are shop floor control, inventory control, quality control and various other activities.

In this example, the major considerations of CAM are placed in the generation of process planning route sheets, process cost estimation and the derivation of NC codes.

21.33 Definition of CAPP

It is important to discuss Computer Aided Process Planning

(CAPP) at this point because it has often been identified as an important link between design and manufacturing in a CAD/CAM system. Process planning can best be defined as the sub system responsible for the conversion of design data to work instructions. Its task consists of translating part design specifications from an engineering drawing into manufacturing operation instructions required to convert a part from rough to a finished state.

Geometric features, dimensional sizes and material specifications of the part must be available in order to select an appropriate sequence of processing operations and specific machines or workstations. Operation details such as cutting speeds, feed rates and tooling information are then determined. From these values, the standard times for the process and the expected processing costs are then calculated. The resulting process plan is documented as either a cost estimate, a job routing (or operation route) sheet, or as coded instructions for NC equipment. All three applications mentioned above are considered in the case study of this proposed teaching simulation modelling example.

21.4 CAD/CAM

The combination of CAD and CAM in the term CAD/CAM is symbolic of efforts to integrate the design and manufacturing functions in a firm into a continuum of activities, rather than to treat them as two separate and disparate activities, as they have been considered in the past.

21.5 MICROCOMPUTER BASED INTEGRATION OF CAD AND CAM SYSTEMS

It suffices to say that the success of integrating CAD and CAM requires "glue" in the form of plans, architecture, databases and utilities (both hardware and software). This glue facilitates effective transfer of information between the design and manufacturing environments.

21.51 Basic hardware elements

The workstation used consists of

(1) An IBM-AT with EGA card.
(2) A digitizer with AutoCAD template to serve as an input device to CAD and CAM functions using a puck.
(3) Printer and plotter as output devices.

21.52 Software packages

The three main software packages used for the case study on shaft design and manufacture are:

(1) AutoCAD by AutoDESK.
(2) Lathe Productivity Package by NC Microproducts.
(3) dBASE III Plus or dBASE IV by Ashton-Tate

21.53 *Gear Shaft Design and Manufacture*

Due its simplicity, the gear shaft design is chosen for the case study. To start of with, a basic model of a gear shaft is already created for the user. The shaft considered is loaded with a pulley, two gears and supported by two bearings. The shaft is to be turned on a CNC lathe. It is assumed that the user is familiar with the basic theory behind gear shaft design. Four routines are written in AutoLISP to perform shaft design, process planning and the derivation of NC codes. They are:

(1) Design analysis routine.
(2) Automated drafting routine.
(3) Process planning routine.
(4) NC codes generation routine.

21.54 *Design Analysis Routine*

The purpose of this routine is to calculate the diameter of each section of the shaft given the safety factor of which these sections of the shaft have to satisfy. These diameters will depend upon the combined stress due to bending moment and torque. The routine is user interactive in nature requiring values like the loadings of the external components and also the design factors. These design factors are stored in an AutoCAD facility called the slide library relieving the user from having to look into other sources of these data.

The shaft is analyzed using Distortion Energy Criterion. In specifying the Stress Concentration Factor, the diameter of the shaft is initially assumed. An iterative process is necessary to select the appropriate diameter.

The diameters of the shaft calculated are stored in an external file which is used as input to the process planning routine. In determining the material for the shaft and the type of bearings, the routine calls a dBASE III Plus program to automatically extract the suitable stock available in inventory.

21.55 *Drafting Routine*

Two AutoLISP programs are written; one to draw the 2D engineering drawing of the shaft and the other to draw the 3D representation of the designed shaft. In the process of drawing the designed shaft, an upper half of the shaft is also drawn and stored in a BLOCK which will later be used as input for the CAM routine to generate NC codes for the turning operation.

21.56 *Process Plan Routine*

To simplify the process plan, the following assumptions are made:

(1) machining speed is a function of material hardness and material strength.

(2) tool material has a carbide tip.

The main applications of CAPP considered are:

(1) generation of process route sheet.
(2) process cost estimation.

The process route sheet generation routine consists of 3 subroutines namely:

* development of new process plan.
* generation of process plan summary.
* generation of detailed process plan.

The estimated processing cost is assumed to be a function of the machining time. The machining time in turn is calculated as a function of machining speed, feed, and the depth of cut of each operation pass. The values for the set-up cost and the overhead cost are hypothetically given, whereas the machining cost and the direct labour cost are calculated as a function of the total estimated machining time. All these data are stored in a database file of dBASE III Plus.

21. 7 NC Code Generation Routine

The Lathe Productivity Package is made use of in this CAM routine to automate and simplify the tooling process for turning applications. Its input are the data output from the design analysis and process planning routines.

21.58 How AutoCAD, Lathe Productivity Package and dBASE III Plus work together -

Data extracted from AutoCAD are formatted in a form called Comma Delimited Format (CDF) which can be readily imported by dBASE III Plus programs. The procedure to transfer attributes from AutoCAD to dBASE III Plus is briefly outlined below:

* create a template file with a TXT extension.
* assign a name for each of AutoCAD drawing's attributes using ATTDEF function in AutoCAD. Define the drawing and its attributes as a BLOCK and use the INSERT command to assign data to the previously defined attributes.
* use ATTTEXT function to extract the attributes from AutoCAD.
* load the extracted data into dBASE III Plus using COPY FROM command in dBASE III Plus.

The values of the attributes stored in database files under dBASE III Plus can also be extracted for use by AutoLISP routines inside AutoCAD. However, these attributes must first be converted to the format recognizable by AutoLISP. A simple BASIC program is written to accomplish this format conversion. The CDF data output from dBASE III Plus is converted to a "one word per line" format readable from within AutoLISP.

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This interchangability of data between an external database and AutoCAD means that smooth information flow is possible between departments within a company.

The building block approach of AutoCAD to geometry development is extremely adaptable to numerical control usage. Since the Lathe Productivity Package is totally integrated inside AutoCAD, the parts programmer has all the functions of AutoCAD available to assist in the tooling process as well as the added functions of the former.

21.6 CONCLUSION

In its simplest form, integrating CAD and CAM systems means that useful information is easily transferable back and forth between design and manufacturing. As manufacturing companies begin to acquire a reasonable amount of computing hardware and software, it becomes timely and appropriate to more effectively utilize their existing resources by focusing on the integration of activities within their companies. This will significantly help us reach the kind of creativity that is needed as a nation to insure long term productivity growth.

By using a simple example such as shaft design and manufacture to demonstrate the integration of PC-based CAD and CAM systems, this proposed example has shown that the personal computer offers a new trend and an exciting future for engineering design and the manufacturing industry.

22. *GENERAL SPECIFICATION*

It is virtually impossible to compile a general specification for physical modelling systems as the equipment required could vary considerably from centre to centre and application to application. Depending on the projects attempted, at the various centres, different components and equipment would be needed for successful operation.

However, the following could be used as a guide for a general requirement at each TAFE centre teaching Integrated Manufacturing and related courses:

1. Provide a complete IM flexible teaching cell (similar to the TQ system) consisting of a CNC lathe, CNC Mill, two robots, visual inspection machine, AGV, two small conveyors and robot traverse unit. The specification of the equipment for this cell is as indicated in the section on machine specifications, Appendix F and other areas of this report.

2. One small teaching robot (similar to TQ's MA2000 or MA3000). Specification details can be obtained from the equipment included in Appendix F and the machine specification section of this report.

3. One small educational CNC Lathe and one small educational CNC Mill (similar to the Spectralight series). Specification details as per the machine section of this report and Appendix F.

4. One small lightweight engraving machine (similar to Roland's CAMM-2). Specifications are as per Appendix F and the machine detailed section of this report.

5. One small lightweight plastic film cutting machine (similar to Roland's CAMM-1). Specifications are as per Appendix F and the machine detailed section of this report.

6. One compact 3D Modelling Machine (similar to Roland's CAMM-3). Specifications are as per Appendix F and the machine detailed section of this report.

7. At least 3 IBM Compatible AT PC's for interfacing and controlling of CIM physical models. Specifications as per standard TAFE Computer Unit (TAFENET & CTU) details.

8. One CIM cell simulator device including software (similar to the Cimulator). Specification details as described in the machine detailed section of this report.

9. One PLC data communication and logic training board. Specification details as described in the machine detailed section of this report.

10. At least two Fishertechnik or Lego type kits for modelling purposes. Refer to Appendix F for details.

11. Two commercially available programmable logic controllers with built in power supplies.

12. A kit of components consisting of counters and timers, servo, stepper and brake motors, microswitches, photocells, proximity switches, pneumatic valves and solenoids, pressure and flow control switches, sensors, relays, reed switches, magnets, diodes, transistors, resistors and other suitable electronic components. This kit should include wire, cables (data and electrical), plugs, vero boards, bread boards, sockets, screws, lugs, solder and other consumables necessary for building electronic devices.

13. Various mechanical components, timber, plastic, nylon, etc. for building models to be supplied as required. This should be organised at the local teacher level for model and project construction.

14. One small train set for use as a model AGV and to teach logic control, etc.

15. One CIM software emulation package similar to the six modules available from Delmar Publishers Inc. Please refer to the simulation section of this report for details.

16. Suitable CAD/CAM software packages (such as AutoCAD, Quickdraw, VersaCAD, CadKey, SmartCAM, AutoCAM, MasterCAM) for interfacing and post processor communication direct with machine tools. Several of these packages are already available at some TAFE Centres and as such specification details are readily available from TAFE Computer Units (TAFENET & CTU).

17. Innovative students and dedicated teaching staff to develop and construct suitable physical models and projects.

All of the above are recommended for the successful teaching and application of CIM physical modelling. However, the suggested bare essentials at each centre should be items 2, 3, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 and 17.

Other devices and equipment could also be used, the list is by no means final. With the suggested package of equipment, together with innovation and dedication, Physical Modelling and Simulation could be successful utilised for teaching CIM and Mechatronic techniques and applications in a cost effective manner without the need for large industrial machines and packages.

23. CONCLUSION

This report has discussed many options which readers may or may not agree with. However, I trust that it provides some suggestions and ideas that stimulate thinking towards providing continuing education in integrated manufacturing in a cost effective, efficient and productive manner. TAFE needs to provide its customers with the best service it can within the constraints and limits of its available resources.

23.1 COMPUTER CENTRED SYSTEMS

The technical vision of the factory of the future is a plant operated as one big, computer controlled cell. A part can be computer designed (computer aided design) and its fabrication instructions can be generated by computer aided manufacturing (CAD/CAM). Then the correct material can be automatically selected and automatically moved through the computer controlled equipment necessary to fabricate and assemble it. Along the way, the part will be subject to computer generated test procedures. Link it all together and you have computer integrated manufacturing (CIM) or as I prefer just plain integrated manufacturing (IM).

Personally I do not think that for multiple products the true automated factory will result, certainly not in Australia. We will always need people as an interface within integrated manufacturing to make the whole thing work.

Limited instances of true CIM are working today (however, not in Australia yet), but a major software problem is linking all the various systems. In most companies, islands of automation operate independently of each other because the computer languages used by each cannot traverse the gulf between them, but headway is being made on that problem too. General Motors' Manufacturing Automation Protocol (MAP) is a long step toward developing a standard software interface between machines and systems.

Artificial Intelligence (AI) is a phrase denoting software that replicates features of reasoning; that is, it uses a set of decision rules to make limited judgements that go beyond just applying straightforward formulas to data. The best known laboratory versions are programs that play chess and win against all but the most expert human opponents.

In many companies, a materials system and an accounting system using computers is old hat. Order entry is by computer. Distribution inventories are controlled by computer. Sometimes all these systems are rolled together into one big system with exchange of data. Material Requirements Planning (MRP) is extended to link with capacity, accounting, financial, and logistics data, perhaps into one grand approach called Manufacturing Resources Planning (MRPII) which true integrated manufacturing requires.

The potential in such approaches is great if the people using them can surmount the problems. Computer systems do not correct basic problems by themselves. People do, and more can be wasted with computers than without them.

The aim, of course, is to add value to everything we do and eliminate costly waste. The key point is to recognise that computerisation of manufacturing provides technical possibilities to create waste as well as eliminate it. Managements sometimes incorrectly assume that automation is synonymous with manufacturing excellence. They are too much fascinated with the technology and too little fascinated with the totality of human development necessary to make it work well.

A computer is a tool. AI is a tool. A robot is a tool. Linked together, automation still consists of tools to be used wisely or unwisely. If the name robot did not suggest humanoid characteristics, robots might be better applied tools.

In the end, people make anything work. Companies striving to make IM work tell the same story. It takes leadership from the top and an integrated effort by all functions of the organisation. People must learn to think in a new way. Computer integrated manufacturing is really people integrated manufacturing. People and process development come first - pre automation preparation.

Computerisation alone does not identify waste, correct many quality problems, rethink how to structure the design of a family of products, set a marketing strategy, or make suggestions for improvement. It does not create a need for disciplined integration, such that these problems must be addressed, if they can be seen through all the systems surrounding them. If basic disciplines can be achieved in a simple way, the expense of automating the waste can be avoided. Automate where waste is eliminated by doing so.

23.2 REVOLUTION

Change and revolution in manufacturing are words that Australian business people have had trouble with understanding and implementing. However, our competitive situation is dire. Traditional manufacturing techniques will not work well enough any longer if we are to become World Class Manufacturers.

Small changes are not good enough, we need to adopt more radical approaches in both management philosophy and techniques. We need a "**revolution**" in our thinking, we need to be flexible, we need to be willing to change and above all we need to listen and communicate with all levels of our manufacturing enterprises.

Success in manufacturing today requires that Australian managers match overseas standards and become internationally competitive in terms of cost, quality and delivery.

Although yesterday's methods were quite successful, they are now very outdated. Use of techniques such as Just In Time (JIT) Manufacturing, Total Quality Management (TQM) and Integrated Manufacturing (IM) are essential if more Australian companies aim to compete with overseas firms both locally and abroad.

The main requirements for successful use of these techniques are willingness to change entrenched attitudes, coupled with patience, time and above all, a commitment from top management to make them work. JIT, TQM and Integrated Manufacturing challenges managers to re-examine their traditional approach to managing manufacturing firms and to embrace a new set of values involving a progressive reduction in the production costs and improvement in quality of manufactured goods. These changes cannot be made overnight.

TAFE can assist greatly in the challenge, however, TAFE must first accept the challenge. Using physical modelling techniques to introduce and train students in Integrated Manufacturing will provide industry with the much needed skills at a fraction of the cost that would be required using full size equipment.

23.3 TAFE MANAGEMENT COMMITMENT

If quality education, continuous improvement and the principles of TQM are conspicuously and continuously on the agenda and in the communications of top management, without the implementation of carefully planned innovations, the initiative is bound to fail. Lip service to any topic, especially quality improvement and integrated manufacturing, is the kiss of death.

What is important is what top management pays attention to, so top management must pay attention to quality in all areas. One method of embedding quality in the corporate mindset is to include it as a factor in the strategic planning and competitive analysis processes, where it will become a subject of major importance requiring continuing attention.

If TAFE and the various Governments work together to help develop a better trained workforce then Australia is on the way to becoming a World Class Manufacturer.

23.4 TRAINING

Hundreds of industrial companies now have many believers, in TQM/JIT and IM, around the world, but many are frustrated over the question of how to implement their beliefs.

WCM means continual and rapid improvement. Similarly, WCM implementation means continual and rapid training. In other words, the training effort must somehow be streamlined so that it doesn't keep progress on hold.

Everyone is a trainer and this is a must if we are to learn how to be world class manufacturers. In the past training has been an easy target for budget cuts; training budgets have long been lean in most manufacturing companies. There are exceptions: IBM, for example, have always maintained high training budgets. Aside from the inherent benefits of training, IBM has relied on training to make its no lay off policy possible. Training to avoid lay offs helps make people more versatile and better able to see the big picture, but those are long term benefits. WCM requires training for versatility and involvement in problem solving, which are short run, everyday benefits.

The message is clear:

1. Australian industry must inject substantially more resources into training to match the prodigious sums that WCM companies in Japan and West Germany invest in it.

2. Training is the foundation of implementation.

3. Training is everybody's business.

23.5 THE ROLE OF TAFE

The New South Wales Department of Technical and Further Education has been involved in teaching and training all levels of industry and business in not only the so called traditional Industrial Engineering techniques, but also in Just In Time (JIT), Total Quality Control (TQC), Manufacturing Resources Planning (MRP), Computer Aided Design (CAD), Computer Aided Manufacture (CAM), Computer Aided Engineering (CAE). Flexible Manufacturing Systems (FMS), Computer Integrated Manufacturing (CIM), etc. Not only are these subject areas part of Certificate and Associate Diploma Courses, they are also available as stand alone short courses.

Other States in Australia are also heavily involved in Integrated Manufacturing education. There are centres of manufacturing technology training in both Victoria and South Australia which have done a great deal in providing industry with the necessary training and education in Integrated Manufacturing and Total Quality Management. Western Australia and Queensland are also proceeding along the same path.

TAFE in New South Wales also provides fee for service courses conducted at organisations own premises. These have been very successful and around 12 TQC courses were run in 1988 in the Sydney area at such companies as GEC, Taubmans, Van Leer, ASEA Brown-Boveri and Castrol.

TQC, JIT, MRP and CAM courses are well attended in NSW at all colleges to the point that extra classes often had to be arranged to cope with the demand. TQC always has very large classes and continues to very popular with a demand that is hard to meet with the limited resources available.

This is a major problem; Australian industry and business are asking for training in the techniques which have made Japan and West Germany a success in the manufacturing world, but this has resource implications at a time when governments are trying to reduce costs. What is called for is a greater appreciation, by all parties, that if we manage effectively and invest in the training of the workforce, greater productivity will come.

State and Federal governments have a role in providing funding and resources to supply industry with the training and "tools" it needs if we are to achieve World Class Manufacturing. There must be a major priority given to training and educating industry and the business world in the new technology areas. TAFE has a major role to play in educating business and industry in the philosophy, principles and techniques necessary for our manufacturing survival.

A good example is the NSW TAFE Department, mainly through the efforts of a few dedicated teachers, which has done an excellent job in getting the message across and was the first TAFE organisation to start a course on TQC. However, we must do more; we must use a TQM approach to the teaching of all subjects. A start has been made in this area, with teachers from the Industrial Engineering Division of the School of Mechanical Engineering, in NSW, conducting TQC classes for other teachers within the school. Other teachers have conducted TQM seminars, at the college level, for all staff and a few pilot projects are being attempted. TAFE Departments in other states are also spreading the message.

I believe that we are currently teaching, in the majority of cases, the right material in our colleges, and are using the right tools. However, we are not teaching it in enough locations and the appropriate subjects should be taught at more colleges than at present in NSW and other states. We must focus more on the proper integration, orientation and technical support of these concepts in light of modern manufacturing systems and their special requirements.

TAFE needs to work on the knowledge base basis, that is to use the knowledge of its expert teachers, in each field, to train others and to ensure the experience and knowledge is not wasted and stored for future reference and use. TAFE, like industry, has valuable assets - its people. They must be utilised for the transfer of experience, knowledge and skills, especially in the latest technology areas, to students. In this way Australia can continue to work towards true integrated manufacturing.

Simulation techniques will help considerably in this area as TAFE cannot possible hope to provide high capital equipment in every area. Modelling, properly utilised, in conjunction with the skills of its staff, will achieve the same teaching objective as obtained by using full scale equipment.

A reliable method must be developed, and a favourable environment created with continuing education, to keep every student and employee up to date and practiced in the method. In this way we should obtain the driving power for managerial success in TAFE. There is a need for TAFE to impart knowledge and skills in the principles of managerial engineering and how to apply them for Australia to compete as a World Class Manufacturing nation.

23.6 THE ROLE OF INDUSTRIAL ORGANISATIONS

Consultants and industrial and management institutions all have a part to play in educating the business sector in learning and applying the principles and techniques of JIT, TQC, MRP, CIM, etc.

Consultants, such as the Technology Transfer Council which prepared a report on JIT Manufacturing Opportunities for the N.S.W. Government, have done much to present the benefits of JIT to the manufacturing sector. They treat each company as a project and design a programme to meet each individual's need. In this way appropriate techniques are used for specific companies and implemented accordingly.

Institutions and business organisations have also provided members' evenings with guest speakers (people from industry who have applied the techniques to their own organisations) and lecture training programmes. The following organisations provide knowledge and applications to industry and business:

(a) Institute of Industrial Engineers.
(b) Institution of Production Engineers.
(c) Institution of Engineers Australia.
(d) Australian Institute of Management.
(e) Australian Production and Inventory Control Society.
(f) Australian Organisation for Quality.
(g) Total Quality Management Institute.
(h) The Institute of Quality Assurance.
(i) Society of Manufacturing Engineers.
(j) Australian Institute of Engineering Associates.
(k) Standards Australia.

23.7 THE ROLE OF GOVERNMENTS

As the widespread application of particularly JIT, TQM and IM are now urgently required the State and Federal Governments have a vital role to play with respect to:

1. Awareness and Promotional Activities.
2. Development of Appropriate Infrastructure.

The experience of those already involved has been so profound, that the most important need now is to keep the momentum going.

Visible Government support is needed to convince many companies that they may not be here in five or ten years time if they don't adopt a different approach to their mode of operation.

Government funding and incentives are very important and together with the encouragement and endorsement of the "newer" techniques will go a long way to helping Australia become a World Class Manufacturer.

Of importance is the fact that Governments have the necessary consultation mechanisms in place to bring people together and thereby ensure effective introduction of what is often called a radical new approach to manufacturing.

Integration of TQM with Manufacturing Systems is important for World Class Manufacturing. It should be noted that the traditional tools of industrial engineering are still important and should be used, but we now find them imbedded in a larger environment of integrated sub systems. We are now moving from "islands of automation" and "functional fox holes" to data integrated systems. If we are to fully address the problems of integrated manufacturing, we must base both long and short term decision making upon consistent, accurate, integrated data.

We have, in the past, made excuses, rather than progress. We have thrived on chaos for far too long. An attitude of good enough is not good enough today, and if we do not change, the gravestones marking our industrial plants will read "We thought we were good enough".

A recent survey of manufacturers by the Australian Bureau of Statistics reinforces the bad news. Only a third of those surveyed had implemented Integrated Manufacturing techniques such as CAD/CAM, CNC and FMS. Only 15% practised Total Quality Management or Just In Time Production. This is a sorry story indeed and indicates apathy on the part of Australian manufacturers. If they are not prepared to take up the challenge then the future could be very bleak indeed.

One of the very best ways to improve productivity is through improving the excellence of everything we do, thereby eliminating waste and providing our customers with world class products and services.

We must get our act together and learn from the Japanese and others if we are to survive in the world market place. We have the tools and people to become world class manufacturers, so let's stop talking about it and work towards excellence as others have.

Improvements are like inventions. If we are motivated, and persistent enough to believe that we can accomplish something, then we will realise our dreams. History has proven this over and over. It is a challenge to the established structures, assumptions, old systems, and habits that I wanted to convey in this report. It is an imagination for the future and an optimistic thinking which will keep us moving forward.

I am optimistic about the future of Australian manufacturing and I am sure we can thrive on excellence rather than chaos. It is no good working towards the year 2000 if we do not change our attitudes, philosophy and techniques. We cannot wait any longer; if we do then we just won't be here in the year 2000.

Richard Baker
<< R & R DATA >>

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25. APPENDIX A - CIM TECHNIQUES FOR INDUSTRY AND BUSINESS

25.1 CAD APPLICATION SOFTWARE, INTEGRATION & COMMUNICATION

We will now discuss how CAD packages have developed from humble beginnings to the point where several high quality versions are currently available. We will also look at latest trends in software development and what the future holds.

25.11 HISTORY

Technical computing and its application in the building and construction, mining, textile and manufacturing industries is less than a generation old. It was in the early 50's that John Bennett, Professor Emeritus of Computing Science at Sydney University, performed the first structural analysis by computer at Cambridge University in the UK. We have come a long way since then with large complex advanced analyses being performed daily as a matter of routine.

Indeed, without these packages it would not have been possible to put a man on the moon, have advanced supersonic aircraft such as Concorde nor have the standard of intercontinental data communication that is available today.

The 50's saw the beginning of computer graphics and, indeed, in 1956 a US Engineer (perhaps the Jules Verne of CAD) prophetically drew out the elements of a CAD system. It can be seen from the slide that these show a remarkable correlation with the CAD systems of today.

However, it was to be over a decade before the first generation of commercial CAD Systems became available, with companies such as Computervision launching their first offerings onto the market in the early 70's. These, and even the far more sophisticated developments of the late 70's, are now seen as the dinosaurs, the leviathans, of CAD/CAM systems.

In 1977 the first wave of a new revolution started - that was the development, by Steve Jobs in his backyard garage, of the Apple I. This was the birth of the microcomputer revolution and, a decade later, Jobs has just launched his "NEXT" machine which will see a further revolution in speed and capabilities in the next decade.

Although Apple were the initiators of the first microcomputer, it was not until IBM announced the first PC in the early 80's that microcomputers became "legitimate". Since then the pace of development has continued exponentially and unabated with, for example, recently the "Personal IRIS" being announced with incredible real time graphics capabilities.

The early 80's also saw the introduction of the workstation concept for CAD, with Autotrol being the first company to use the Apollo as a platform for their software.

In 1982 the next revolution started - that was the announcement of the first version of AutoCAD. Just as the IBM PC became the de facto standard in the MSDOS world, AutoCAD was destined to fulfil a similar position in the microCAD arena. The reasons for this were the superb marketing of the product and the wide array of platforms on which it was made available.

Other products, such as VersaCAD and RoboCAD, would perhaps have provided a real challenge at this stage if they had had a similar promotional approach.

By 1985 it was becoming evident that most 2D CADrafting could be quite capably handled by micros, with the only limitations of this hardware being their database capabilities.

25.12 ACADS INVOLVEMENT

In 1981, when AutoCAD was barely more than a gleam in its founding fathers' eyes, the federal government published the first report on the application of CAD in Australian industry. ACADS was the author of the publication and 3000 copies were subsequently circulated, sold and widely distributed.

One of the primary conclusions, highlighted by the report, was that the key to effective productivity of an installed CAD system was the availability of "overlaid" front end application software. The CADrafting software was seen as the basic tool with which to build the total system. Numerous case studies, in different application areas and countries, have substantiated this. It is significant to note that AutoCAD has spawned hundreds of third party packages.

Also foreseen in 1981, but hardly realising its important role, was the future need for data exchange between CAD systems. Both national and international groups are devoting considerable resources to this and ACADS has provided input to the IGES standard. AutoCAD's DXF has itself become something of a "de facto" standard and Release 10 further improves its communications capabilities.

25.13 APPLICATION SOFTWARE

Over the past 20 years a vast amount of application specific software has been developed, primarily in languages such as FORTRAN and BASIC and, more recently, in PASCAL and C. Much of this software is now an everyday tool of trade in professional practices but the user interface to most of them still remains primitive.

It is certainly far less sophisticated than those which many users are accustomed to with packages such as LOTUS 1-2-3, DBASE and word processing packages such as MSWORD, WORDPERFECT, SPELLBINDER & WORDSTAR. Hence, many users are looking to simplify the method of entry to their application packages, to make them far more user friendly and integrate them with the current generation of CAD software.

This will also have the added benefit of enabling data to be reused: it must be remembered that the initial entry of data into any computer system is costly and, it is only when that data is multiply reused, that the real productivity and cost savings eventuate.

Which software should be chosen for this integration process? There are tens of thousands of programs existing and it is important that only the best of these be selected for integration. In this respect ACADS', and other similar overseas organisations', Comparative Reports on Software Evaluation are invaluable in "picking the winners".

25.14 METHODOLOGY OF INTEGRATION

Freedom of choice is one of the hallmarks of democracies and, although it would be far simpler if there were only one CAD package which everyone used the real world decries that this should be so. It is hence very important that any integration ensures that the application software is not inexorably tied: rather that there be a clearly defined system interface. This will also allow the application software to be maintained as a separate entity by the authoring organisation, which can ensure that a professional level of support and documentation are maintained.

It must also be recognised that there will be an increasing need for direct data exchange between CAD systems themselves and to that end the availability of direct translators, such as those supplied through OCTAL, and neutral format (IGES) translators is very vital.

It is significant to note that in the Standards Australia, together with ACADS, have launched IGES-4 as a National Standard. This year a 2D subset for the A/E/C Industries will also be published by our National Standards Association; this will lead to simpler transfer of information within the industry. This subset has been developed for Standards by an ACADS Working Group and has drawn heavily on contacts through FACE, the International Federation, in both the USA and several European countries. The good news is that we all seem to be heading in the same direction!

25.15 THE FUTURE

2D CADrafting, and to some extent 3D CAD modelling, is now an everyday tool of trade. However the question of product databases, classification and real "modelling" are the challenges for the future. This is where the proposed ISO-STEP Standard (and corresponding US PDES) will emerge in the 1990's as the key factors.

An ISO Group, primarily European based, is currently working on the whole question of "information protocol" for the building and construction industry and tackling the whole question of building modelling. This will be particularly necessary as robots are introduced to the process - both for the construction and routine maintenance of the buildings of the future. A new international journal "Computer Integrated Construction" has recently been launched from the UK and will provided up to date information.

Future developments are limited only by our imagination - a real challenge to us all.

25.2 HOW DOES CAD FIT INTO MANUFACTURING?

How can CAD interact with other software packages to build a more complete manufacturing system?

CAD is not just a drafting tool, but has uses in areas ranging from product design, to NC programming, purchasing, production and even marketing.

By interfacing CAD with other software tools the full versatility of integration starts to be realised. One must look in greater depth at the approaches that may be taken when creating a computerised system that may be used to generate NC programs from products that have been designed or drawn in a CAD package.

By using a computerised system to generate an NC program that relates directly to the drawing of a product guarantees greater accuracy and quality in manufacture. It also has advantages in reduction of material wastage, response times and the overall cost of the final product.

To those manufacturers that take a superficial view of CAD and see it only as a drafting package for preparing product drawings - check your AIM.

CAD is a tool, it is not a magic wand. Companies cannot invest in CAD or CAM or CIM and somehow expect because the dollars have been spent economic miracles will take place. Bad products will not increase sales, poorly trained workers will not produce top quality products, scrap, waste and high warranty costs will not provide increased profits.

New high technology tools are becoming increasingly available to our manufacturing companies, but unfortunately a very high proportion of our manufacturing companies are not in a position to make the best use of them.

The problems are many and varied, but I hold total quality control to be the most important and powerful tool available to industry both yesterday, today and tomorrow.

To achieve total quality control the whole company including all the King's men must be involved.

To manage quality you must have facts not opinions or best guessed. To collect and store these facts one needs many things and one of the most important is a good management system.

I believe that Australian companies will not and cannot compete on a world scene without making full use of the latest technologies. Manufacturing companies must introduce CAD/CAM with NC and CNC machines as well as manufacturing philosophies embodied in systems like Just-In-Time where appropriate. In coming years it will be commonplace to see PC's on every office desk and increasing numbers on the production floor. We are already seeing the paper tape being eliminated with direct connection of PC's to NC machines.

The thrust behind all this is to obtain productivity improvement by the elimination of NON-VALUE ADDING steps in the production process and by getting the facts right, being able to control the capacity to manufacture and the quality system.

This may all appear straight forward so where is the problem?

Do you try and make the system fit the business or do you make the business fit the system? The truth is you can't do either until you know:

(a) How the company operates.
(b) Ensure that the way the business operates is effective.
(c) Ensure that it continues to operate in a repeatable and effective manner.
(d) Design a system to automate this process.
(e) Train employees/operators to use the computer systems and understand the disciplines required.
(f) Use the data now available to further understand and improve the process.

The amount of detail about the management/manufacturing process required to carry out this task is massive. You must study the process, in particular the administration process, sales, service, goods received and despatched, material handling and finally the ordering of material.

From the intense study of the company and analysis of how it operates, you must create a number of management policies which document the "current best way" of running the system - you want people totally involved but computers are expert systems and certain disciplines must be maintained.

In a JIT environment, for example, you cannot afford to come unstuck with quality or material supply, if you do, the manufacturing process comes to a halt. The resources which are consumed by companies to administer the buying and selling of goods is very wasteful and vast savings can be obtained by a concerted effort in this area.

It is possible to order material in the correct quantity today from the triggering of a Kanban card to the faxing of a computer generated order in under 5 mins.

When the goods are received it is possible to enter them (paperwise) in under 5 mins and when the invoice is received from the supplier the creditors department, by checking the screen for order/goods received/etc., can process the order for payment in less than 5 mins.

Analysis shows on the above process alone, that many companies are running at 50 to 80% failure rate per invoice, because goods are not supplied by due date and need to be rescheduled (sometimes many times), goods delivered may not match the requirements of the order, etc.

In most non Just In Time companies much of what I have said lies hidden from view because of excess stock, lack of good communication and data records and the breaks in the material flow path.

Once a total integrated system is installed a strong discipline is required to stop operators cheating the system. Staff will tell you it is not economically viable to try and solve the problem.

Why?

Why would someone do that? I'll tell you why, because its the easy way out, appears in the short term to be cost effective, its allowed to happen by poor supervision, lack of training, bad management through lack of accurate information. To reap the benefits of a integrated system you need to work closely with your suppliers/employees otherwise the system will not deliver all the benefits you should be receiving.

With the data now available, you can obtain performance charts of suppliers who deliver on time, who has the worst record for price increases, records of quality defect returns etc. Faster response to your own warranty problems and feedback to engineering and production to eliminate the problems.

You can obtain some massive productivity improvements from graphical CNC programming and use of CAD, but I now believe the benefits to flow from real control of purchasing, quality and elimination of waste in administration, can make the improvements flowing from reductions in the production time, pale into insignificance.

Too much effort is placed on "reducing the time" we spend Value Adding in the interests of productivity and "too little" effort eliminating the non-value adding processes.

Designers cannot reside in ivory towers with their drawing boards or CAD systems, they must get down on the production floor and talk to production engineers and workers, there is a lot to be learned. Products must be designed for manufacture and therefore capable of being manufactured by the people and the machines in the company. CAD/CAM can help this process in a most powerful manner.

World competition has not only elevated quality standards to new heights, it has forced manufacturers to look at the whole process including design but most importantly, the way we think.

A recent quote by Mr. Doug Lewis of General Dynamics "The Goal of CIM is Simple : Getting the right data, tools, parts and skills to the right process at the right time. The data is the toughest". I have a comment on that, I agree data is tough but in Australia getting the correct skills can also be pretty tough.

Expert systems tend also to require expert people too.

25.3 CAD/CAM - AN OVERVIEW

A brief formal definition of CAD/CAM is the application of computer technology to any or all aspects of production from design through to fabrication.

To be more complete, we could break it down a little further. CAD describes the use of computers to aid in the creation of schematics, plots and other drawings which are of sufficient accuracy to be used to guide the production of manufactured goods, components or structures.

CAM, on the other hand, describes the use of computers to produce data employed to assist in or control all or part of manufacturing processes. These processes include such things as numerically controlled machine tooling, parts programming, and robotics.

By putting the power of CAD and CAM together, industry has a formidable production tool that can not only add speed to most manufacturing tasks, but can make them more efficient, more accurate, and more versatile.

There is no easy way to be more succinct about what CAD/CAM means. It is a very complicated business. It is hard to get a firm handle on this technology, and most people end up getting thoroughly bogged down in tedious definitions and incomprehensible jargon.

However, if we just look at the technology we can begin to see that the world of CAD/CAM is, at its roots, essentially visual. It consists of computers and the pictures they can draw. At that level it seems straightforward.

The complications come in the application of computer pictures to practical industrial problems. After all, when we say CAD/CAM is "visual", we imply many things. Creativity, for instance, is one such implication. As much as anything, it is creativity that has given rise to the entire CAD/CAM industry. The ability to use computer pictures to create useful items, drawings, designs, illustrations, is what has spurred additional research and developments in CAD/CAM. That research has not slowed.

25.31 Extending Our Vision

Developing new tools is second nature to human beings. Perhaps the most important of all our new tools is the computer. The proof of that can be found by noting the myriad of ways in which we put computers to use.

CAD/CAM is just a small segment of the computer industry, but its among the fastest growing. The potential for applying computers to manufacturing and draughting tasks is still not fully defined, let alone realised. The future of CAD/CAM is bound to be rich and various. Australia is fervently pursuing it in many industries as a stepping stone to full CIM operation.

Using computers to produce and manipulate pictorial data augments our modern penchant for all things visual. Visual media are a powerful means for disseminating information, expressing ideas, and advancing opinions.

25.32 CAD/CAM Vs. Computer Graphics

To get a precise understanding of what CAD/CAM is, we must also be aware of what it is not. It is valuable, therefore, before we begin to fall into a semantic triangle, to understand the meanings of and the differences between the terms "computer graphics" and "computer aided design/computer aided manufacturing". In common usage the terms are often synonymous.

"Computer graphics" is the more general term. It refers to the entire branch of computer science which deals with the creation or modification of pictorial data for any purpose. "Computer aided design/computer aided manufacturing", on the other hand, refers more specifically to the application of computer graphics to problems encountered in draughting or in the support of production processes. By extension, it also entails things beyond computer graphics, such as numerical control, group technology, and data base management.

More important, CAD/CAM also implies a technology in which there is an interactivity between a person and a machine - that is where the computer operator and computer system communicate in meaningful ways. This is a singularly important concept.

The distinction is useful because it provides a convenient way to differentiate between two entirely different ways of thinking. Computer graphics is a generalised, multi disciplined approach to creating any kind of image. CAD/CAM, on the other hand, is an ordered, comprehensive application of graphics technology to a specific task - product development. In either case, they are decidedly visual disciplines. A person and a machine work together manipulating lines and space and form and colour and geometry and in doing so create something new.

25.33 A Tool for the Mind - An extension of our Hands

Perhaps the simplest way to regard CAD/CAM is as a tool for the mind rather than a tool just for the hands. It extends our mental abilities, makes the creative part of design work faster and more visual, allows us, in fact, to see what we are thinking. To this extent it may even enable us to extend our imaginations into areas never ventured before. This is not an overstatement, but make no mistake - CAD/CAM is, after all, a tool, and only as good as the people who use it.

Computer graphics allows us to draw with a computer rather than a pencil. However, CAD/CAM allows us to do more. It allows us to draw and then to evaluate what we have created. This is very important extension to simple graphics, because it is in the evaluation that the creative talents of the engineer and draughtsperson can be most revealed.

Yet while an integrated CAD/CAM system may be new and unusual, the tasks required of it are much the same as those required of engineering and draughting tools in use half a century ago. CAD/CAM requires no new engineering or design concepts. Design analysis, mathematical and mechanical modelling, draughting, documentation, process planning, machine tooling, fabrication, and group technology are all old concepts and were around before CAD/CAM became established in the marketplace.

25.34 The Power of Integration

The real power of CAD/CAM as a design tool, however, is larger than simply speeding up the design cycle. CAD/CAM also has a built in ability to integrate all the tasks related to the entire design manufacturing process. By coordinating both the tasks and the data generated by those tasks, the CAD/CAM system is a ready made focal point for the entire design and manufacturing operation.

By breaking down these tasks even further we can see how this integration might work. Consider the individual tasks that go into taking a product from idea through production. Take as an example, designing a glass mould.

The company is in need of a mould design which can be used to manufacture a wine glass. Using the specifications required by the product design, the mould designer first creates a mathematical model of the mould and of the finished wine glass. By doing this, the designer can account for the important design considerations of the mould at once and then analyse the possibilities online. With the entire product depicted in purely mathematical terms, the designer can consider fluid flow, stresses, the implication of applying heat and cold, densities, as well as the more visual properties of complex curves and surfaces, three dimensional space, and intersections. The CAD/CAM system totally eliminates the need to build a physical model of either the wine glass or the mould.

When the mould designer is satisfied with the mathematical model, he or she can proceed to build a mechanical model of the wine glass mould. The mechanical mould represents a practical application of the information generated by the mathematical model. It takes into account such real world considerations as commercially available materials, standard manufacturing tools, and their tolerances. Moreover, the part image (in this case, the finished class) and the mould image can be displayed on the workstation screen simultaneously so the designer can compare the two visually.

Next the designer translates all this information into standard engineering drawings. The drawings are a record of all the physical attributes of the design and might well depict the mould from a variety of angles. The system will help create these varied perspectives automatically.

There is a danger in all this, however. The object in automating the design process with CAD/CAM is to create engineering drawings that are useful but not redundant. By speeding up the ability of the designer to create drawings the CAD/CAM system may encourage a proliferation of unnecessary drawings. However, if these drawings are grouped together in families according to the type of part depicted or according to the perspective depicted, the system can actually reduce the number of new designs being created,

The efficiency of the system lies substantially in how it is managed. through proper management, designers will be able to find existing drawings that will fit the needs of their current project. In this way, design retrieval functions are streamlined and costs are further reduced.

25.4 A PRACTICAL APPROACH TO INTRODUCING CAD/CAM TO THE AUSTRALIAN MANUFACTURING INDUSTRY

The Australian Manufacturing Industry is presently going through a regrowth and learning phase brought about by the increased demand for Australian made products.

Manufacturing companies fall into three main categories relating to CAD/CAM (new technology).

1. **Experienced Users:** Companies that have been using CAD/CAM technology for some time and developed a large, skilled, efficient team to implement it.

2. **Limited Experience:** Companies that have some CAD or CAM equipment with limited experience in the area, probably experienced with CNC, but new at CAD.

3. **Future Users:** Companies producing goods with old technology equipment without experience or knowledge of CAD/CAM.

Experienced users can be divided into two sub groups:

(a) A company having a parent company overseas where development knowledge of CAD/CAM is passed back to the Australian firm, e.g. Ford, General Motors, etc.

(b) Firms that have made a commitment to lead Australia in the high technology manufacturing area, e.g. Diecraft Australia, Bell Dies, etc.

These two sub groups have invested millions of dollars in CAD/CAM hardware, software, and the gaining of necessary experience to operate and become technically efficient and profitable in the manufacture of their products.

This experience has been gained over the past ten years, usually on main frame or super mini computers. Staff required to operate in this category are top level personnel who have been through a very expensive learning curve to become proficient.

It would appear that the less experienced categories have an immense task if they emulate the more experienced companies. However, with the advent of powerful micro computers, and the development of relevant software in the past three years, the situation is somewhat less arduous. Micro Based CAD/CAM is a solution.

25.41 WHY MICRO BASED?

Approximately 90% of the Australian manufacturing companies have less than $20 million turnover. This means the solution used to introduce the new technology must be cost effective.

1. Mobile Workforce

   A large percentage of the Australian workforce moves from company to company, therefore the micro based CAD/CAM system which has a shorter operator learning curve than other more expensive systems, has a distinct advantage when it comes to attracting or training replacement staff with the required skills.

2. Computer Hardware

   Current trends and the speed of development in the computer hardware industry are showing that whatever computer is purchased today will be totally outdated in less than three years. Faster computing speeds and huge storage capabilities are happily operating from ever decreasing size boxes.

   Current state of the art micro computer workstations can be purchased for less than $15,000 with some having speeds reaching 6 MIPS, 25MHz processing, RAM figures only fantasised about a few years ago, and screen graphic resolution of 1024 x 1024 or better.

3. Hardware Obsolescence - A Fact of Life

The lower initial cost of the micro computer based workstation will allow the computer hardware to be thrown out after three years, or at the least, parked into a less demanding role in the company, such as the Accounting Department.

The selection of micro computers will allow a company to update frequently into the future and remain current with the degree of flexibility required. Micro computers are a good low cost starting point and if higher capabilities are necessary, they can be linked to a mainframe computer.

4. Maintenance Costs

The maintenance costs on a non-micro computer are such that a company could afford to buy at least three or four complete micro systems each year.

25.42 MICRO CAD/CAM IMPLEMENTATION

Due to the rapid developments in computers over the past ten years there is a low cost solution taking practical small steps to become productive with CAD/CAM.

(i) Analyse needs before talking to suppliers. Ask yourself these questions (or find the answers to them):

* What company products could be manufactured more efficiently using computer numerical controlled machine tools?

* What productivity improvement and cost saving could be expected?

  - Smaller inventories
  - Smaller economic batches

* What method is the company currently using to produce store and modify component drawings?

(ii) Introduce a Micro Based CAD/CAM System

Talk to other uses. Send staff on training courses. Ask the suppliers to see a demonstration of a complete operational system, not simply CAD or CAM. Then purchase a micro based CAD/CAM system.

(iii) Train Suitable Staff

Select suitable staff to be trained on the system from the drawing office or middle level trade background. Train more than one team. The optimum combination is a person from the drawing office partnering a person from the shop floor.

With suitable operatives they will tend to train each other from their respective strengths. The actual training should be undertaken at both a recognised training centre, such as TAFE, and on the job. However, this may be subject to availability.

Also middle level management should gain awareness training on the system so that they will be more supportive. Information and experience gained from the training should be incorporated in the selection of the machine tools.

(iv) Selection of CNC Machine Tools

Go through a similar process as for the selection of CAD/CAM systems. This is the most expensive step and should be planned and implemented correctly. The micro computer to machine tool communication link should be set up and tested during this stage.

(v) Tool Setting Procedures

A common tool setting and offset procedure should be adopted and strictly adhered to throughout the company. Any small changes in tool specifications should be notified to all relevant sections immediately.

(vi) Time to Become Fully Productive

Transition Phase: Change in procedures and the time taken to learn the new procedures will result in a temporary reduction in productivity. It is essential for management not to pressure their staff to become more productive during the experience gathering period.

The natural tendency to overload staff in order to achieve immediate monetary returns from the expensive equipment must be avoided to prevent equipment and product damage.

Time should be allowed for the teams to become fully competent with the new equipment. Encouragement, understanding and participation by management is essential during this early phase. As the people operating the equipment gain more experience and confidence, improved productivity will follow.

25.43 SELECTION OF SUITABLE MICRO BASED CAD/CAM SOFTWARE:

1. SOFTWARE

The main points to be considered are:

- Popular, widespread use software.
- Possible emergence of user groups.
- Easy to use.

- Basic and extended training available locally, and at reasonable cost.
- The package should be capable of covering future company strategies.
- An interactive artificial intelligence language is a must so that effective CAM software can be supported.
- Local technical support.
- DXF DXB & (IGES?) neutral files available in order that interaction with other systems can be achieved if desired.
- Support third party "add on" software.
- Ensure ease of access to updates at reasonable cost.

2. MICRO CAM SOFTWARE

The key features to consider are:

Easy to use.
- Quick to operate and learn.
- Basic and extended training available.
- Development and technical support in Australia.
- Automated rough cut metal removability to desired shape.
- Finish cut option.
- Tool offset compensation for flat or ball nose cutters on sloped or radius surfaces calculated and set in CAD system (rough and finished cutter paths generated).
- Access to the machine tool canned cycles.
- Sub program capabilities.
- Machine tool communications.
- Micro turnkey type system where the software is customised to suit your needs, or will you be responsible for the extensive tailoring required before it becomes productive?
- No other language to learn.
- Pre production cutter path checking facilities.

25.44 CAD/CAM PROGRAMS FOR HOME OR OFFICE

The lower cost of Micro CAD/CAM systems makes it possible for a contract tool designer or consultant to produce design drawings and the machining programs from the home or office. The machining instructions can then be transferred to a local contract tooling shop's CNC machine where the die or component will be manufactured.

Communications between the two parties is essential and tool and machine setting parameters known by the tool designer.

25.45 TAKE CARE WHEN SELECTING THE CNC MACHINE TOOL

Traps for the Beginner:

When a company is purchasing a new CNC machine tool for the first time, the management and staff will only gain experience in operating the machine once it has been installed.

At first, just operating the machine at the base level is enough to cope with, as the operator's competence improves to a level where the machine's option capabilities can be tried, it is often found that the options were not part of the machine purchase. This is like purchasing a pushbike with one pedal missing, and when you try to purchase another pedal you may be told it cannot be fitted after the sale.

1. Always purchase a machine with all the options and memory size that will be required in the future.

2. Check price differences on quotes for the same machine that all options and memory sizes are the same.

3. Make sure that the controller has appropriate communication port to allow information transfer to a CAD system.

25.451 CNC Machine Maintenance: Who's Fault?

CNC machines are generally manufactured with different companies being responsible for the controller, electrical switch gear and the mechanical section. This makes for an interesting situation when a problem occurs.

The solution sometimes is to communicate to all the companies involved that you don't care who's fault it is, you just want the machine fixed. This may require bringing the maintenance technicians from all companies on to the site at the same time.

25.46 OVERVIEW OF CAD/CAM INTRODUCTION

It is recommended that new entrants into the CAD/CAM hi-tech area should do so by way of micro computers.

These micro based CAD/CAM systems should be introduced using small, practical steps which include operator and management training, tool setting procedures and the time allowed to become experienced. This will yield improved productivity.

By the time the company is experienced and ready for the step towards a larger system, current trends would indicate a larger system may not be necessary, because with the rapid developments taking place in both hardware and software, the power and capability at the micro computer level will handle even the most complex tasks in the not too distant future.

For companies already experienced and successfully using a mainframe or mini CAD/CAM system, the expensive learning curve and transition phase is behind them. The direction to take in the future, considering the rapid developments taking place in computing hardware and software, would be to introduce stand alone micro systems to complement their mainframe. The micro systems would free the mainframe to be more productive at solving extremely complex tasks.

Those companies about to introduce CAD/CAM are in a fortunate position because recent developments in computer hardware and software has reduced the costs involved.

25.5 NC PROGRAMMING: CURRENT AND IN THE FUTURE

Numerical control has come a long way since the early days. This section will discuss the direction NC and CNC has followed from its beginnings to the current day and its future utilisation in the Integrated Manufacturing environment.

25.51 EVOLUTION OF NC

In the early days of the industrial age, machine tools were manually operated. The resulting process was often slow and of reduced accuracy.

This century has seen machinery become more automated, thereby reducing machine-operator intervention in the manufacturing process. As automation increased, machines that may turn out 20,000 components per day, will generally be able to produce only a limited class of components. Until recently prototypes and low volume components were produced by manually operated machine tools.

With the advent of new hard-to-machine materials and requirements for very high tolerances, the best human operators have reached the limit of their abilities. These requirements together with the need for component flexibility, have lead to a form of automatic machine control. Known by the generic name, Numerical Control (frequently abbreviated NC).

25.52 NUMERICAL CONTROL

NC is not a kind of machine tool but a concept of machine control whereby numbers, letters and symbols are used to convey instructions to the machine. NC is a technique for controlling a wide variety of machines. For this reason NC has been applied to assembly machines, inspection equipment, and metal cutting machine tools (to name only a few applications).

NC is a method of controlling an operation, and the instructions for control are in the form of a permanent process control records that may be utilized any number of times at a later time and date.

The numerical control system forms a communication link which has many similarities to conventional processes. Symbolic instructions are input to an electronic control unit which decodes them, performs any logical operations required, and outputs precise instructions that control the operation of the machine. Many NC systems contain sensing devices that transmit machine status back to the control unit. It is this feedback that enables the controller to verify that the machine operation conforms to the symbolic input instructions.

25.53 COMPUTERISED NUMERICAL CONTROL

Computerised Numerical Control (CNC) is a numerical control system wherein a stored computer program is used to generate some or all of the basic numerical control commands from more generic NC input instructions. The difference between conventional NC equipment and CNC is the addition of the computer as part of the machine tool controller.

25.54 CAD/CAM

Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) are the functions of using a computer as a tool to aid in the design and manufacturing processes. The design stage involves the use of a computer program to both generate and evaluate a database which is able to graphically depict the part to be manufactured. The CAM stage, using additional software, and generally additional user input, acts on the database to produce the required NC code to manufacture the part on the NC controlled machine tools.

Distributed Numerical Control (DNC) can be defined as a system connecting a set of numerically controlled machines to a common computer storage media. The computer system looks after data storage, data retrieval and sending to the various machine tools. The NC data can be sent to a machine tool as a complete program or distributed on demand as the machine tools require the data.

Using a CAD/CAM system to generate any required NC data involves a number of steps. As a first step, a geometric database is generated. This geometric database can then be used to generate a file generally containing APT like statements which relate to machine tool cutter locations. For this reason this file is termed a load of tools, spindle speeds and turning on coolants, may also be included. A post processing program with the aid of a machine data file converts the cutter location file data to the appropriate NC data. The machine data file is machine specific data file so that a general post processor may be used to prepare NC data for any number of machine tools.

25.55 CAD/CAM MACHINING FUNCTIONS

A range of procedures are available for generating cutter location files. They include:

- point-to-point machining
- drive curve machining
- planar milling
- surface machining

Point-to-point operations are an easy way of creating tool path data for functions such as drilling, tapping, boring, counterboring, and reaming. Other uses might include spot welding and riveting operations. The points at which the operations are to be carried out are selected from the graphical database. Certain parameters for say a drilling operation may be saved in a cutter location file cycle command. These cycle commands are readily converted machine tool cycle commands.

Drive curve machining provides a way of generating a tool path using a number of geometric curves to control the movement of the cutting tool. The cutter motion is generally controlled in discrete steps along individual curves. With the definition of a planar part surface on which the tool makes contact, the use of a drive curve along which the tool moves and the definition of a check curve which may be used to limit the movement of the tool, the tool path may be constructed of a series of discrete tool movements. Previously defined check curves may become current drive curves. End of curves are also used as intermediate tool stopping positions.

Planar milling can be used to provide multiple tool passes on a planar surface. Geometric curves or special boundary entities are used to limit the tool movement. Both pocketing routines inside the defined boundary or profiling on, inside or outside the boundary are also possible. Depending on the algorithm used, additional avoidance pockets can also be defined such that the tool does not enter into these areas.

Surface milling can be applied to any geometric surfaces. Various algorithms are used for determining how the cutter will move over the selected surface(s). Most of the algorithms follow a common procedure. This includes the determination of a set of points on the surface (or off the surface by a preselected amount of stock is required). The tool programming point can now be determined through the use of surface normals, tool axis vectors, and tool geometry. Any gouge checking procedures can then be applied between the tool in its current surface contact position, other regions of the surface and adjacent surfaces. In moving the tool from one contact point to the next contact point through a straight line, the surface which need not be flat, may also be gouged. Any predefined intol/outol may be taken into consideration by adding intermediate surface points and/or of setting the surface contact points along surface normals to meet the required intol/outol values.

25.56 CAD/CAM MACHINING DEVELOPMENTS

It is questionable if we will ever reach the capability where a graphical database for a part to be manufactured can simply be presented to the machining module of a CAD/CAM system and expect the complete cutter location file and/or NC data file to be generated. Each machine shop tends to cut similar parts somewhat differently. There is no best way to cut any particular surface type. The best method to machine a surface depends on a number of factors such as how the surface is orientated, how accessible the surface is and what is the machine tool configuration. For most manufacturing operations, tolerances, feeds, spindle speeds, depth of cut, clamping and a dozen other criteria will always need to be specified.

25.57 NC DATA REVIEW AND EDITING

CAD/CAM systems can reduce the time spent on rework and machine down time by allowing programmers to view and edit the tool path graphically. The ability to see the tool move around the part and check that there are proper clearances between tool and fixtures has saved many a programmer's nerves.

Displaying the tool moving around the part is one form of checking. Another more useful method would be to display the resulting surface that would be left after the tool path has been replayed on the graphics screen.

After the NC data has been generated some editing is sometimes still required. Again it would be useful if the NC data can be compared to a graphical model so that any changes made can be verified of the machine tool.

Both methods of editing should allow the simultaneous display of the tool graphically displayed on the part and the relative line of code in the cutter location file or the NC data file.

26. APPENDIX B - ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS

26.1 ARTIFICIAL INTELLIGENCE

Artificial Intelligence (AI) is a scientific field concerned with creating computer systems which can achieve human levels of reasoning. More precisely, AI is the branch of information science that focuses on developing computer programs able to perform tasks normally associated with intelligent human behaviour.

This is to be achieved through a collection of computer supported techniques emulating some of the natural capabilities of human beings. Examples are knowledge representation, inference capabilities, problem solving, engaging in dialog, and understanding natural language, as well as speech recognition and synthesis, computer vision, and robotics.

Artificial Intelligence can also be defined as a branch of information science whose objective is to endow machines with reasoning and perceptual capabilities. Characteristic of AI is that it:

1. Manipulates symbols rather than numbers.
2. Makes inferences and deductions from information at hand.
3. Applies knowledge in solving a problem.
4. Uses its knowledge and its associated rules to prune the exponential growth occuring in complex real world situations.

Today the focus today is on ***knowledge engineering.*** Knowledge engineering is the process of capturing and representing knowledge in a computer system. It includes acquisition, learning, knowledge directed database specification, and design methodologies. Knowledge based environments encompass such issues as decision support systems, CAD/CAM, robotics, and VLSI (very large scale integration) design.

A rule based system is able to reason about its own search effort in addition to reaching decisions about the problem domain. That calls for a new way of structuring based on four areas:

1. *A knowledge bank* containing domain facts and rules associated with the problem.

2. *A inference mechanism* acting as the control structure for utilising the knowledge bank in search of a solution to the problem.

3. *A global database* keeping track of input data, problem status, and the relevant history of what has been accomplished so far.

4. *A dialog engine* able to engage in person - machine communication, guide, extract answers, and present results.

Knowledge engineering is the applied science side of artificial intelligence.

The top challenge in this applied science effort is *knowledge representation:* from *knowledge acquisition* to the development of *rules* and the facilitation to be provided by the *interactive use* of those rules. The latter is known as *knowledge utilisation*. Knowledge representation is presently a rather manual process of working with experts. Therefore we seek automatic methods of transferring and transforming knowledge into computer representation.

Knowledge engineering deals with *know how* which is inherent in the development of several processes, the most important being:

* Learning systems.
* Knowledge directed specifications.
* Design methodologies for rule based systems.
* Symbolic computing approaches.

Just because many tasks cannot be automated by using conventional computing techniques, they require the capability of symbol manipulation. Symbol manipulation calls for valid, tested approaches provided by knowledge engineering, which is also instrumental in constructing inference paths for decision, explanation, and justification.

Knowledge engineering describes the process under study and outlines its rules. Such work reflects the often neglected fact that there is a fairly close correlation between the kinds of knowledge existing in an organisation and the sort of problems faced in conducting the organisation's business. Much of the work on knowledge engineering involves the acquisition of know how. It starts with the capability of extracting knowledge from experts, mapping it in computer based form, and then using it.

26.2 EXPERT SYSTEMS

Expert systems are playing an increasing vital role in many computer systems. Yet there remains a lot of confusion about what an expert system is and when it can be applied. This type of software provides the tools and techniques to capture human expertise and automate human reasoning.

Conventional programs tell the computer what to do; with expert systems, we tell the computer what we know. If a well defined set of instructions can be prepared for obtaining a solution, then traditional programming is in order. For these systems, the programmer or analyst gives the computer a detailed road map for performing repetitive tasks with different data. If, on the other hand, we have no step by step method and the solution relies on a large body of knowledge, an expert system is called for.

Expert systems approach ill structured problems the way people normally solve them: by matching facts about a given situation against a knowledge base to reach a conclusion.

They consist of three basic parts: a working memory or database containing facts about the current situation or problem, a knowledge base containing information based on the expert's experience and knowledge about the specific problem and an inference engine, which is the mechanism for using the information in the database and knowledge base.

For most expert systems, the knowledge base is rule based. That is, it comprises a set of if-then statements, or rules. Each rule consists of one or more conditions and a conclusion. If the facts about the current situation in the working memory match the conditions stated in the rule, the rule is "fired", and the conclusions of that rule are added to the facts about the situation in the working memory.

The inference engine, also called a rule interpreter, examines facts about the situation in working memory and the rules in the knowledge base. It identifies the rules to be fired and determines in what order the rules will be implemented. The inference engine also is responsible for telling the user what rules have been fired and how the system arrived at its conclusion.

Inference engines have two basic control strategies: forward chaining and backward chaining. For example, assume the following knowledge base:

Rule 1: If (animal flies) and (animal is a mammal) then (animal is a bat).

Rule 2: If (animal is a bat) then (animal is nocturnal).

Rule 3: If (animal has hair) then (animal is a mammal).

Suppose that the facts entered into working memory are "animal flies" and "animal has hair".

Forward chaining involves searching the knowledge base to determine which rules can be fired based on facts in working memory. As we know that "animal has hair", Rule 3 can be fired, and the conclusion that the "animal is a mammal" can be added to working memory.

Due to the fact that we know that "animals flies" and "animal is a mammal", Rule 1 can be fired and that the conclusion "animal is a bat" can be added to working memory. Lastly, because "animal is bat" is true, Rule 2 can be fired and "animal is nocturnal" can be concluded.

Backward chaining involves proving a hypothesis is true. Assume for the above illustration that the goal is to prove the "animal is a bat". The conclusions in the knowledge base are searched to identify the conditions for "animal is a bat".

Rule 1 indicates that "animal is a bat" if "animal flies" and "animal is a mammal". As "animal flies" is known to be true, the conclusions in the knowledge base are searched for conditions for "animal is mammal".

Rule 3 indicates that "animal is a mammal" if "animal has hair". As "animal has hair" is known to be true, "animal is a mammal" is proved, and the goal is reached.

Expert system shells contain pre packaged knowledge representation diagrams and inferencing techniques that provide a framework for the development of expert systems.

Many shells include step by step guidelines with examples letting the developer implement user friendly, interactive expert systems without knowledge of either programming or expert system techniques. (TAFE should start off using this approach when introducing this topic). Some allow for inclusion of uncertain data and imprecise knowledge; others construct rules based on a set of examples.

Successful implementation of an expert system depends on several key components. First a well defined application domain must be established, and domain experts must be available to provide the expertise to build the knowledge base and to validate system results. Second, an expert system developer or knowledge engineer must be available to work with the domain experts to create the knowledge base and build up the system.

The knowledge engineer is also responsible for determining the hardware environment and selecting tools.

With a considerable investment in time and money, an employee can develop expertise and become a valuable asset. This asset tends to erode through attrition, promotion and retirement. If the knowledge, experience and advice of experts is captured, it can be used after they have gone.

TAFE needs to work on the basis of using the knowledge of its expert teachers, in each field, to train others and to ensure the experience and knowledge is not wasted and stored for future reference and use. TAFE, like industry, has valuable assets - its people. Their expertise, in the latest technology areas, should be utilised for the transfer of experience, knowledge and skills to students. In this way Australia can continue to work towards true integrated manufacturing.

Simulation techniques will help considerable in this area as TAFE cannot possible hope to provide high capital equipment in every area. Modelling, properly utilised, will achieve the same objective in conjunction with the skills of its staff.

A reliable method must be developed, a favourable environment created and continuing education to keep every student up to date and practiced in the method. In this way we should obtain the driving power for managerial success in TAFE.

What I really mean is that TAFE needs to provide reliable methods to impart knowledge and skills in the principles of managerial engineering and how to apply them for Australia to compete as a World Class Manufacturing nation.

27. APPENDIX C - INTEGRATED MANUFACTURING OF THE FUTURE

27.1 INTEGRATED MANAGEMENT OF THE FUTURE

Thanks to the Japanese initiative, there is much talk about the fifth generation computer. The key to this generation is in the networking of multiple processing units. This linking provides a new task; that of dividing the problem so multiple processing units will be able to work on portions of the same problem concurrently and in parallel, then piece together the whole solution.

Together with the fifth generation computer is the notion of fifth generation management (FGM), which assumes a well developed and flexible infrastructure of networked functions, together with their computers and applications, capable of referencing a common data architecture. In the first four generations of management, raw material and information are passed serially from one department to the next Moreover, the hierarchical mode of organisation predominates, even in the third and fourth generations of management.

In FGM, each of the functions becomes a node, or decision point, on the network. These nodes become reference points, or knowledge centres, capable of teaming with other nodes to support the enterprises's business strategy. FGM assumes the computer integrative management of the manufacturing enterprise. First its focus is not just on the manufacturing function, but on the entire enterprise. Second, it is integrative, not integrated, because manufacturers are involved in a continually evolving integrative process. Third, each of the departmental functions and sub functions become nodes in a network capable of bringing their accumulated knowledge to bear in an interactive mode as the functions work in parallel.

Goaded by promises about CIM, companies are focusing on the technology and forgetting the logic of management. The new computer based technology is slowly being put into traditional manufacturing companies.

The traditional manufacturing logic has been to divide and sub divide the production processes to manage the sequential flow of raw material through work in process to finished product. This makes it easier to assign responsibility and assign responsibility and maintain accountability. It is the source, unfortunately, of many internal political battles, even as the informal organisation gets the work out the door. Often, the written company policy is superseded by a series of accommodations between functional departments.

However, this has led, in many instances, to what can be referred to as "human disintegrated manufacturing" because humans have had to conform to the idiosyncrasies of an environment that has been slow to appreciate and use the range of their talents. Moreover, the hierarchical organisation has made meaningful communication between departments cumbersome at the best.

Many companies are indeed stumbling along with their efforts to install CIM, and as long as the emphasis is primarily on the computer and manufacturing with a bent for interfacing, this trouble will persist. Problems occur because each functional department has its own dialect which is difficult to understand by the other functions without adequate translation.

In the traditional manual manufacturing approach, human translation takes place each step of the way. For example, manufacturing engineering takes engineering drawings and red pencils them, knowing the product can never be produced as drawn. The experience and collective wisdom of each functional group, usually undocumented, is an invisible yet extremely valuable company resource. Computer interfaced manufacturing (CIM I) bypasses this reservoir of knowledge.

Each functional department has its own set of meanings for key terms which causes part of the problem. Terms such as "part", "project", sub assembly", and "tolerance" are understood differently in different parts of the company. When files with these and other terms are to be used directly in other departments, there will be problems because of the following conditions:

(a) The same words are used, but they have different meanings.

(b) Different words are used, yet they may have the same meaning.

(c) The same words have differing shades of meaning.

(d) The same words take on different meanings, depending on the context in which they are used.

Experienced employees can interpret different meanings for key terms and compensate for them. This ability is a valuable company resource, although it is not usually recognised.

It is not enough to simply interface these nodes or decision points. They need to be related to a common reference context: strategic vision, values, common reference data architecture, group technology, and so forth.

The common reference context has three time elements: the strategic business vision (future orientation), the flexible infrastructure of networked computers and professionals (present orientation), and stored knowledge and common and agreed on definitions of key terms (part orientation).

Now let us consider an additional layer representing the transition to CIM II (computer integrative management of the manufacturing enterprise), which supports FGM. The new logic assumes networked infrastructure and adds a way of coordinating the managers, professionals, and employees in a dynamic and flexible manner, allowing for reconfiguration of the business.

The traditional organisation was held together by a "command and control" structure where everyone's job was clearly defined. However, the new "Knowledge Era" requires a different approach to control and coordination. As the functions use the computer networked infrastructure to communicate in an iterative manner, management must provide focus and direction.

Rather than being separate boxes on an organisational chart, in a flatter and more participative environment the responsibilities of functional decision points (nodes) overlap. However, there is the potential for ambiguity in this type of structure, and it is management's responsibility to handle this ambiguity and variety. A clearly articulated strategic business vision becomes the glue of organisation.

When attention shifts to integrating the functions in a more dynamic whole, then the stage will be set for more rapid progress. Certainly CIM I, the interfacing of the key functions, is a necessary precondition for CIM II, as it is part of the process of building the necessary communications infrastructure. However, the physical linking of functions will not lead to true integration, hence the distinction between CIM I and CIM II concerned with connectivity, the physical linking of computer nodes, but it is also attitudinal and referential.

In short, the distinction between CIM I and CIM II is as important, if not more so, than the shift from material requirements planning (MRP), which dealt with just production and inventory control, to manufacturing resource planning (MRP II), which includes most aspects of manufacturing planning and control.

Traditionally, manufacturing enterprises have been thought of as hierarchies managing activities through a process of serialised handoffs of product information from one function to the next.

However, there are challenges to this model. First, companies are producing more with less direct labour (3-15% costs, depending on the industry). Second, they need fewer levels of management (down from 8-12 levels to 4-6 levels). Third, the transformation of data and information into useful knowledge is now as important, if not more so, than the transformation of raw material into finished goods. Only a few touch the product, but almost everyone touches information about it.

Manufacturing in the 1990's will demand a qualitatively different approach to management from what has been known in the past. What type of management will this be? This question is at the heart of the quest for FGM.

Unfortunately, many mistake computer interfaced manufacturing (CIM I) for CIM II. CIM I leaves the traditional structure in place and simply wires together the various functions through digital communication. It still operates in a sequential fashion. CIM II is based on the various functions working together in parallel.

The logic of traditional manufacturing management, even with CIM I, is almost 180 degrees from the logic of CIM II. If this goes unrecognised, then new technology will continue to be "stuffed" into old organisational skins. The logic of CIM II rests on a much deeper understanding of organisational integration. This leads to the search for understanding of FGM, which needs its own perspective. In FGM, what has to be integrated? How is this integrative process to be carried out? To simplify a complex process, FGM will require inter weaving five threads.

In a manufacturing enterprise, five major areas need to be dynamically interrelated and integrated. Traditionally, each area lives in its own world with its own professional societies and training. Each has its own educational feeder systems. The task is to weave a tapestry that utilises the strengths of the entire garment.

The five threads of CIM II include management context, business, technical, information architecture, and production systems. The points of intersection of the tapestry should be thought of as the nodes where decisions are made.

The task of managing a network of nodes is qualitatively different from managing a standardised set of functions, as it is done in second generation organisations. FGM requires nodes (people as decision makers) to interact on an ongoing basis as new products and processes are developed. Marketing perceives a new opportunity, so it has engineering sketch a possible design. Manufacturing engineering is asked to simultaneously sketch the production process, and finance assists in determining costs. These functions work back and forth to refine their concepts and determine the probability of market success. Each of the functions serves as a node and is involved with things to resolve.

A nodal network is a give and take or back and forth environment, rather than a sequential hand off process. This means there is a need for continually focusing the efforts the efforts of the nodes, and this requires a good and clear strategic business vision.

In all companies, a strategic business vision is not an off the shelf commodity. It must be crafted and grown through the interactions of many key persons in the organisation and must be engineered in the creative sense of the word. Often professionals and middle managers have innovative solutions to marketing's perceived needs, and these individuals can help develop a strategic vision in dialogue with top executives.

In a nodal organisation, many responsibilities overlap. the horizon of concern extends beyond the narrowly confined borders of individual functional responsibilities. For example, engineering worries about how a product will be serviced. The black and whiteness of second generation management is replaced by the fuzzy borders of FGM.

The fuzzy borders of overlapping nodes imply that there are problems to be faced in developing marketable products and that processes cannot be easily compartmentalised. Most business challenges require the insight and experience of a multitude of resources, which need to work together in teams to get the job done.

Rather than being thought of as conventional functions, the nodes in FGM are knowledge centres that unite around the challenge to bring the insights of their disciplines to its solution. Nodal knowledge centres do not wait for responsibility to be assigned. Instead, managers and professionals assume responsibility for projects after the proper internal negotiations.

Integration requires more than just technology. FGM an CIM II cannot be achieved without strong executive leadership. Success in this arena demands technology with the realignment of departmental charters, reward systems, accounting practices, organisational designs, career paths, and management styles.

FGM nurtures an integrative atmosphere where knowledge centres are expected to work together in an iterative fashion. In this context, management can more effectively lead interrogatively; that is, by well placed questions. These questions can be extremely effective in keeping the various working teams focused on the organisation's objectives.

Top executives also can use questions to bring the various functions into closer working relationships. Too often CIM is an undertaking of the manufacturing manager or engineering manager. However, the litmus test of true CIM II effort will be based on the involvement not only of manufacturing and engineering, but also of marketing, finance, human resources, and information systems.

Needless to say, these changes can be threatening and can upset the culture and delicate balance of political accommodations between functional groups. Change brings more uncertainty than most people are ready to cope with, thus hampering the transition to FGM.

Traditional management cultures have assumed that the key to success is in managing the "routine". This has often led to an under utilisation of the talents of managers, professionals, and workers because they are expected to "fit in" like cogs.

Well defined bureaucratic structures hold traditional manufacturing enterprises together. Yet these companies lack the quickness of mind and nimbleness of foot to adapt to changing competitive environments. Automation is seen as a way to further eliminate people and to make the processes even more routine. FGM, on the other hand, is focused on managing variety.

FGM is a creative response to the need to manage variety, ambiguity, uncertainty, and even chaos. Therefore, managers, professionals, and workers need to learn to work as over lapping nodes and decision points in a larger network.

If in FGM, key managers and professionals need to work together as teams with issues to resolve, narrowly defined job responsibilities and restrictive departmental charters will be hindrance. Instead, a climate of trust, openness, and information sharing is essential, made possible by changes in reward systems, job definitions, and departmental charters. CIM II provides the technical resources to enhance human capabilities to mange the variety of constantly changing competitive conditions.

In addition to the shift to a more nodal form of management, the management context thread refers to the values and operating philosophy established by executive management. In manufacturing companies over the last five years, acceptance of a new set of operating values has begun. This includes Just In Time, Total Quality Control, and Design For Assembly.

Companies are realising that the cost of poor quality is much higher than conventional wisdom has assumed. JIT and TQC now are becoming more widely accepted, and they can often serve as excellent lead ins to CIM II, since they expose the real problems and opportunities within the manufacturing enterprise. In fact, not only are they excellent lead ins, but they are also essential components of CIM II.

One of the most exciting ideas of FGM is the shift from an organisational architecture of narrowly defined functional responsibilities to one of overlapping nodes.

The traditional architecture of management assumes a fairly static environment where responsibilities can be well defined. The best metaphor for this organisation has been the organisation chart drawn on paper. This serves as a spatial representation of the key responsibilities in the organisation. However, an organisation exists more in time than space. Time is a more difficult metaphor to describe and picture, especially human and organisational time.

New tools are needed to focus the nodes on the business and technical challenges of the company. A shared vision needs to emerge to help sharpen this focus, and it will come not only from the top executives, but also from within the enterprise. It will be translated into concrete results through the use of project management techniques and small group involvement activities (SGIA).

Certainly, the use of teams is not a new phenomenon in manufacturing. FGM tips the scales, however, in a new direction. The general disciplines remain, but within the context of nodal organisational architecture. The nodal project management teams are supported by an evolving digital information infrastructure, together with well thought out standards and protocols, so that it is easy to pass meaningful information between nodes.

This nodal project management approach requires open ended careers and overlapping departmental responsibilities. There must be room for organisational growth that then creates a higher level of engagement and commitment on the part of all employees. Moreover, motivation is, in part, self generating as the quality of human interaction improves.

Taken together, these shifts suggest several important contrasts between traditional management and FGM.

Functional departments will begin to give way to knowledge centres built around a more explicit understanding of human and organisational time. They will develop cellular manufacturing and other JIT techniques, TQC principles, engineering standards, and the like so that these resources can flow with the organisation over time and be drawn on as a resource.

It is likely in the future that there will be managers of major knowledge centres much as mangers of functional departments exist today. Rather than giving orders, they will be sharing their vision. Rather than giving orders, they will be sharing their vision. Moreover, they will spend a lot of time identifying and developing the talent they need for their centres.

This leads into the second point: people will more explicitly seek "careers" rather than "jobs". A job is a slot to fill; careers, on the other hand, presuppose intellectual involvement in the tasks at hand and expect the person and teams of persons to be "decision nodes".

This is also why education, rather than training, is the key. In the functions and slot model of industrial organisations, people had to be trained to fit into the organisation. In FGM, people will be expected to grow in understanding of their professional responsibilities. TAFE has a major role to play in this education process now and in the future, if Australia is to compete with other countries and become a World Class Manufacturer in all fields.

The problem with members of traditional management philosophies is that they have been poor learners. They have not taken the time to sort out their visions of the future and experience, lessons, and knowledge of the past. Tneir weakness is that they have imploded into the present, creating a black hole of understanding. This leads to informational amnesia. without strong roots in the past and without the broadening vision of the future, both of which exist in the present, amnesia sets in.

Finally, data is assumed to be disposable. Records are kept, but retrieval is cumbersome at best. Data is one of the most important assets that a company has. The 1990's will be the decad f the data.

FGM can offer a whole new way of organising and managing manufacturing enterprises. Rather than the divisive fragmentation so common in companies, a dynamic interaction is in the offing that will challenge as businesses build and grow.

28. *APPENDIX D - DICTIONARY OF ACRONYMS*

28.1 ACRONYMS USED IN THE REPORT

ACADS	Australian Computer Aided Drafting Society
ACTU	Australian Council of Trade Unions
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
APT	Automatically Programmed Tool
ASCII	American Standard Code for Information Interchange
BIT	Binary Digit
BOM	Bill Of Materials
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CAPP	Computer Aided Process Planning
CIM	Computer Integrated Manufacturing
CL	Cutter Location
CNC	Computer Numerical Control
CNCS	Computer Numerical Control Simulator
CTU	Computer Training Unit (TAFE)
DNC	Distributed or Direct Numerical Control
EPROM	Erasable Programmable Read Only Memory
FEA	Finite Element Analysis
FGM	Fifth Generation Management
FMS	Flexible Manufacturing System
GT	Group Technology
HZ	Hertz (frequency)
IGES	International Graphics Exchange Standard
ISO	International Standard's Association
IM	Integrated Manufacturing
JIT	Just In Time (Production)

MAP	Manufacturing Automation Protocol
MAPT	Micro Automatically Programmed Tool
MHZ	Megahertz
MRP	Materials Requirements Planning
MRPII	Manufacturing Resources Planning
MSDOS	Microsoft Disk Operating System
MTIA	Metal Trades Industry Association
NC	Numerical Control
OPT	Optimised Production Technology
OS/2	Operating System 2
PC	Personal Computer
PLC	Programmable Logic Controller
RAM	Random Access Memory
ROM	Read Only Memory
SGIA	Small Group Involvement Activities
TAFE	Technical And Further Education
TAFENET	Technical And Further Education Network (Computer)
TQC	Total Quality Control
TQM	Total Quality Management
VA	Value Analysis
VAM	Value Added Management
VE	Value Engineering
VLSI	Very Large Scale Integration
WCM	World Class Manufacturing

29. *APPENDIX E - AN EXAMPLE OF A FMS FOR TRAINING*

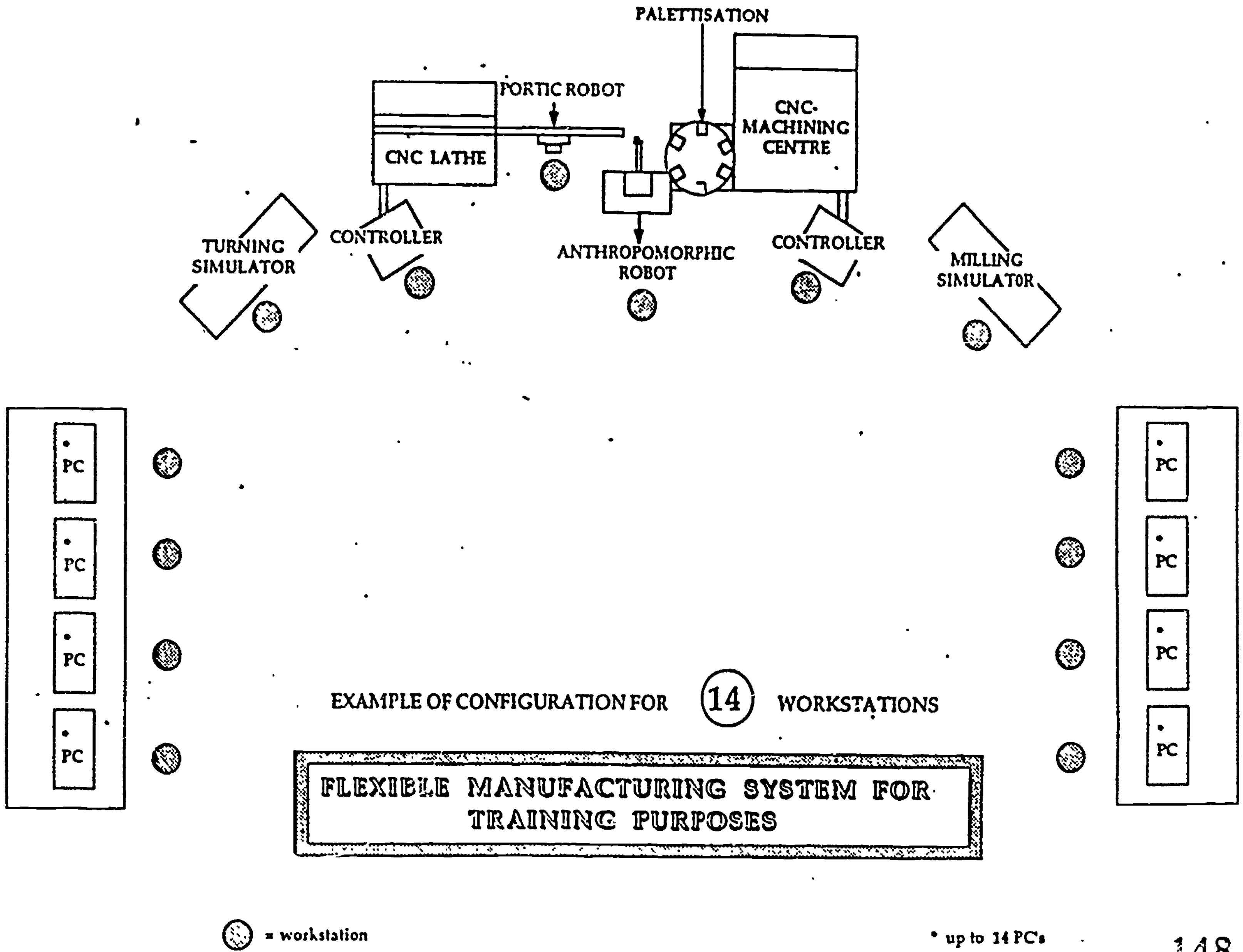
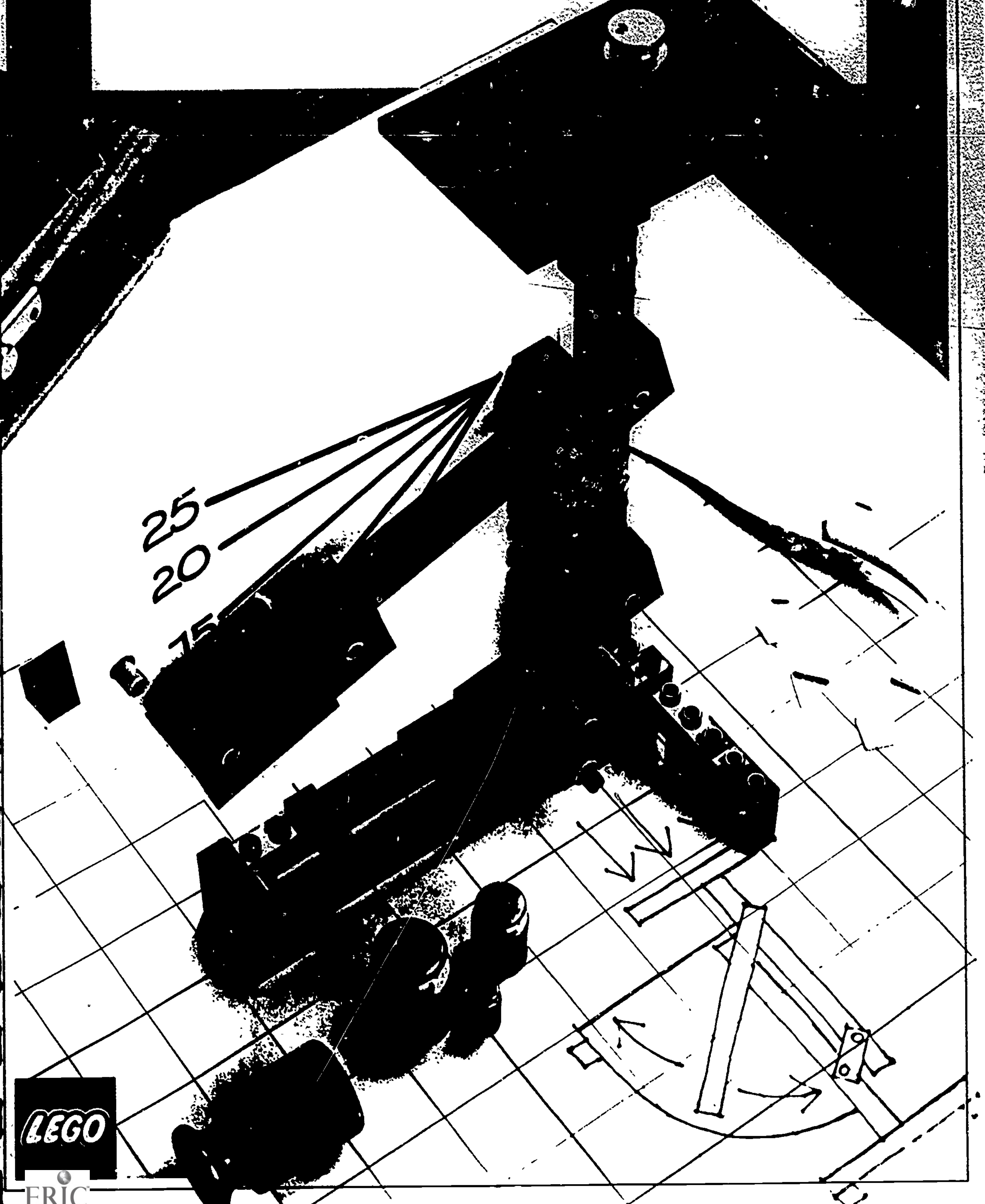


Figure 14. A Typical FMS For Training Purposes.

30. APPENDIX F - LEGO, SMALL CNC, ROBOTS & CNC EQUIPMENT

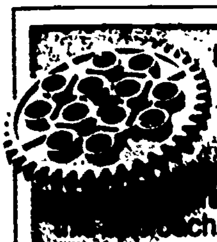
LEGO® Technic Basic

Science and Technology Equipment for Schools.



LEGO

Mechanical principles are



Mechanical principles are easily understood when students build and investigate their own models in a "learning by doing environment".

The problem solving approach is an exciting and meaningful ...y to learn about stability, levers, gears, pulleys, friction, the ...nsmission of energy, etc. LEGO Technic Sets are ideal for ...ch.

LEGO Technic I – Simple Machines – introduces most of the basic mechanical concepts, including gears, pulleys, and levers.

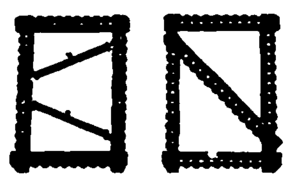
LEGO Technic II – Powered Machines – goes a step further and introduces worm gears, the electric motor, chain links, universal coupling, and differential gearing.

Teacher's guides are available for both sets, see extracts below and on page 4.

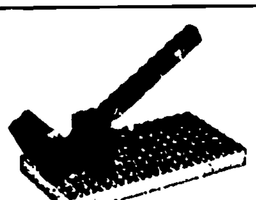
LEGO Technic Class Packs

As with any good class resource, these materials are most effective when there are sufficient materials to get a whole class working on a topic. As each set is suitable for two, possibly three students, we have created Class Packs of sets. These offer realistic and economical solutions for the busy classroom teacher.

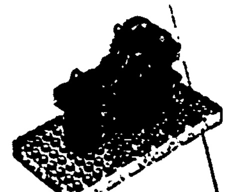
Inquire about Simple Machines, Powered Machines and Technology and Control Class Packs.



Stability and structures



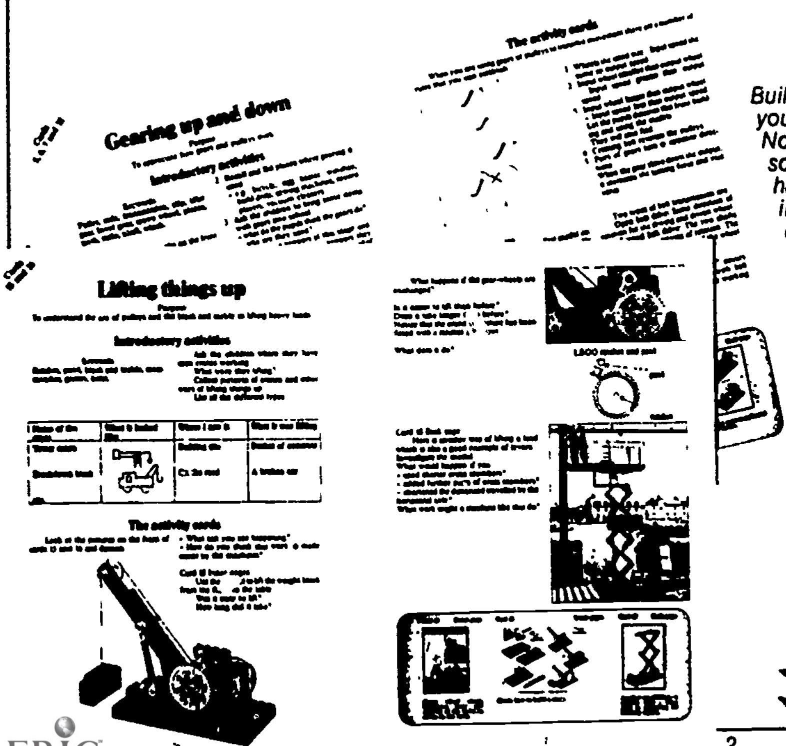
Levers

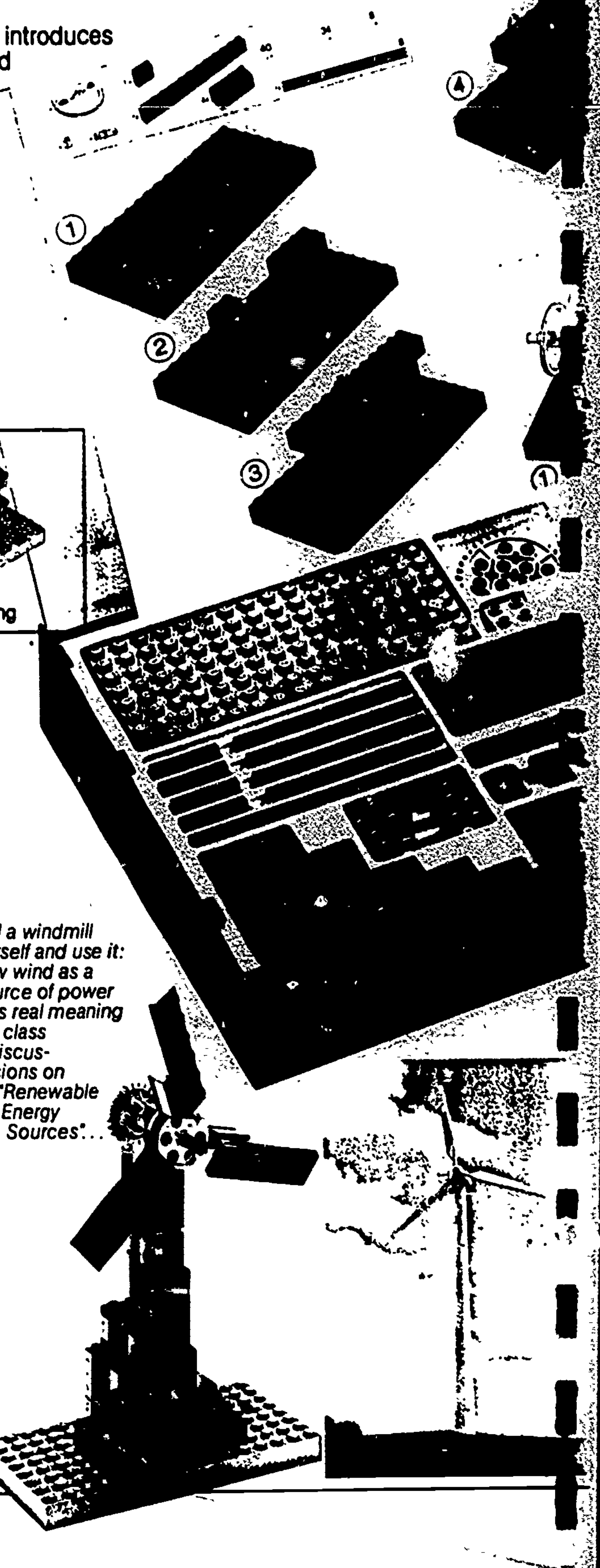


Gearing

1035 Teacher's Guide for LEGO Technic I

A complete guide on how to utilize the LEGO Technic I set in the classroom. The guide is aimed a primary school teachers. The guide explains the most important mechanical principles one by one and suggests activities to suit. There are also suggestions for topic or project work, e.g., farming, energy and technology (see extracts).



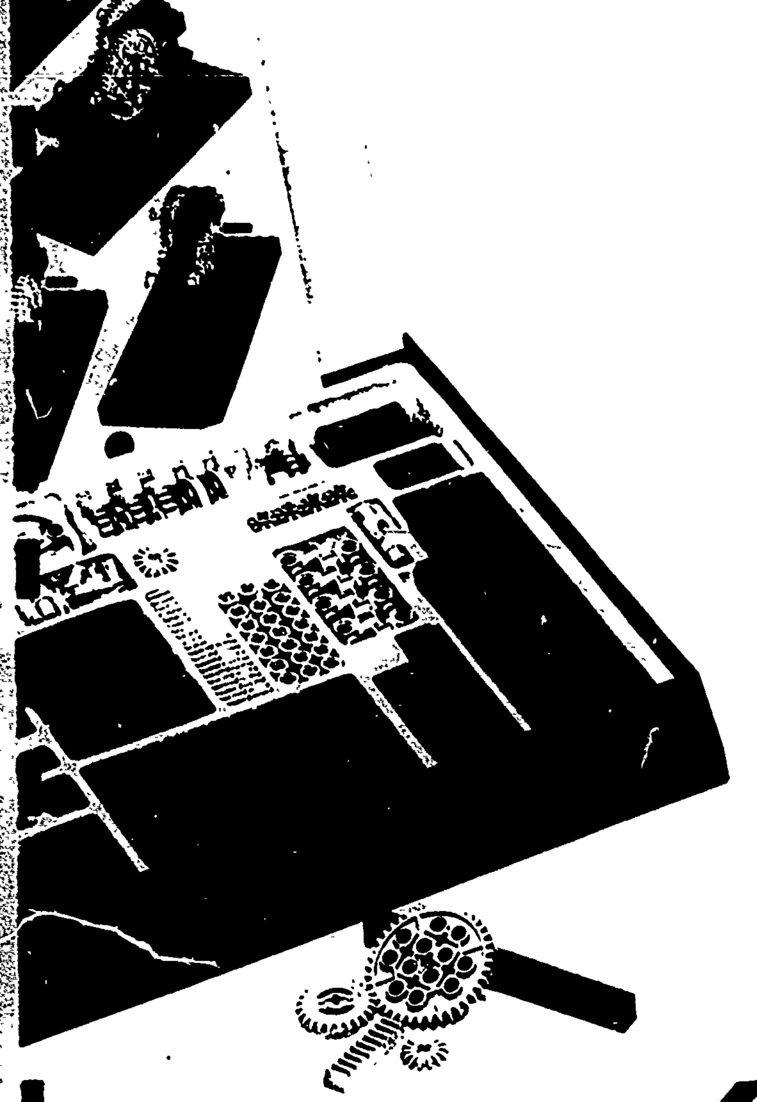


Build a windmill yourself and use it: Now wind as a source of power has real meaning in class discussions on "Renewable Energy Sources"...

simple

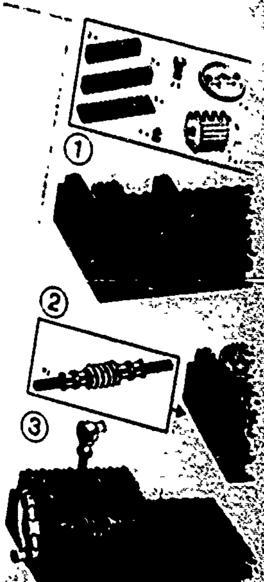
1030 LEGO Technic I – Simple Machines – Complete Student's Set

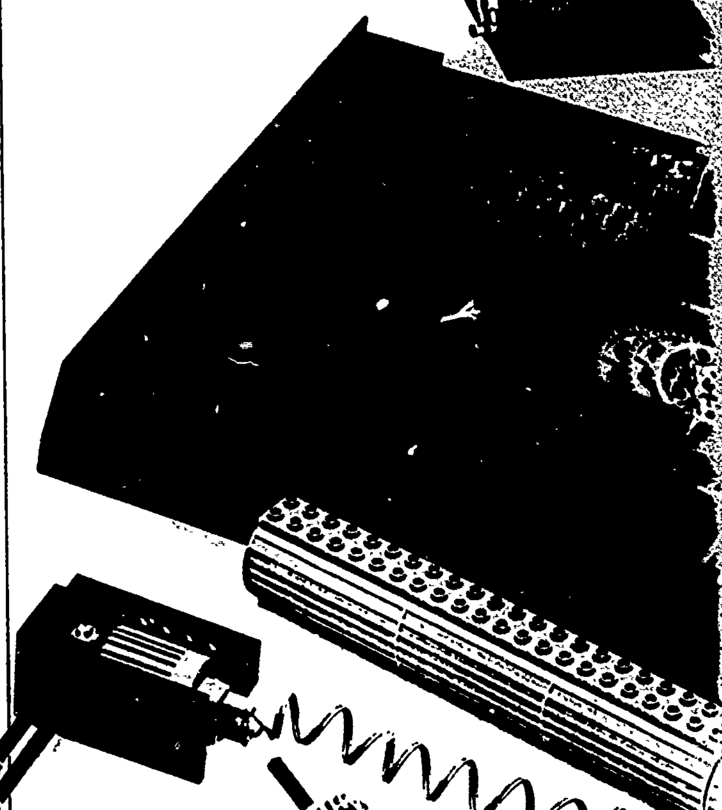
Contains 179 LEGO Technic elements, such as gears, belts, racks and pinions, a strong storage box with transparent lid, and 20 activity cards. Suitable for 2–3 students working together.

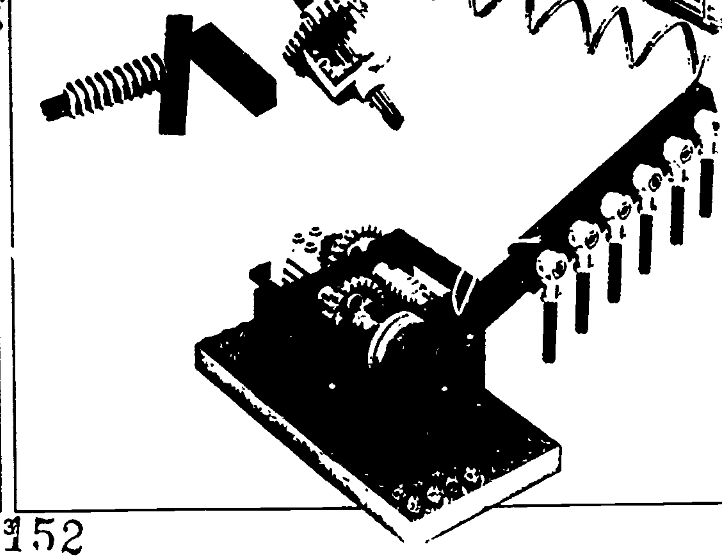


1032 LEGO Technic II – Powered Machines – Complete Student's Set

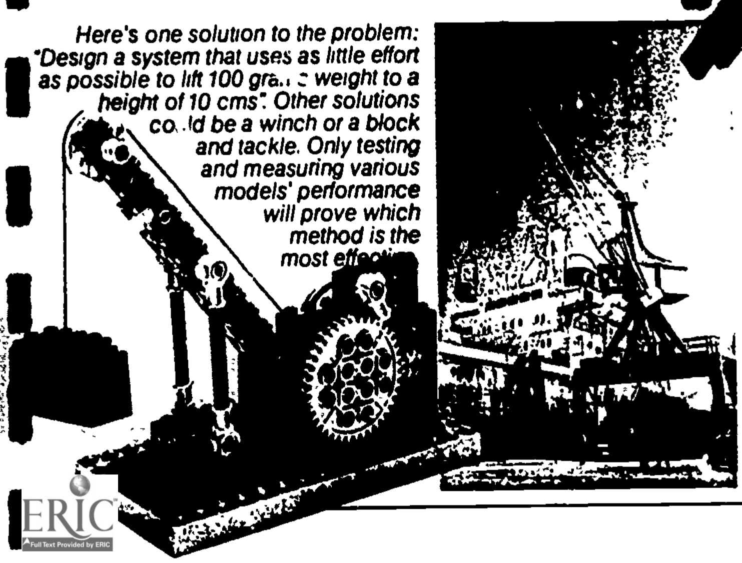
Contains 278 LEGO Technic elements including a 4.5 V DC motor, a battery stick, gear wheels, worm gears, chains, a differential gear, a strong storage box, and 20 activity cards. The set is suitable for 2–3 students working together.

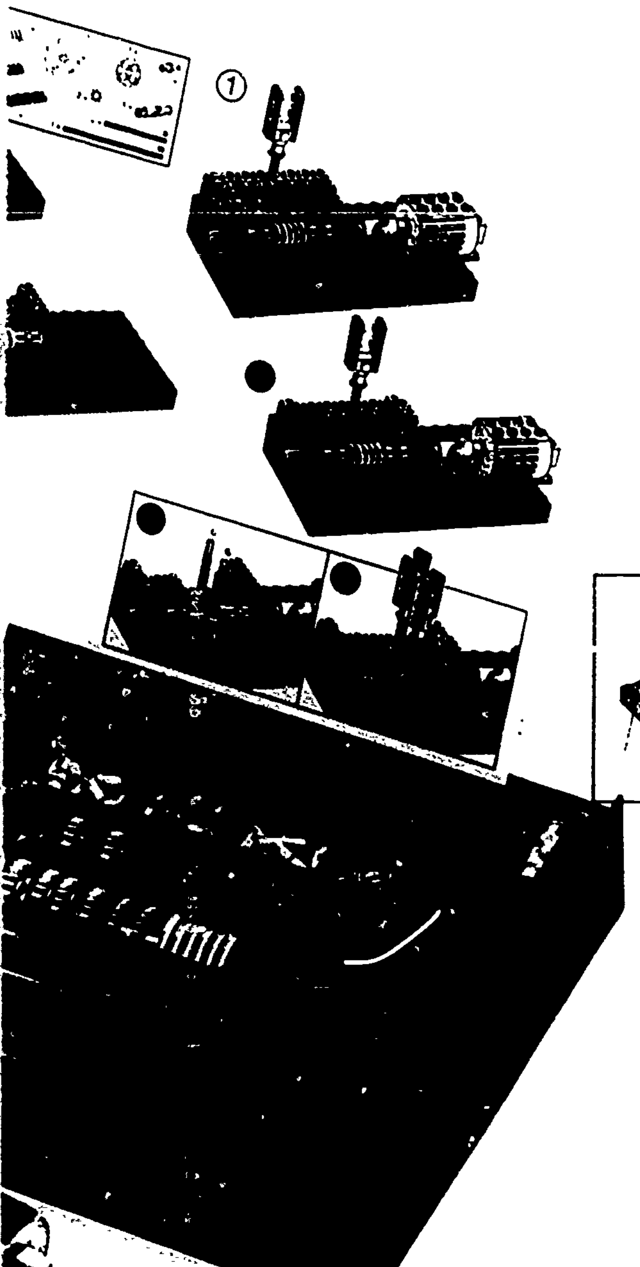






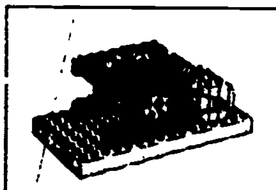
Here's one solution to the problem: "Design a system that uses as little effort as possible to lift 100 gra… weight to a height of 10 cms". Other solutions co…ld be a winch or a block and tackle. Only testing and measuring various models' performance will prove which method is the most effe…

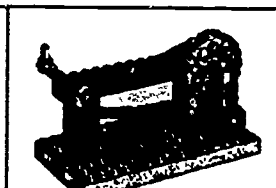




Who should use LEGO Technic?
If you are a Primary Teacher, these materials are the most highly motivating resource available for science and technology teaching and problem solving. There's lots of help for the teacher in the Teachers Guides and in the range of free Topic Outlines available from the LEGO Educational Consultants.
Have fun as you are learning with topics such as Structures and Frameworks, Inventions, Making Work Easier...
In secondary schools the materials are ideal for investigating "Machines" and doing quantitative and qualitative work on Levers, Pulleys, Gears, Mechanical Advantage, etc., etc.
The Technic II motor doubles as a generator leading to exploration of efficiency in energy interconversion and transmission.

The Sets in this Brochure
The range of LEGO Technic products in this brochure consists of:
1030 LEGO Technic I
1031 Extra Activity Cards for LEGO Technic I
1032 LEGO Technic II
1033 Extra Activity Cards for LEGO Technic II
1034 Large Resource Set for LEGO Technic I and II
1035 Teachers Guide for LEGO Technic I
1036 Teachers Guide for LEGO Technic II
1038 LEGO Technic Buggy
1039 LEGO Technic Manual Control Panel
All the Sets above are compatible with the LEGO Technic Control range of materials for schools.
The LEGO Technic Control materials explore computer control of a wide variety of domestic and industrial machines.
A separate brochure illustrates this part of the range and is available from your LEGO Educational Consultant or The LEGO Education Division. (See back page for details.)

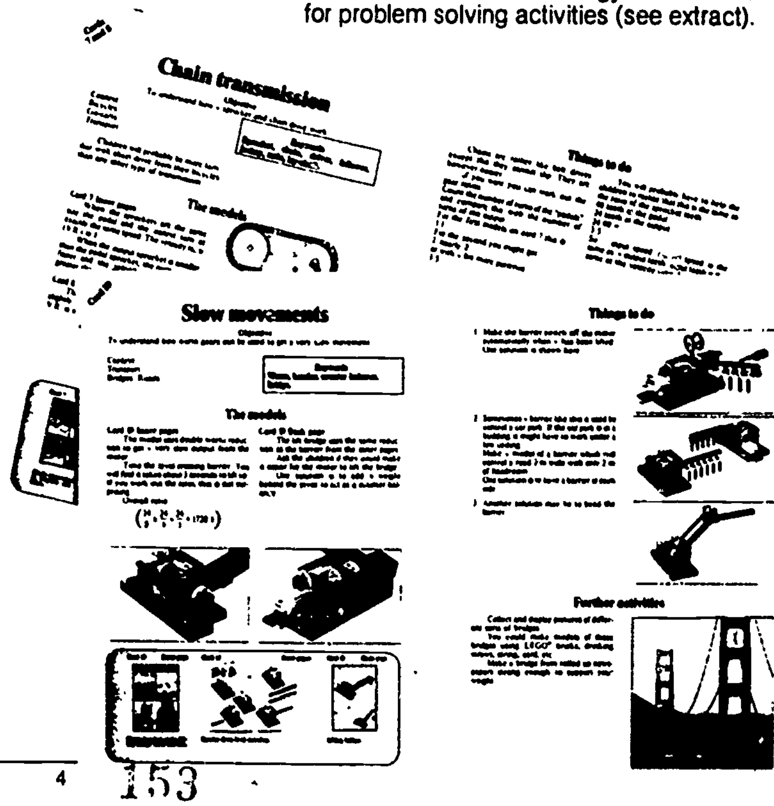

Belt transmission


Chain transmission


"Pulleys"

1036 Teacher's Guide for LEGO Technic II

A complete guide on how to utilize the LEGO Technic II set. The guide is suitable for teachers of students, Years 5 to 9. Describes how to work with mechanical principles and how to use them in technology. Gives ideas for problem solving activities (see extract).



Worm gears are often used for applications where a very slow movement is needed. This barrier uses double worm reduction to get a very slow output from the motor.

simple

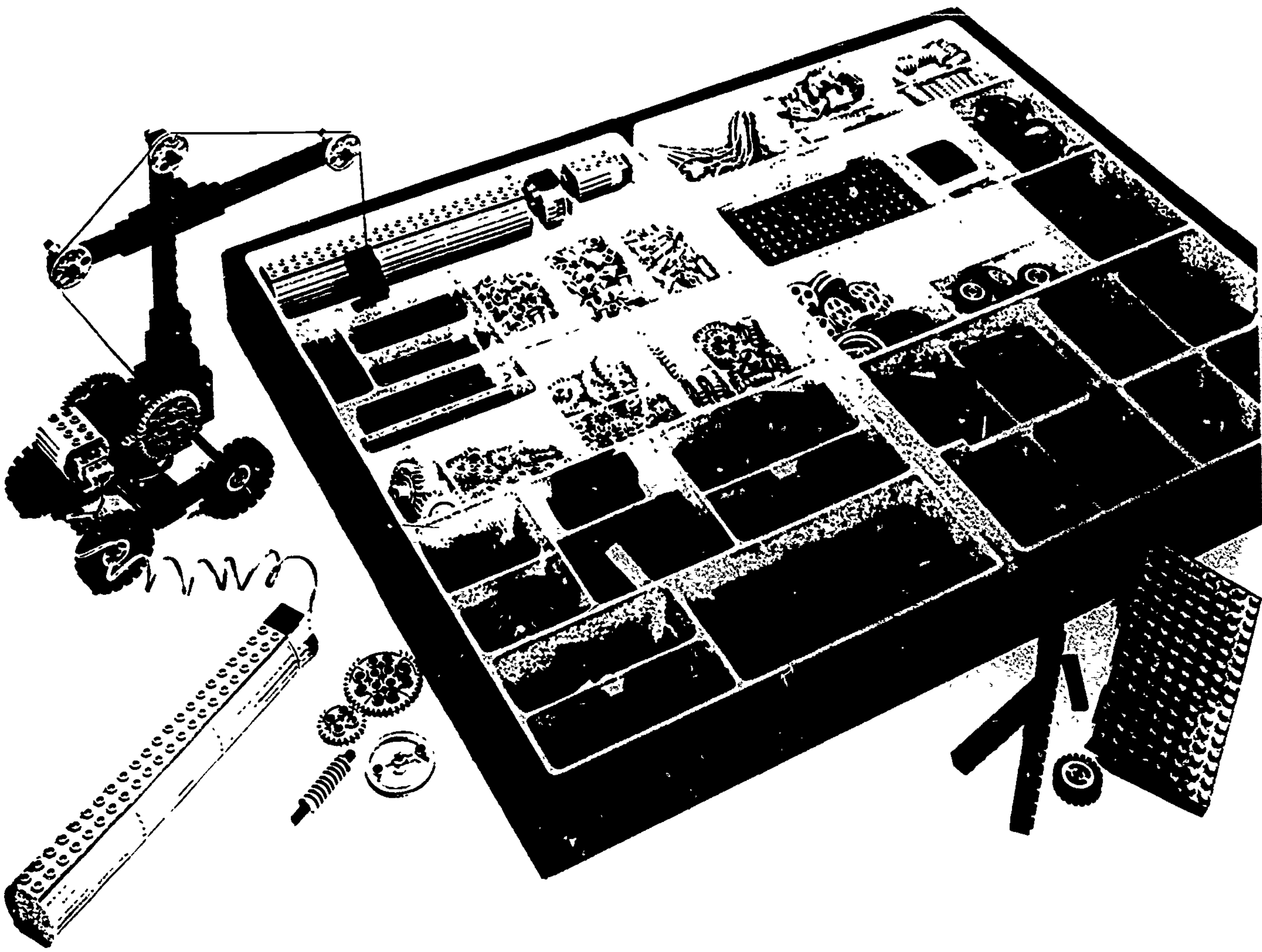
Large Resource Set for LEGO Technic I and II

- Contains 1516 LEGO Technic elements of all kinds represented in LEGO Technic I and II (see these sets for further details)
- Supplements large constructions and group projects
- Good supplement when doing problem solving activities
- Provides a stock for replacement of lost components in student's sets
- Contains teacher's guides for LEGO Technic I and II
- Includes 2 motors, switches and battery boxes
- Strong storage box

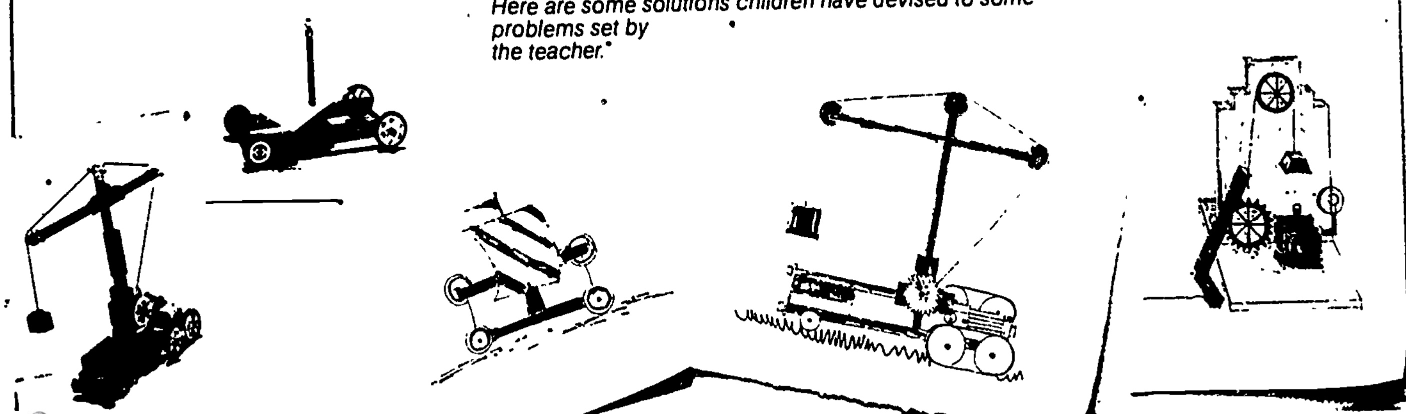
LEGO Spare Parts Service

All items from the LEGO Technic I and II sets are available from our extensive spare parts service (art.nos. 1314 – 1341)

Ask for spare parts information from your LEGO Educational Consultant or from
The LEGO Education Division
LEGO Australia Pty. Limited
P O Box 639
Lane Cove 2066



"Problem solving is an exciting and meaningful way to learn. Here are some solutions children have devised to some problems set by the teacher."



Classroom Packs for Busy Teachers.

The LEGO Education Division also supplies classroom packs of materials for a wide variety of subject areas and age levels, e.g.,

- ☐ Early Childhood Packs for young children
- ☐ Social Studies Packs for Primary Schools
- ☐ Mathematics Packs for Primary and Secondary schools
- ☐ Science and Technology Packs for Primary and Secondary schools
- ☐ Computer Control Packs for Primary and Secondary schools.

For further information contact:

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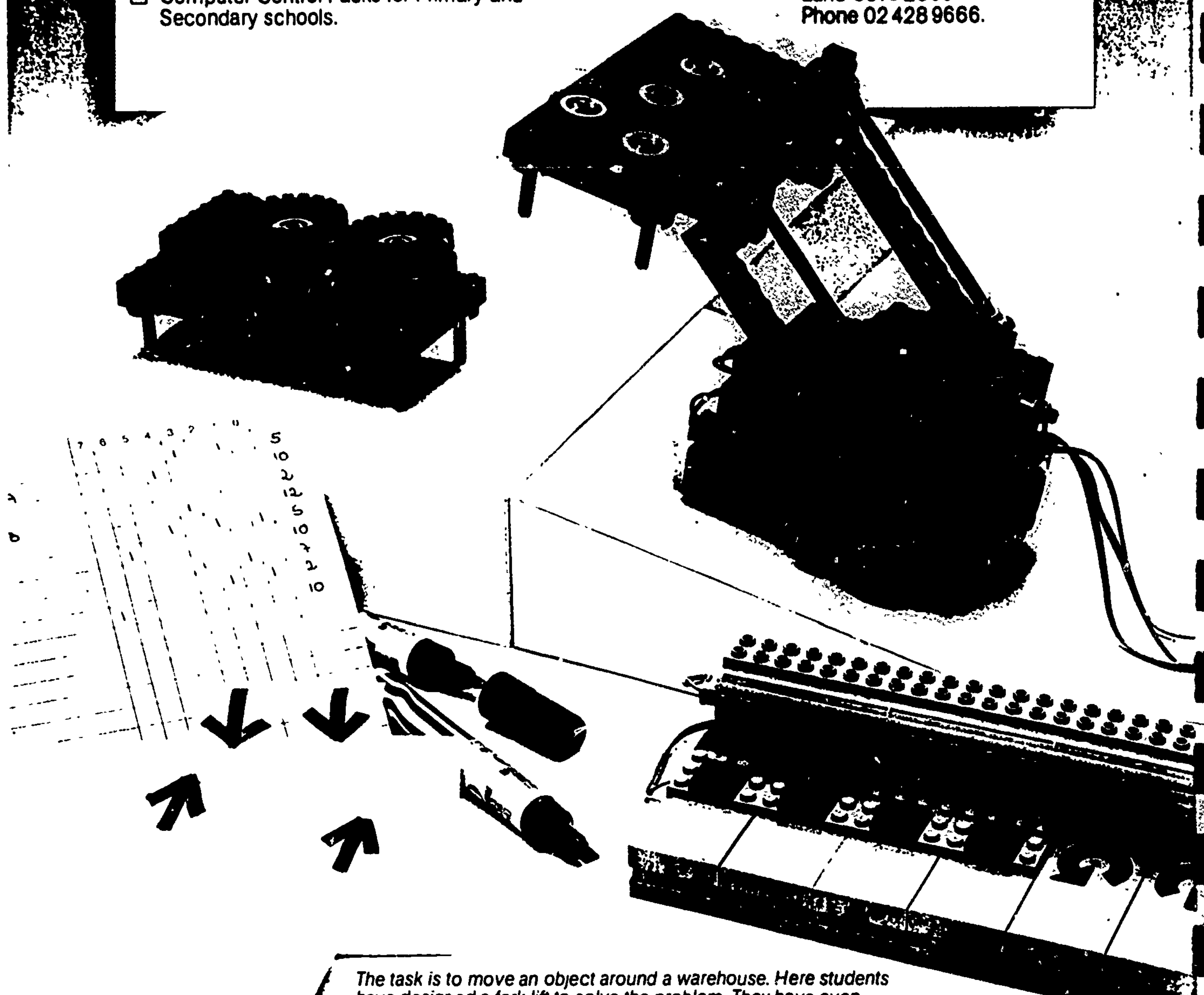
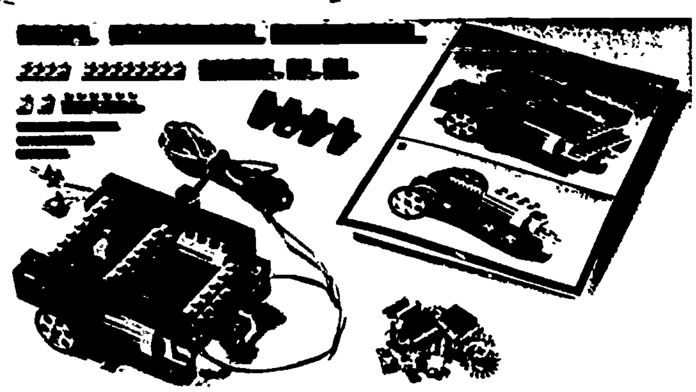
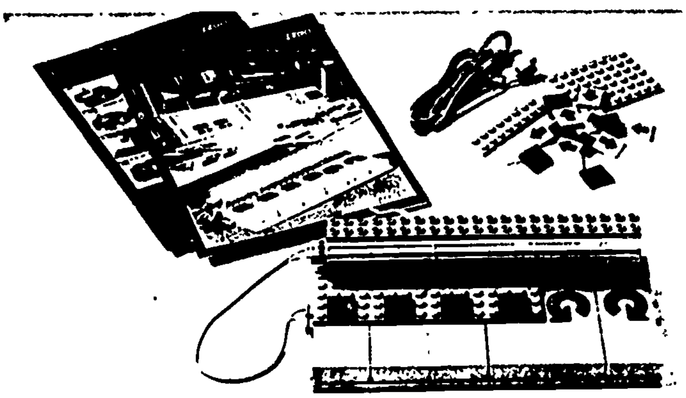
Phone 02 428 9666.



The task is to move an object around a warehouse. Here students have designed a fork lift to solve the problem. They have even written a control program.



1038 LEGO Technic Universal Buggy I
Contains 117 LEGO Technic elements including special elements such as 2 x 4.5 volt DC LEGO motors, worm gears, and gears. The set also includes a full-colour workcard for building 2 different models. Add a felt tip pen and some elements from a Technic I or II Set and you have a "Turtle" that draws big colour graphics.



1039 LEGO Technic Manual Control I
Contains 39 elements including special elements such as 3 switch panels, 3 electric cables and 1 battery box. The set includes a full-colour workcard for assembling different control panels. Excellent for controlling large constructions with more than 1 motor.

LEGO® Technic Control

Technology and Computer Control Kits for Schools

LEGO

LEGO Technic

LEGO Technic Control materials are the ideal motivating resource to help you teach Computing, Computer Awareness, Science, Maths, Technology and Industrial Arts, Physics and Engineering.

The emphasis is on relevance, realism and ease of use. Realism in the building and use of the models and realism in the LEGO Lines Control program. Relevance because the program and models closely resemble the industrial and domestic control systems that affect our daily life.

Realism and relevance motivate students. And motivation leads to learning and success.

Why use LEGO Technic Control materials in the classroom or laboratory?

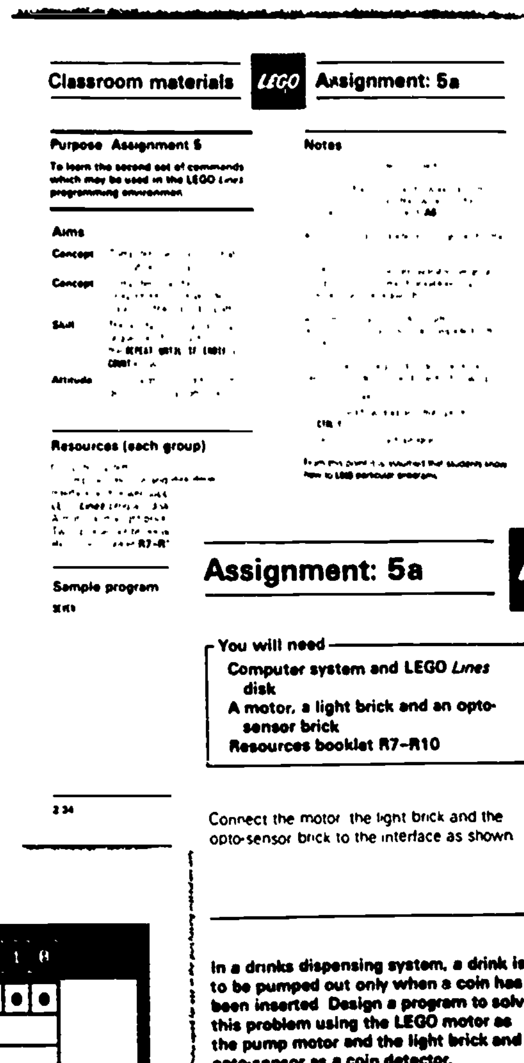
a) Very simply, LEGO materials are so universally understood and liked by children that motivation is high from the moment they are introduced into the classroom.

b) In modern living we are constantly "interfacing" ourselves with computer operated machinery, washing machines, sliding doors, bank tellers, car park gates, traffic lights... If education is to reflect real life and prepare students for it – there is a solid reason for teaching using this approach.

c) Using the build-it-yourself approach students *really* understand so much more about machines, computers, themselves and real life. The skills of planning and co-operation, manipulation, measurement, logical thinking, recording and evaluation are stretched and reinforced by building and programming realistic automated machinery and systems.

d) And finally, Computer Studies and Computer Awareness courses will all contain segments on the application of computers in everyday situations. Senior computing courses now have strands involving Robotics or Control, the impact of "computerization" on our lifestyles, computer programming, etc...

Computer Control of motorised mechanical processes is now a fact of life and LEGO motorised models provide ideal "systems in miniature" to explore computer control.



950 035 Teachers Resource Pack for Apple Computers
1455 Teachers Resource Pack for BBC Computers.

Both the above packs are very similar in content. In fact, the same activities can be carried out in classes with both types of computer allowing maximum ease in lesson planning.

The material has been developed to form a course in Computers and Technology. The concept was developed by British Schools Technology (BST), the Micro Electronics Project (MEP) and the LEGO Group with strong input from Australia. The Apple version was entirely devised, written and trialled in Australia.

The Teachers Guide gives very thorough step-by-step guidance for the teacher with lots of planning hints for classroom organization.

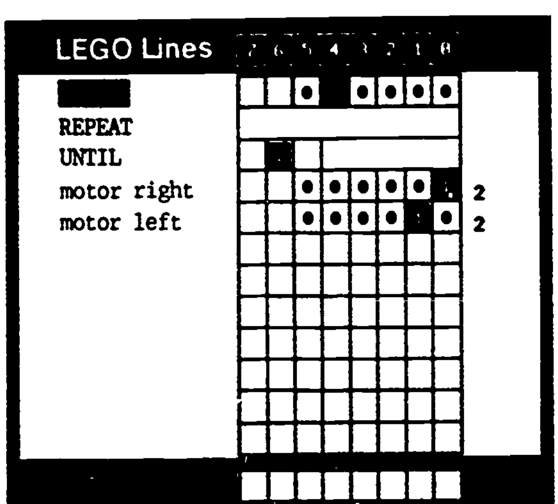
The kit assumes *no* knowledge of computers! You can either use the kit as a systematic step-by-step course in Computers and Technology suitable for Grades 7 to 10 or choose parts of it as a multi-disciplinary resource. The Guide gives lots of hints for starting points for Maths, Science, etc.

For the enthusiasts or senior classes there are sections for Basic, Machine Code and Logo methods of communicating with models or scientific tools built from the sets.

All the materials invite the step-by-step algorithmic approach to problem solving *and* the (more natural) trial and error discovery methods.

Ten identical Student Resource Books are designed to supply a complete class the information necessary for groups to progress at their own speed on any project.

All projects, assignments, programming sheets, etc., are in laminated loose leaf form in a special folder. All these materials are photocopiable.

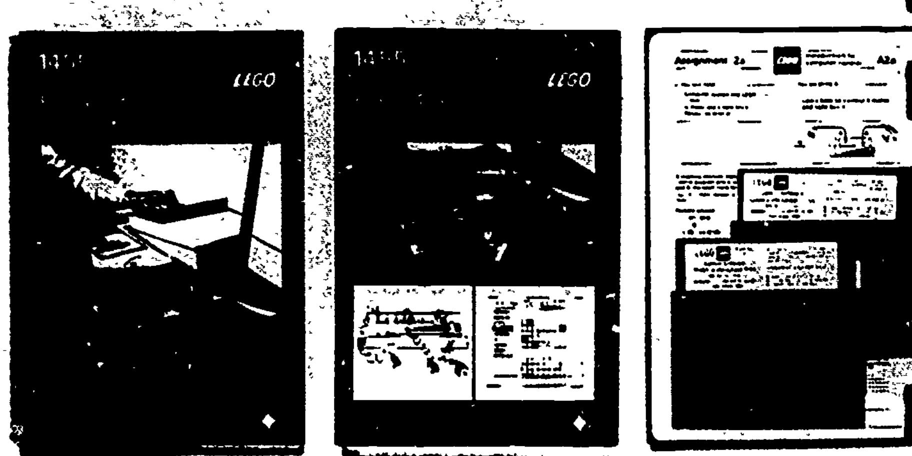


LEGO Lines is a special control program designed for maximum flexibility and challenge. It requires no prior knowledge of computers.

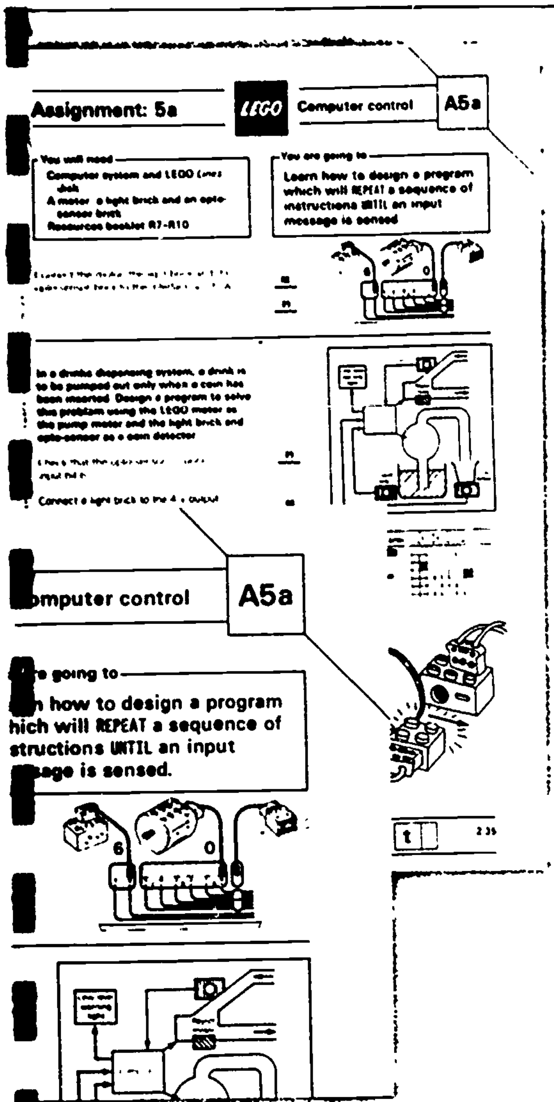
Students use simple key strokes to program the six outputs and two inputs to create immensely powerful control sequences.

There are only seven key words: REPEAT ENDREPEAT FOREVER END IF COUNT and UNTIL.

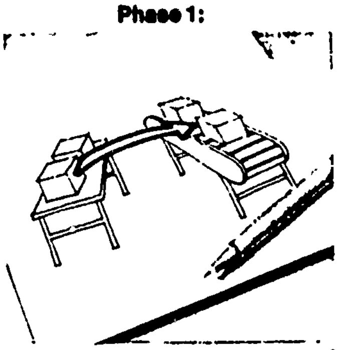
The last three make the computer "look" at the LEGO optosensor built into the models. (Please note: BBC version illustrated).



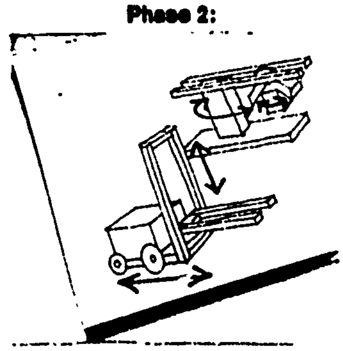
Solving a control problem



Phase 1:

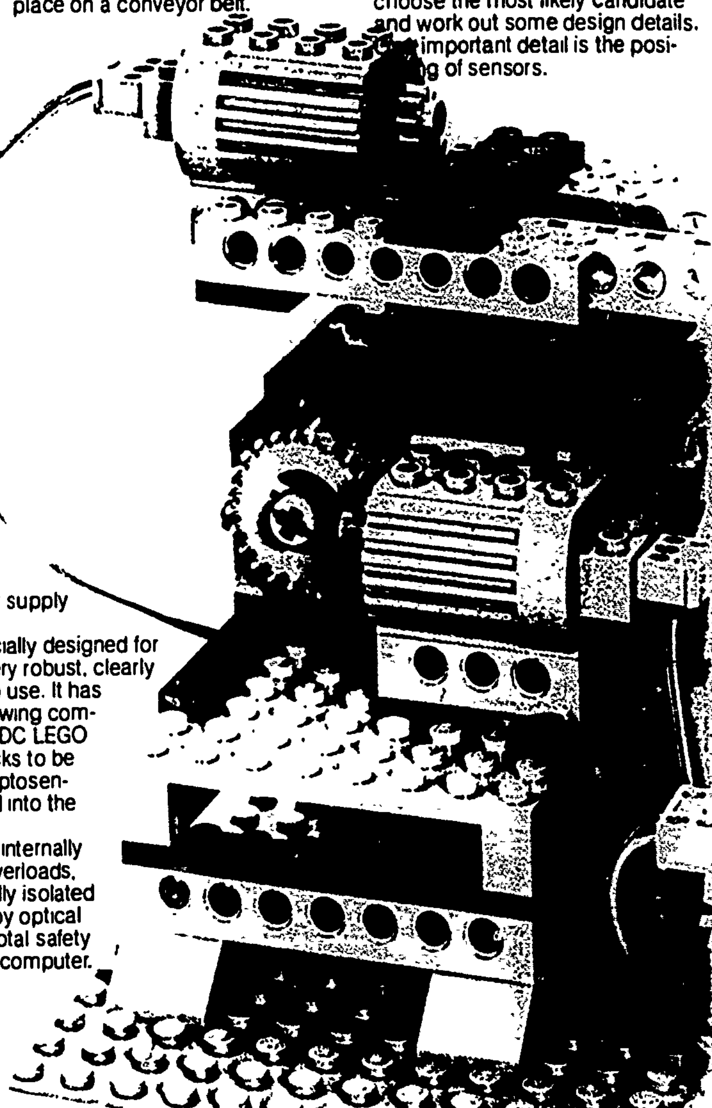


Phase 2:

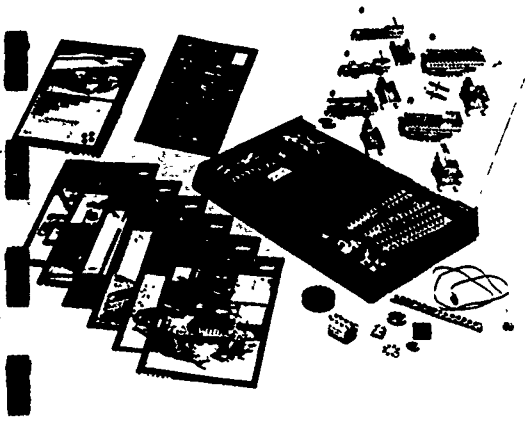


Problem
Design a device which can pick up LEGO bricks from platform and place on a conveyor belt.

Work out a number of ideas that may solve the problem. Then choose the most likely candidate and work out some design details. One important detail is the positioning of sensors.

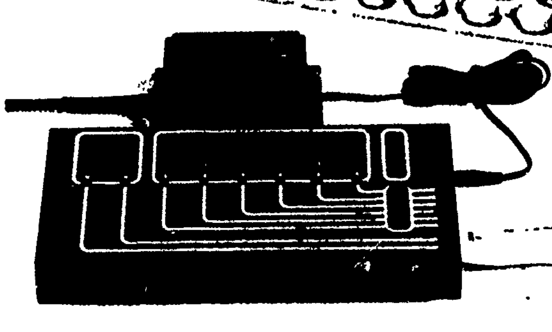


D LEGO Technic Control I
ontains 404 elements including special elements such s 2 x 4.5 volt DC motors, light bricks, 2 LEGO optosen- , and counting discs. All elements are supplied in a dy work bench storage box with transparent lid. The ncludes 5 full-colour building instructions, inspiration r other models, and a user's guide.
uggested models include an automatic washing hine, an automatic supermarket door, an "intelligent" veyor belt, a robot arm, a programmable ferris wheel, eerable racing car etc., etc.
ne optosensor contains an infra red emitter and receiver d is a patented LEGO product. Its low mass, flexibility reliability makes it a powerful scientific tool in its own .



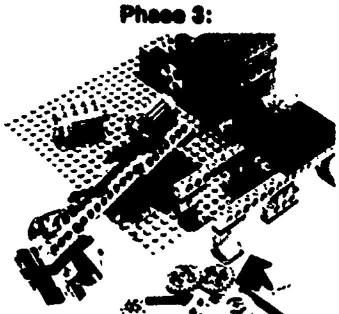
9750 LEGO Interface A
The interface comes with a special power supply and a user's guide.
The interface is specially designed for school use and is very robust, clearly labelled, and easy to use. It has six output ports, allowing combinations of 4.5 volt DC LEGO motors and light bricks to be connected. LEGO Optosensors can be plugged into the two inputs.
The interface is fully internally protected against overloads, etc., and is electrically isolated from the computer by optical coupling, meaning total safety for the user and the computer.

9750



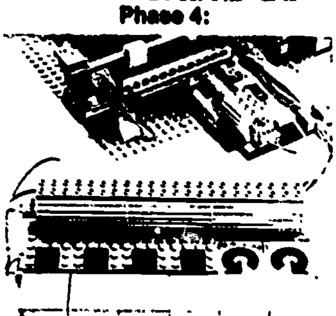
ı using LEGO Technic Control I

Phase 3:



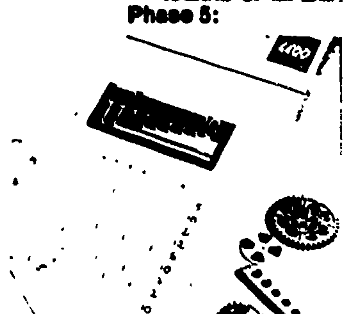
Build a model! You can either build a model from the building instructions from the LEGO Technic Control I Set, adapt the instructions, or build one according to your own designs.

Phase 4:



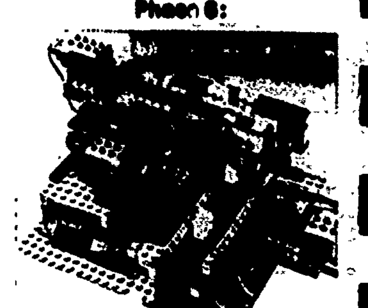
Testing! Now is the time to test and time the functions of your model. The LEGO Technic Manual Control panel allows full testing of all functions (except the sensor) without the problem of overrunning any action. Repeating of the manual control sequences can form the basic preprogramming for the computer. At this stage "feedback" is by the human eye!

Phase 5:

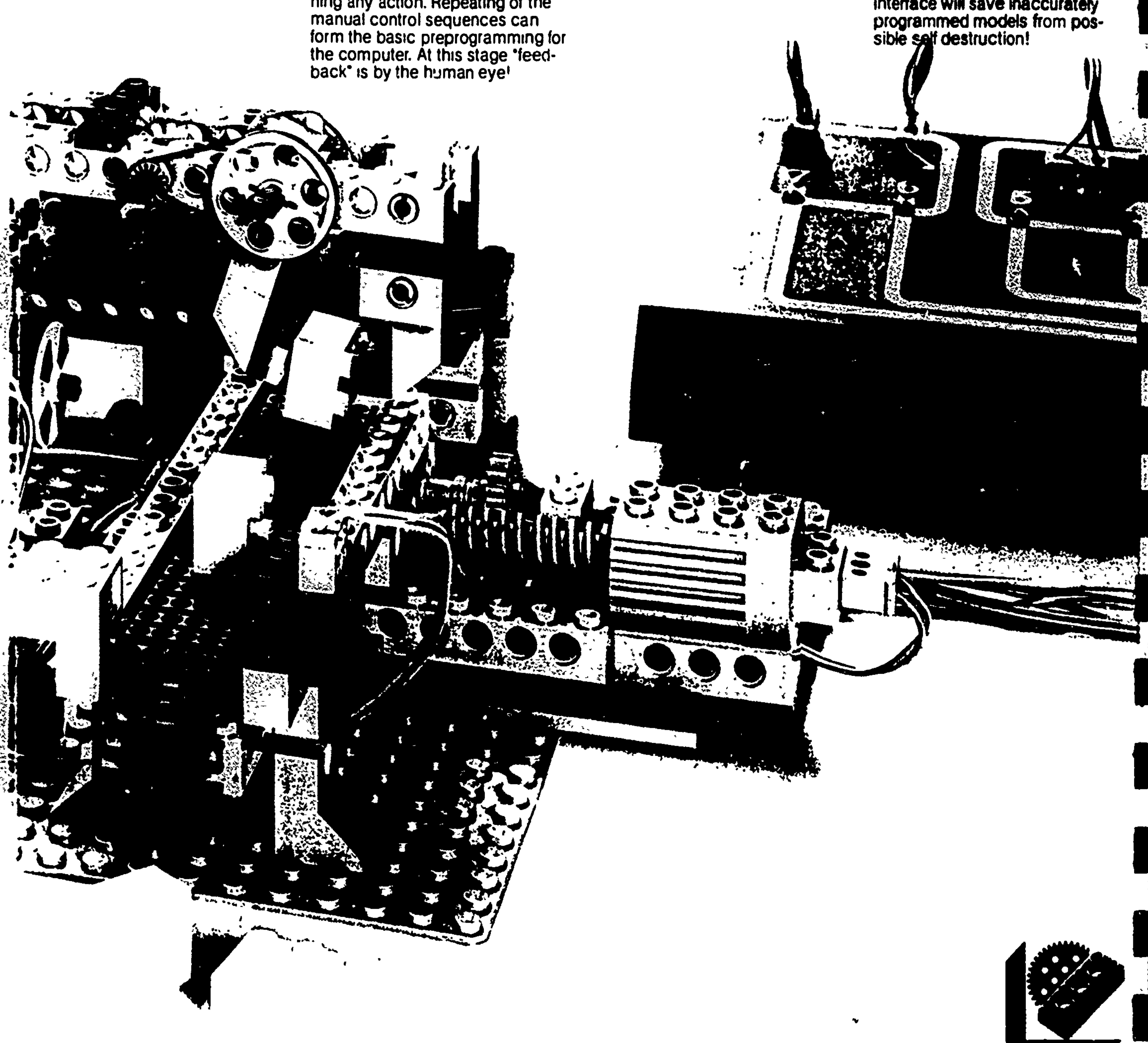


A few attempts at working the control sequence using the manual control panel and a watch should refine the sequence enough for it to be typed directly into the computer.

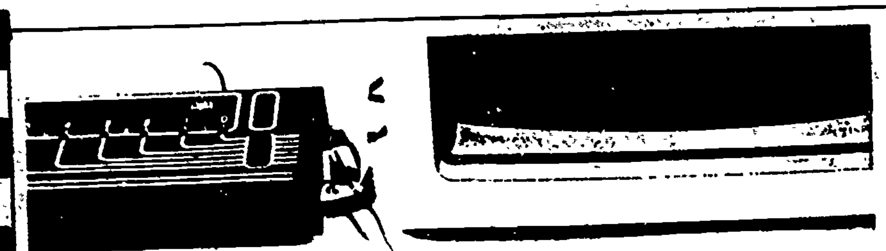
Phase 6:



And now the first run under computer control! Here the accurate timing and regulated power outputs of the automated system makes its presence felt. The emergency "Stop" button on the interface will save inaccurately programmed models from possible self destruction!

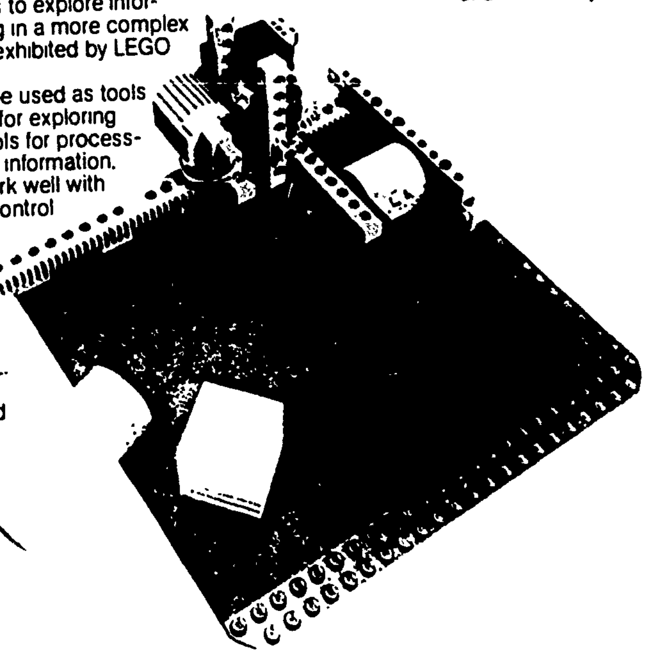


LEGO Technic Control II

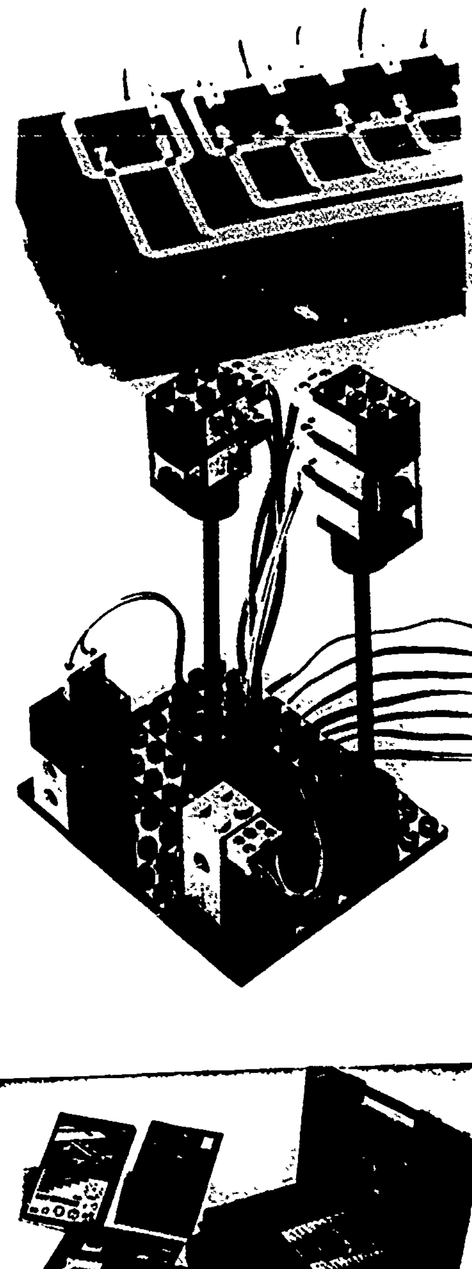


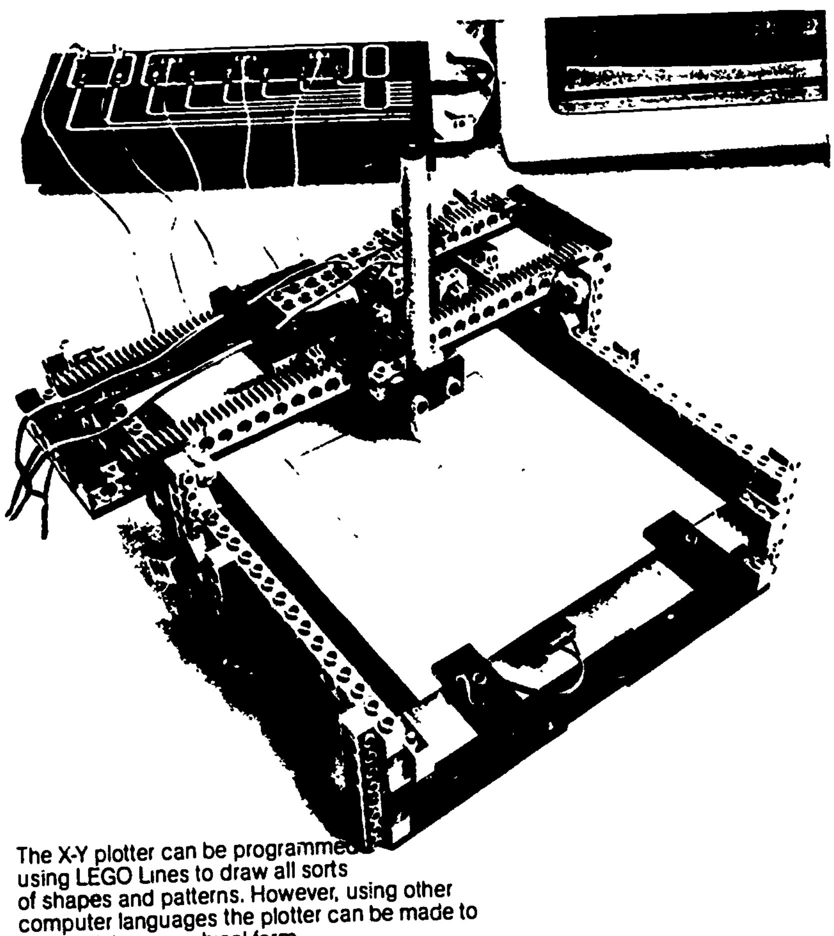
This advanced experimenters set features models which invite computing enthusiasts to explore information processing in a more complex fashion than that exhibited by LEGO Lines.
The models can be used as tools for science, tools for exploring control and as tools for processing and recording information. Some models work well with the LEGO Lines control program, others work best when programmed in BASIC LEGO or PASCAL. Explorations of time, velocity and acceleration can be made with the counting disk and optosensor (making low mass "ticker timer"!).

Here a student has programmed a model to accurately measure the size of different objects.



The traffic light model is simple to build but is a real challenge to program. Real traffic flow situations can be simulated and optosensors can be used to feedback information to the computer.





The X-Y plotter can be programmed using LEGO Lines to draw all sorts of shapes and patterns. However, using other computer languages the plotter can be made to record data in graphical form.

1092 LEGO Technic Control II
Contains 458 elements including special elements such as 3 LEGO 4.5 volt DC motors, 6 light bricks, and 2 LEGO optosensors, and counting discs. The set includes 5 full-colour building instructions, inspiration for other models, and a user's guide.
The models suggested include a measuring caliper, an X-Y plotter, an automatic warehouse, etc.

Classroom Packs for Busy Teachers.

The LEGO Education Division also supplies classroom packs of materials for a wide variety of subject areas and age levels, e.g.,

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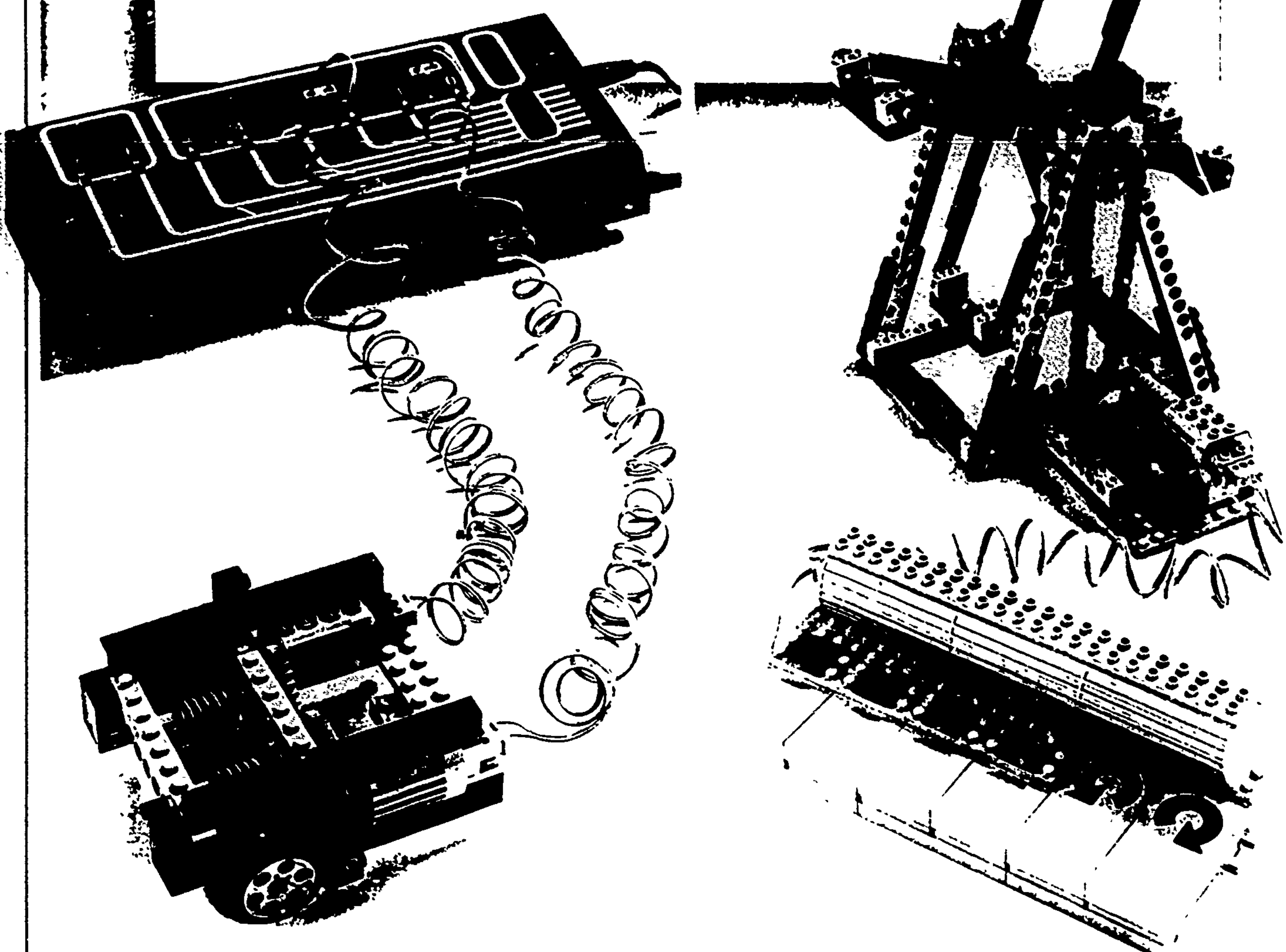
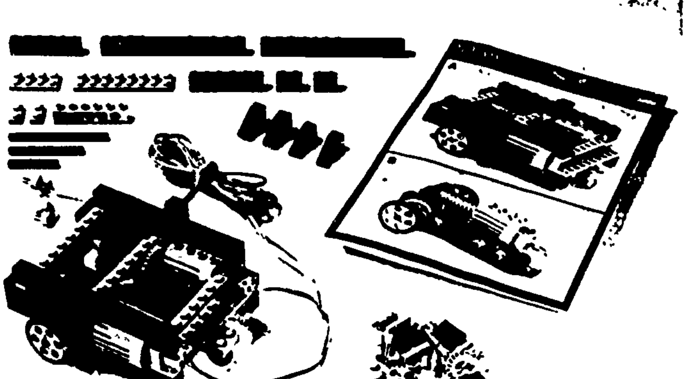
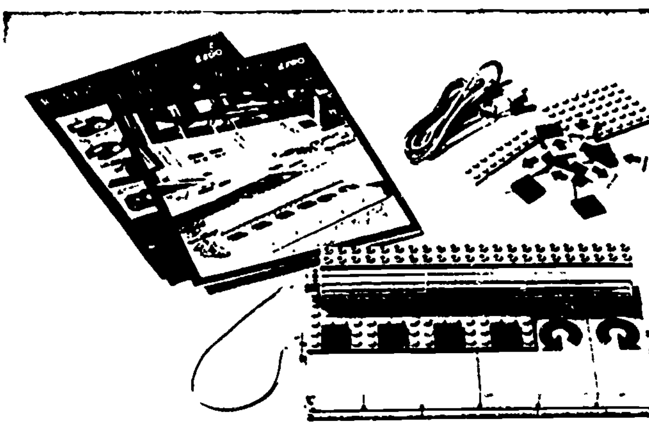




1038 LEGO Technic Universal Buggy I

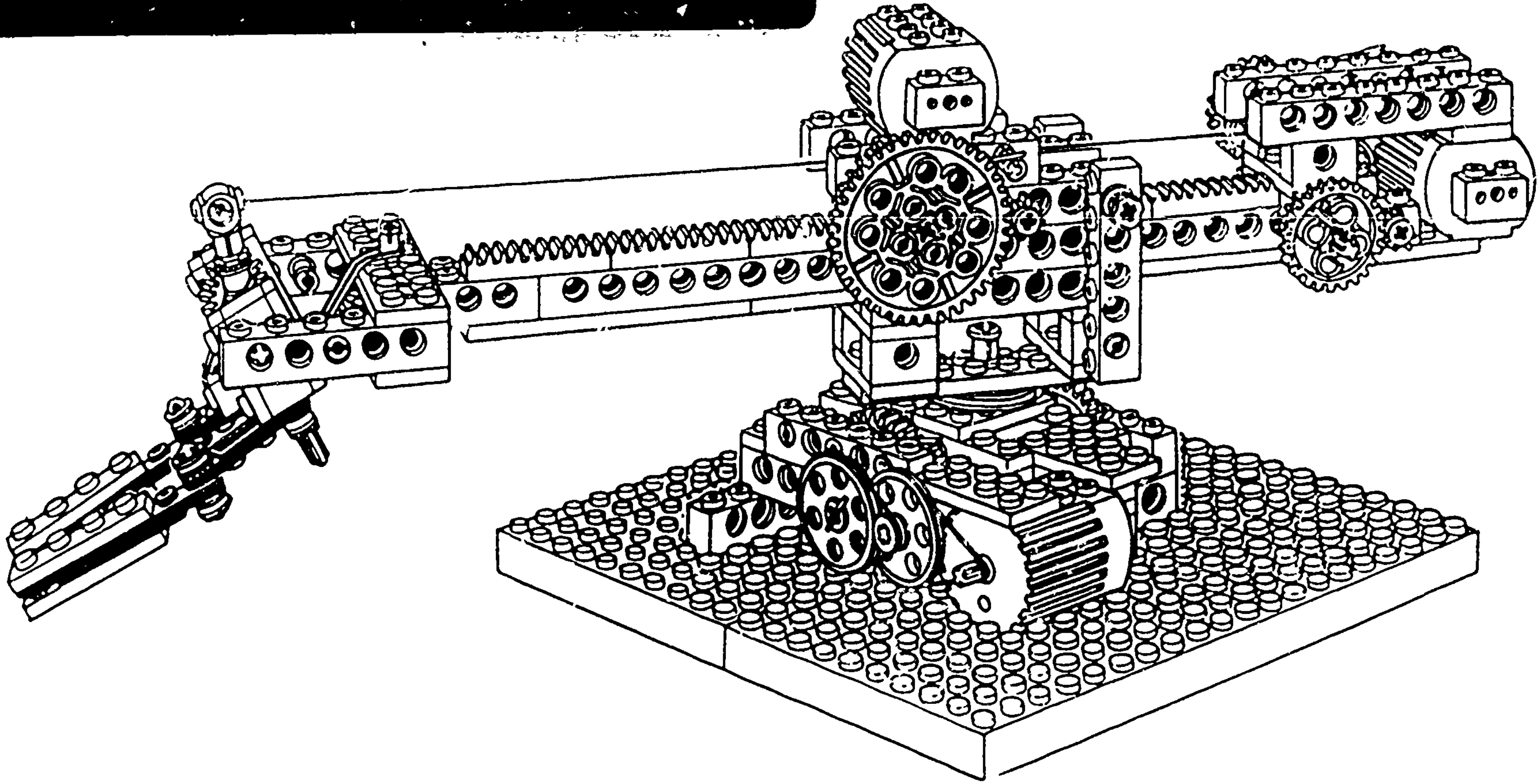
Contains 117 LEGO Technic elements including special elements such as 2 x 4.5 volt DC LEGO motors, worm gears, and gears. The set also includes a full-colour workcard for building 2 different models.
The 2-motor buggy is well-suited to demonstrate vehicle control by the use of either manual control – or with a LEGO Interface A – computer control
By adding a few bricks and a felt tip pen the Buggy can be used to draw geometric shapes or patterns just like a "Turtle".



1039 LEGO Technic Manual Control I

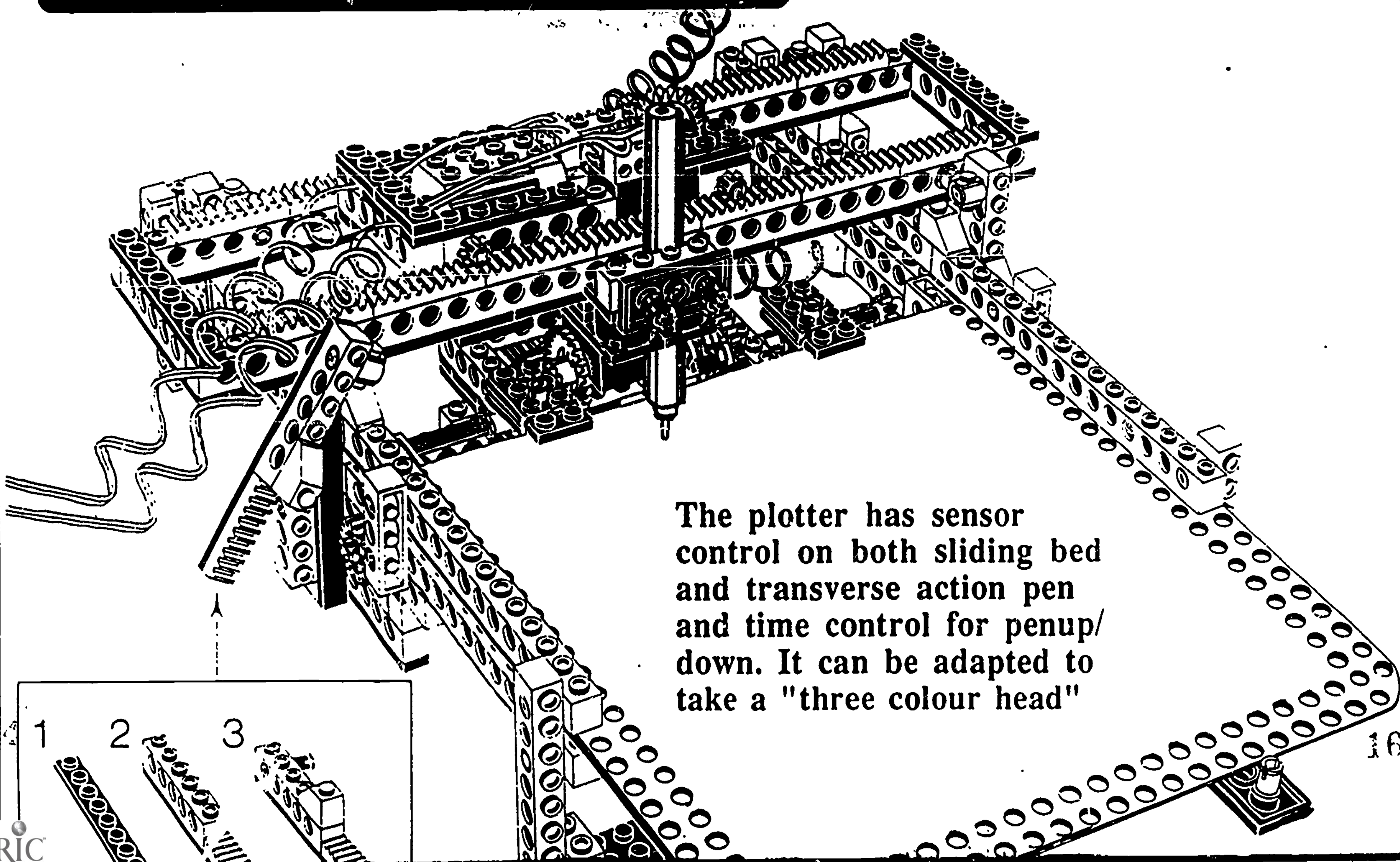
Contains 39 elements including special elements such as 3 switch panels, 3 electric cables and 1 battery box The set includes a full-colour workcard for assembling different control panels Excellent as an intermediate level between simple manual control and computer control

Polar Robot Arm



Although this arm has only three motors it has four degrees of freedom

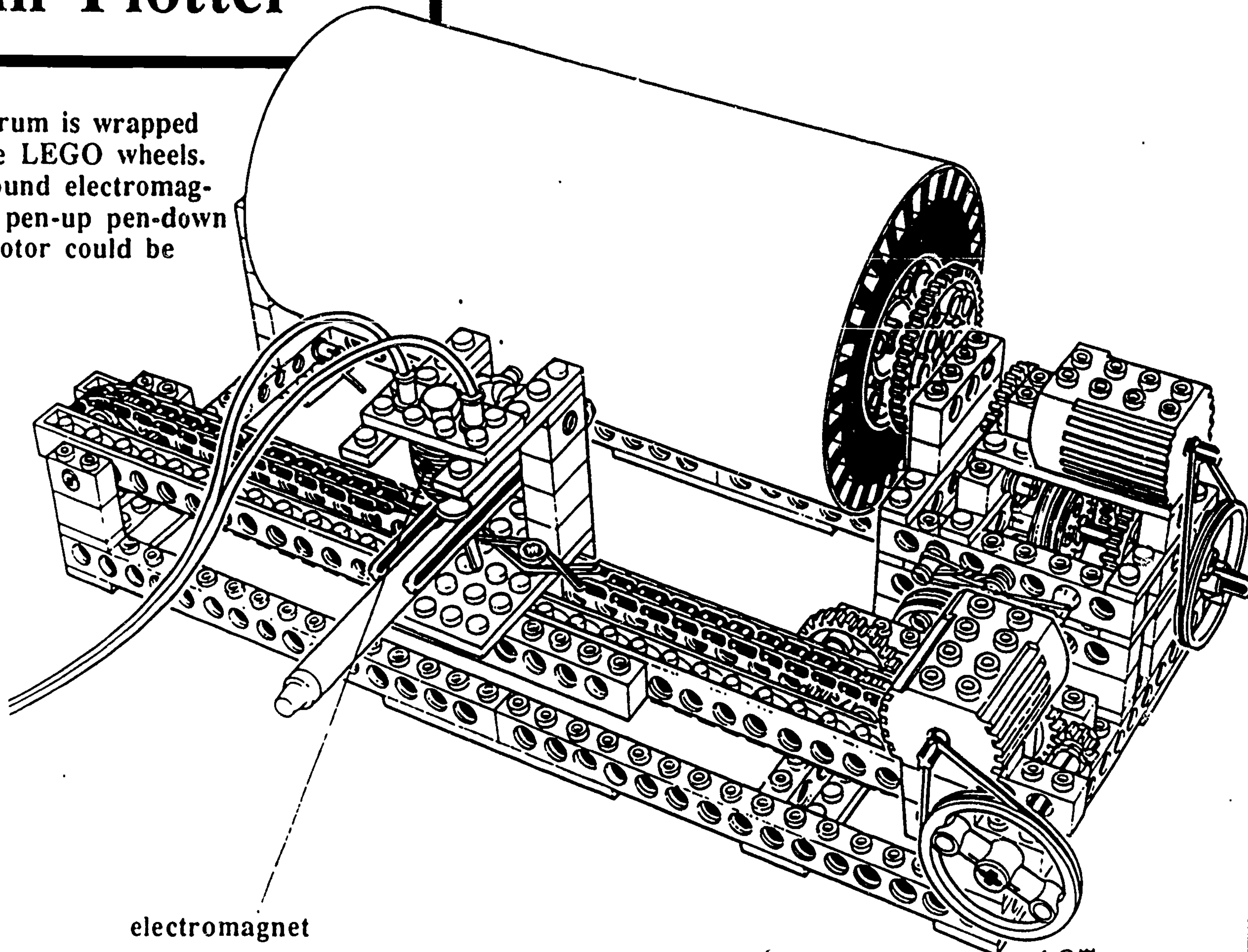
Flat Bed Plotter



The plotter has sensor control on both sliding bed and transverse action pen and time control for penup/ down. It can be adapted to take a "three colour head"

Drum Plotter

The cardboard drum is wrapped around two large LEGO wheels. Here, a hand wound electromagnet operates the pen-up pen-down mechanism. A motor could be useu instead.



Relativity

Relativity Pty Limited
A-62 Telegraph Road
Pymble NSW 2073
Australia

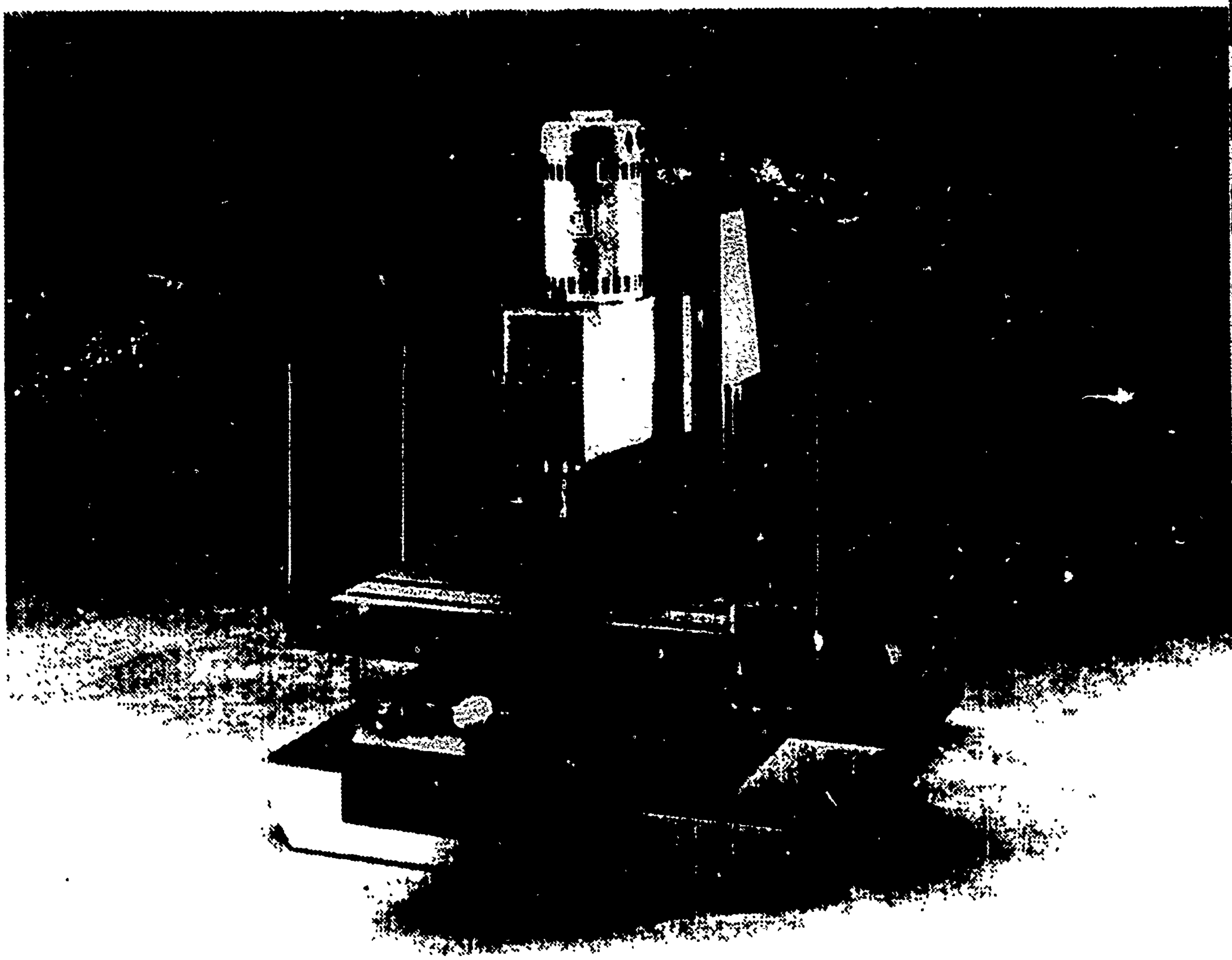
PO Box 288 Pymble NSW 2073

Telephone (02) 449 2575
(02) 44 7618
International +612 449 2575

Facsimile (02) 488 9967
International +612 488 9967

TMC-1000™

TABLETOP MACHINING CENTER



Description

The TMC-1000™ Tabletop Machining Center is a CNC mill system specifically designed for machining of small parts directly from an IBM® PC or compatible computer. Using standard NC G and M codes (EIA RS-274D), the menu-driven TMC-1000™ milling control program provides linear interpolation on the X, Y, and Z axes with circular interpolation on any two axes. Tool path verification software is included with the system to simulate motion of the tool on the computer screen.

The TMC-1000™ is a powerful, industrial grade 3-axis milling system with the capability to machine a large variety of parts in plastics, aluminum, and steel. With the spectraCAM™ option, users can easily machine parts directly from CAD drawings with many popular CAD packages such as AutoCAD®, VersaCAD®, and CADKEY®.

The TMC-1000™ system consists of the 3-axis mill, electronic interfacing, control software, and complete documentation

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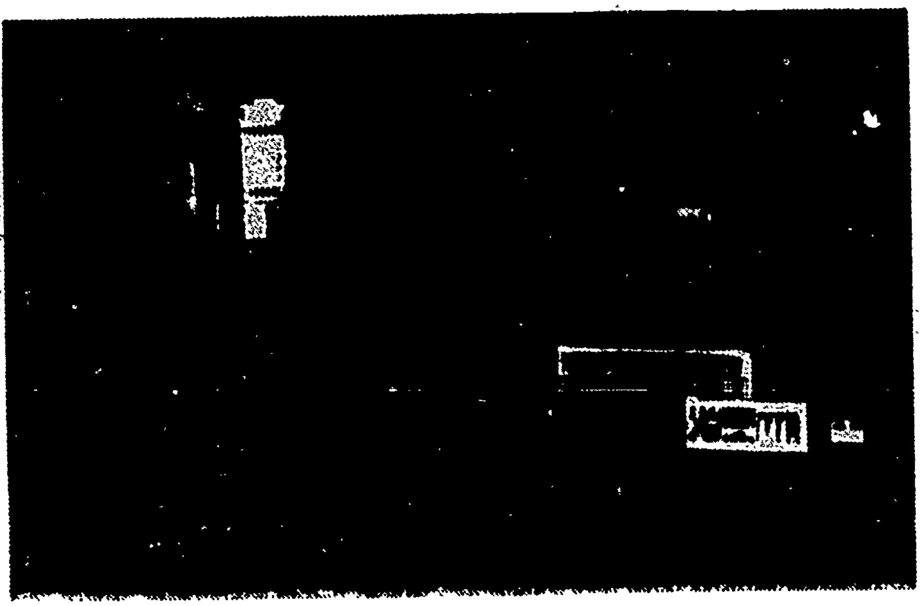


Specifications

MECHANICAL/ELECTRICAL

X axis travel	280 mm
Y axis travel	130 mm
Z axis travel	155 mm
Table size	460 x 160 mm
Throat	165 mm plus options
Feedrates	5 to 635 mm/min
Resolution (half-step)	0.006 mm
Repeatability	+/- 0.013 mm
Spindle	R8 taper
Spindle motor	1 HP DC Controlled
Spindle speed range**	500 - 5000 RPM
Hold down provision	(3) T-slots
Steppers	10.8 kg.cm 200 step
Power required	240V AC 50Hz 7.5A
**	10000 RPM option

STANDARD ACCESSORIES

draw bolt
3/8" hold down clamps
1/4" R8 milling collet
1/4" high speed steel end mill

PARTIAL LISTING OF NC CODES

G-Codes

G00–Rapid traverse
G01–Linear interpolation
G02–Circular interpolation–clockwise
G03–Circular interpolation–counterclockwise
G04–Dwell
G05–Pause
G17,G18,G19 Plane Selection for circular interpolation
G25,G26,G35,G36–Robot synchronization
G90–Absolute coordinates
G91–Incremental coordinates
G92–Preset position

M-Codes

M02–End of program
M03–Spindle on
M05–Spindle off
M10–Clamp air vise
M11–Unclamp air vise
M20–Chain to next program
M25,M26,M35,M36–Robot synchronization
M47–Repeat program

Features

MECHANICAL

- Hardened and ground steel linear ways
- Zero backlash ball screws on all axes
- Stiff sand cast base (1 in wall thickness)
- R8 spindle (compatible with Bridgeport* mill tooling)
- Bellows covers on Y and Z axis ways
- Hard anodized crosside surface

ELECTRICAL

- Direct robot interfacing capability
- High performance "chopper" drive for steppers
- Optically isolated AC Outputs
- Direct bus interface - 1mhz data transfer rate

SOFTWARE

- EIA RS-274D standard G&M code NC programming
- Simultaneous linear interpolation on all three axes
- Circular interpolation with center point or radius entry on any two axes
- Helical interpolation
- Instantaneous X, Y, and Z-axis position readout on computer display
- Tool length offset for up to four tools
- Programmable spindle on/off
- Keyboard and/or Microsoft™ compatible mouse operated menus
- Built-in full screen NC program editor with mouse control
- Graphic tool path verification
- Programmed pause, dwell, chain, and repeat functions
- Computer-controlled jog, go to position, and traverse motion
- Scaling of part programs
- Inch and metric programming
- Incremental and absolute programming
- Program memory for 1000 blocks expandable with chaining command
- Error messages
- Operational mode single block and continuous run
- HELP functions
- CAD/CAM interface option
- Computer disk storage of NC programs on hard or floppy disk drives

SAFETY FEATURES

- Transparent 1/4" Lexon* safety shield
- Emergency stop switch on front of machine

Options

TMC-1200 Milling Machinist Kit - Includes: milling vise with hold-down clamps, R8 Collet set 1/8"-1/2", high speed end mill set.

TMC-1400 Air Vise Robotic Interface - Includes: Air vise, solenoid valve, and all tubing required to interface with 1/4" pipe fittings from filtered shop air (60-70 psi). Air compressor option is also available

SL-654 spectraCAM™ - CAM program allows for automatic programming of the TMC-1000 and input from part geometry created using AutoCAD®, VersaCAD®, CADKEY®, and other popular CAD packages which support the DXF file format

Ordering Information

MODEL NUMBER

TMC-1000 Tabletop Machining Center - IBM PC, PCXT, AT, Personal System /2 models 25 and 30, or 100% compatible CNC Mill System

Specifications subject to change without notice.

LIGHT MACHINES CORPORATION

Relativity Pty Limited is incorporated in New South Wales as trustee of the Relativity Unit Trust

Relativity

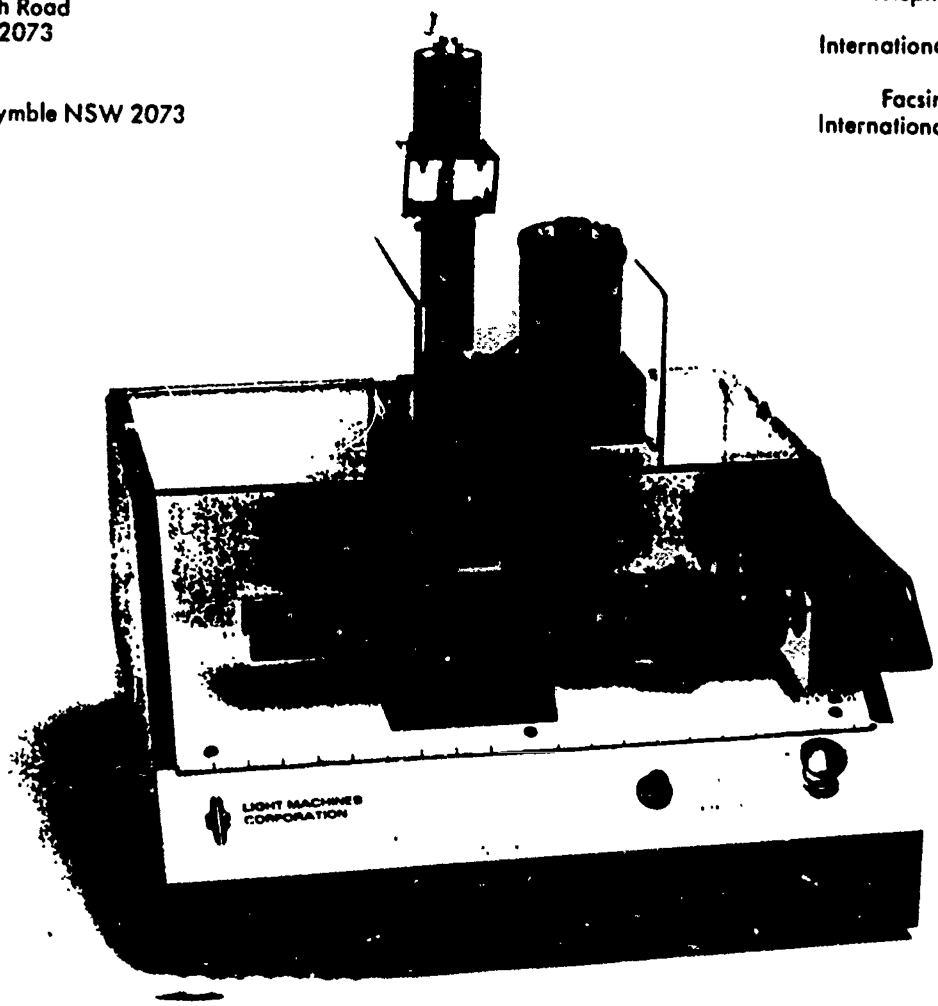
spectraLIGHT ™ CNC MILL SYSTEM

Relativity Pty Limited
A-62 Telegraph Road
Pymble NSW 2073
Australia

PO Box 288 Pymble NSW 2073

Telephone (02) 449 2575
(02) 44 7618
International +612 449 2575

Facsimile (02) 488 9967
International +612 488 9967



Description

The spectraLIGHT Mill system is an affordable and complete solution for hands-on CNC.

The system includes an NC mill with software and an electronic controller which connects directly to the IBM* PC, XT™, AT*, Personal System/2™ model 30, 100% IBM compatible computers or the Apple*IIe™, and IIGS™ computers. The controller allows for direct connection to robotics systems for complete FMS

The menu-driven computer software has a built-in editor and uses standard NC codes (EIA RS 274D), including three-axis linear interpolation and two-axis circular interpolation. Tool path verification, a standard feature of the system, facilitates the graphic simulation of tool motion and the removal of material.

The spectraLIGHT Mill provides a comprehensive, cost-effective and easy-to-use method

Specifications

MECHANICAL/ELECTRICAL

Table to spindle	205 mm
Throat	90 mm
X axis travel	230 mm
Y axis travel	130 mm
Z axis travel	140 - 160 mm
Feedrates	2.5 - 239 mm/min
Resolution (half-step)	0.003 mm
Spindle bore	9.5 mm
Spindle motor	0.5HP AC (0.37 kW)
Spindle speed range	200 - 2000 RPM
Hold down provision	(2) T-slots
Steppers	7.2 kg.cm (200 steps/rev)
Power required	240V AC 6A max.
Base dimension	560 x 560 mm
Shipping weight	approx. 45 kg

SOFTWARE/DOCUMENTATION

IBM model SL-354 - Programming capability 1-1000 NC blocks
Disk storage capacity approximately 20,000 NC blocks
Requires 256K RAM, one 5-1/4" floppy disk drive, color graphics adaptor

Apple model SL-356 - Programming capability 1-300 NC blocks
Disk storage capacity approximately 5 000 NC blocks
Requires 64K RAM, one 5-1/4" floppy disk drive

Control and verification software on diskette
Comprehensive user's manual included

STANDARD ACCESSORIES

5/16"-24 draw bolt and washer
1/4" milling collet
1/8" high speed steel end mill

SAFETY FEATURES

Full transparent Lexan* safety shield with interlock switch
Emergency stop switch on front panel
Adjustable limit switch on mill column

Specifications are subject to change without notice

Ordering Information

MODEL NUMBERS

SL-354 spectraLIGHT IBM PC and compatible CNC Mill System

SL-356 spectraLIGHT Apple CNC Mill System

Features

- Backlash compensation
- Full-step and half-step resolution
- Direct robot interfacing capability
- RS-274D standard G&M code NC programming
- Compatible with CAD/CAM packages to interface with CAD
- Programmable spindle on/off
- Computer-controlled jog and traverse motion
- Instantaneous X and Z-axis position readout on computer display
- Built-in NC program editor
- Graphic toolpath verification
- Programmed pause, dwell, chain, and repeat functions
- Manual and programmable AC outlet control
- Scaling of part programs
- Single step mode
- Inch and metric programming
- One-year limited warranty

PARTIAL LISTING OF NC CODES FOR spectraLIGHT MILL SYSTEM

G-Codes
G00–Rapid traverse
G01–Linear interpolation
G02–Circular interpolation–clockwise
G03–Circular interpolation–counterclockwise
G04–Dwell
G05–Pause
G25,G26,G35,G36–Robot synchronization
G90–Absolute coordinates
G91–Incremental coordinates

M-Codes
M02–End of program
M03–Spindle on
M05–Spindle off
M10–Clamp air vise
M11–Unclamp air vise
M20–Chain to next program
M25,M26,M35,M36–Robot synchronization
M47–Repeat program

Options

SL-204 Milling Machinist Kit – Includes: Milling Vise with hold-down clamps, 1/8" and 3/16" milling collets, 3/8" end mill holder, 3/16" and 1/4" end mills with 1/4" shanks, boring head, boring tool.

SL-414 Air Vise Robotic Interface – Includes: Air vise, solenoid valve, and all tubing required to interface with 1/4" pipe fittings from filtered shop air (60-100 psi). Air compressor option is also available

Relativity

Relativity Pty Limited
A-62 Telegraph Road
Pymble NSW 2073
Australia

PO Box 288 Pymble NSW 2073

Telephone (02) 449 2575
(02) 44 7618
International +612 449 2575

Facsimile (02) 488 9967
International +612 488 9967

Relativity

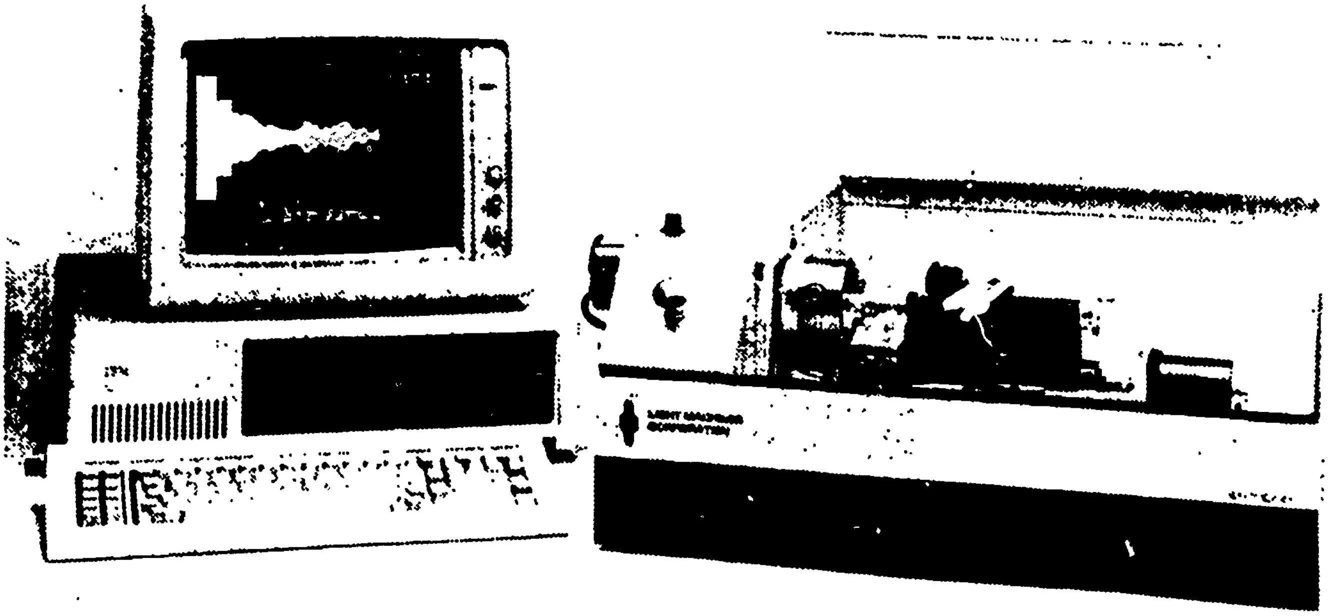
spectraLIGHT™ PC CNC LATHE SYSTEM

Relativity Pty Limited
A-62 Telegraph Road
Pymble NSW 2073
Australia

PO Box 288 Pymble NSW 2073

Telephone (02) 449 2575
(02) 44 7618
International +612 449 2575

Facsimile (02) 488 9967
International +612 488 9967



Description

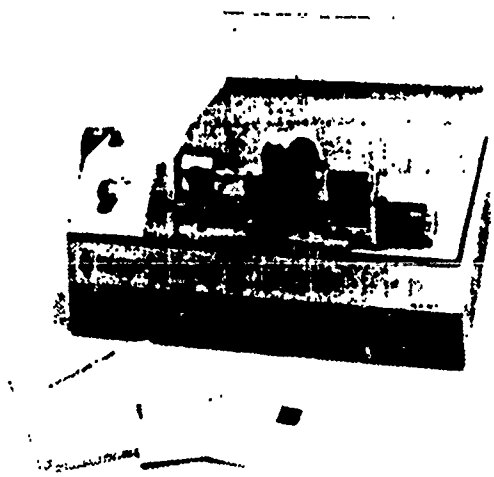
The spectraLIGHT PC system is the affordable and complete solution for hands-on CAD/CAM/CNC.

The system includes an NC lathe with complete software and an electronic controller which directly connects to IBM® PC, XT™, AT®, Personal System/2™ model 30 or 100% compatible computers. The controller allows for direct connection to an air chuck, robot, and the conversion of the lathe to a full three-axis computer-controlled CNC milling machine.

The menu-driven computer software has a built-in editor and uses conventional CNC code, including linear and circular interpolation. Tool path verification, a standard feature of the system, facilitates the graphic simulation of tool motion and the removal of material.

Multiple tool programming with offsets for up to four tools is also included. The optional Graphic-Aided Parts Programming package allows for complete CAD/CAM/CNC integration.

The spectraLIGHT PC provides a comprehensive, cost-effective, and easy-to-use method for hands-on of CNC.



Features

- Backlash compensation
- Full-step and half-step resolution
- Direct robot interfacing capability
- RS-274D standard G&M code NC programming
- Multiple tool programming capability for up to four tools
- Programmable spindle on/off
- Computer-controlled jog and traverse motion
- Instantaneous X and Z-axis position readout on computer display
- Built in NC program editor
- Graphic toolpath verification
- Programmed pause, dwell, chain, and repeat functions
- Manual and programmable AC outlet control
- Scaling of part programs
- Single step mode
- Inch and metric programming
- Easy conversion to mill with milling option
- One-year limited warranty

Front and rear view of controller in rack mount style enclosure showing AC outlet hookups, mill and robot interfaces.

Specifications

MECHANICAL/ELECTRICAL

Swing over bed	90 mm
Swing over cross slide	32 mm
Distance between centers	205 mm
Cross slide length	205 mm
Spindle motor	0.5HP AC (0.37 kW)
Spindle speed range	200-2000 RPM
Spindle bore	10 mm
Spindle taper	#1 MT
Feedrates	2.5 to 230 mm/min
Resolution (half-step)	0.003 mm
Positioning repeatability	+/- 0.013 mm
Hold down provision	(2) T-slots
Steppers	7.2 kg.cm (200 steps/rev)
Power required	240V AC 6A max.
Base dimension	635 x 546 mm
Shipping Weight	approx. 45 kg

SOFTWARE/DOCUMENTATION

Programming capability 1-1,000 NC blocks
Disk storage capacity approximately 20,000 NC blocks
Requires 256K RAM, one floppy disk drive, color graphics adapter
Control and verification software on diskette
Comprehensive user's manual

STANDARD ACCESSORIES

Toolpost with HSS tool bit.
Industrial grade chuck, 3" diameter, 3-jaw self centering with 'T' drive key and 2 sets of jaws.

SAFETY FEATURES

Full transparent Lexan® safety shield with interlock switch
Emergency stop switch on front panel
Adjustable limit switch on lathe bed

Specifications are subject to change without notice

Ordering Information

MODEL NUMBER

SL-104 spectraLIGHT PC CNC Lathe System

Options

SL-706 CURRICULUM PACKAGE - A comprehensive NC training package which includes an instructor's guide, transparencies, and a student manual (SL-707).

SL-202 MACHINIST KIT - Includes drawbar and collet set, high-speed tool set, carbide tool set, steady rest, Allen 'T' driver, cut-off tool and holder, #0 and #1 dead centers, live center, center drill set, face plate, lathe dog, Jacobs chuck, two 2-position tool posts.

SL-304 MILLING OPTION - converts spectraLIGHT PC into a 3-axis programmable milling machine. System includes 3-axis mill software, interfacing, and vertical column with spindle and stepper drive.

SL-602 GRAPHIC-AIDED PARTS PROGRAM (GAPP) - a graphic CAD/CAM package that enables the operator to draw two-dimensional parts on the computer monitor and generate roughing cuts using a "mouse." The software will then automatically generate an NC part program from the drawing which can be stored on disk. Complete documentation and software diskette are included. This package may be ordered without the spectraLIGHT lathe and used as a stand alone programming station with tool path verification software included.

Relativity

Relativity Pty Limited
A-62 Telegraph Road
Pymble NSW 2073
Australia

PO Box 288 Pymble NSW 2073

Telephone (02) 449 2575
(02) 44 7618
International +612 449 2575

Facsimile (02) 488 9967
International +612 488 9967

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Australia

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Telephone (02) 449 2575
(02) 44 7618
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Facsimile (02) 488 9967
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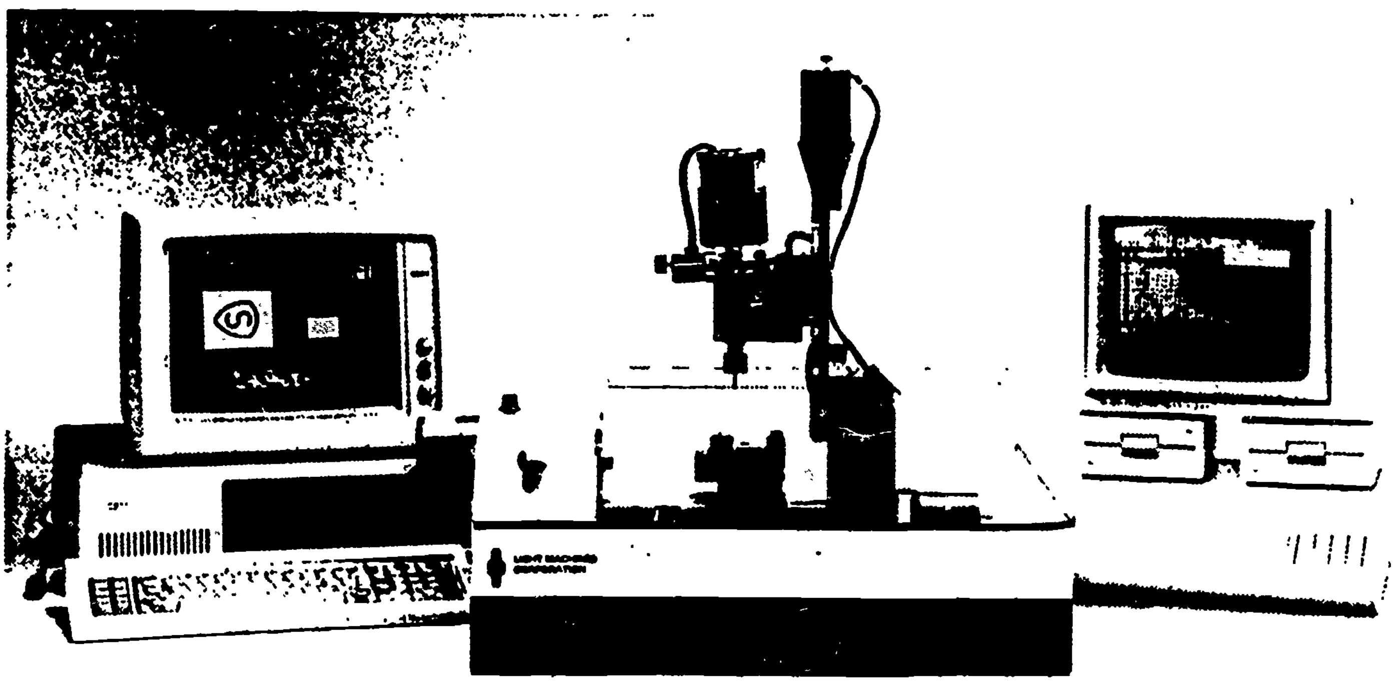
spectraLIGHT™ CNC MILLING OPTION



Description

The Milling Option for the spectraLIGHT system is an economical way to add CNC milling capabilities to the spectraLIGHT lathe. The system consists of a special stepper motor-driven vertical column with headstock and spindle motor that mounts on the spectraLIGHT lathe bed, allowing 3-axis milling operations to be performed. Using standard NC codes (EIA RS 274D), the menu-driven spectraLIGHT milling control program provides linear interpolation on the X, Y, and Z axes with circular interpolation on the X and Y axes. Tool path verification software is included with the system to simulate motion of the tool on the computer screen.

The spectraLIGHT Milling Option offers instructors the capability of introducing students to both CNC lathe and milling operations cost-effectively. Multiple systems can be configured as lathes and/or mills, thus completing students' exposure to CNC concepts.

This option consists of a motorized vertical milling column, control software, and complete documentation. The spectraLIGHT lathe can be converted to a mill in a matter of minutes with relative ease.

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Specifications

MECHANICAL/ELECTRICAL

Throat	65 mm
Travel - X axis	115 mm
Travel - Y axis	170 mm
Travel - Z axis	140 mm
Spindle motor	0.25 HP AC (0.18 kW)
Spindle speed range	200 - 2000 RPM
Spindle bore	10 mm
Spindle taper	#1 MT
Feedrates	2.5 to 230 mm/min
Resolution (half step)	0.003 mm
Positioning repeatability	+/- 0.013 mm
Hold down provision	(2) T-slots
Stepper motor	7.2 kg.cm (200 steps/rev)
Dimensions	50GH x 200W x 230L
Shipping weight	approx 10 kg

SOFTWARE/DOCUMENTATION

Programming capability. 1-300 NC blocks on Apple®
1-1,000 NC blocks on IBM PC®

Disk storage capacity. approx 5,000 NC blocks on Apple.
approx. 20,000 NC blocks on IBM PC

Control and verification software on diskette

Comprehensive users manual/training guide

SAFETY FEATURES

Transparent safety shield

Emergency stop switch on front panel of lathe stops mill spindle rotation

Adjustable limit switch prevents tool from hitting cross-slide

Specifications are subject to change without notice

Features

- Backlash compensation
- Full-step and half-step resolution
- Direct robot interfacing capability
- RS-274D standard G&M code NC programming
- Programmable spindle on/off
- Computer-controlled jog and traverse motion
- Instantaneous X, Y, and Z-axis readout on computer display
- Built-in NC program editor
- Graphic toolpath verification
- Programmed pause, dwell, chain, and repeat functions
- Manual and programmable AC outlet control
- Scaling of part programs
- Single step mode
- Inch and metric programming
- Lathe bed mount allows for quick conversion from lathe to mill
- One-year limited warranty

Ordering Information

MODEL NUMBERS

SL-304 - Milling option for spectraLIGHT PC (SL-104)

SL-305 - Milling option for spectraLIGHT (SL-105) - Note: this model is a 2-1/2 axis system Some of the specifications above do not apply

SL-306 - Milling option for spectraLIGHT II (SL-106)

Options

SL-204 MILLING MACHINIST KIT - includes milling vise milling collets (1/8", 3/16", and 1/4"), 3/8" end mill holder, end mill set (1/8", 3/16", and 1/4") with 1/4" shanks, hold down set, boring head, boring tool with 3/8" shank

SL-501 FOUR JAW CHUCK - includes 4-jaw chuck, 4 jaw hold down set, and chuck -to-"T" slot adapter

LIGHT MACHINES CORPORATION

Relativity

Relativity Pty Limited
A-62 Telegraph Road
Pymble NSW 2073
Australia

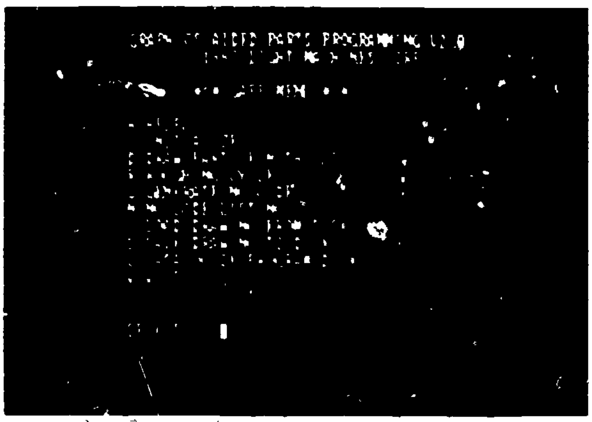
PO Box 288 Pymble NSW 2073

Telephone (02) 449 2575
(02) 44 7618
International + 612 449 2575

Facsimile (02) 488 9967
International + 612 488 9967

GRAPHIC-AIDED PARTS PROGRAMMING

A CAD/CAM PART PROGRAMMING PACKAGE FOR THE spectraLIGHT™ CNC LATHE SYSTEM



GAPP MENU – The user-friendly GAPP menu is displayed on the monitor. The selections are ordered in a logical progression with help functions available.

DRAW PART (FINISH CUT) – Drawing the part, or finish cut, is done with the keyboard or mouse for line or radius moves. The stock outline is displayed after setting up with INITIALIZE

CYCLE – Roughing cuts are entered with the mouse or to remove stock before the finish cut is made

Description

OVERVIEW

The Graphic-Aided Parts Program (GAPP) is a graphic-oriented software package that allows users to design parts and generate NC code that is compatible with the spectraLIGHT CNC lathe system.

Using a "mouse-equipped" Apple® or IBM®PC computer, users can create their own part designs on the computer monitor screen. This Computer-Aided Design (CAD) feature includes profile, roughing cuts, and fine-mode resolution to .0001".

GAPP's user-friendly software includes help functions and error messages that prompt the user through correct programming procedures at every step. GAPP will automatically generate a complete NC code sequence from the finished design, thus providing the Computer-Aided Manufacturing (CAM) link between CAD & CNC.

The GAPP program includes the Tool Path Verification Program that graphically displays the NC cutting process resulting in the finished part. With this, users can verify the results of their efforts before running the NC program on the spectraLIGHT lathe.

STEPS TO CREATE A PART USING GAPP

- Design part and select tooling; sketch dimensions
- Start GAPP; initialize stock size and units
- Draw the part with the finish cuts on the screen; enter M-code functions by keyboard or mouse
- Enter the roughing cuts graphically
- Generate the NC code
- List the code on the screen
- Save the drawing
- Run tool path verification on the program generated
- Machine the part on the lathe

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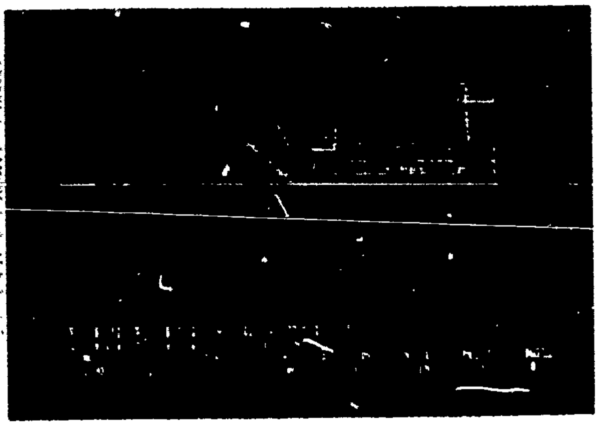
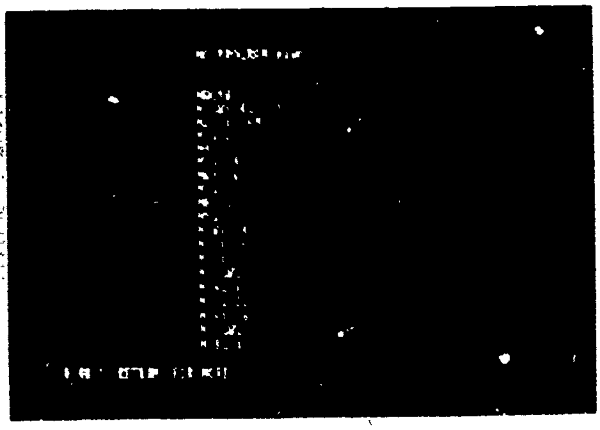
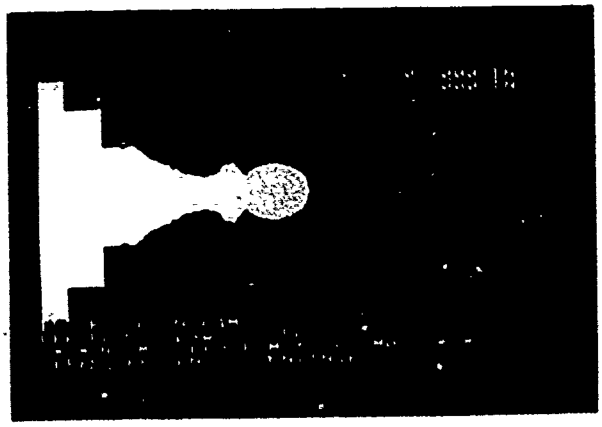


FINISHED DRAWING GAPP's finished drawing showing both the finish cuts and roughing cuts



GENERATE NC CODE - The finished drawing is converted into NC code that can control the spectroLIGHT lathe to machine a part



TOOL PATH VERIFICATION The GAPP generated NC code can be graphically verified on the monitor screen before a part is machined on the spectroLIGHT lathe

Features

- Easy to use
- Logical progression with menu
- Enter arc center by center point or radius with mouse
- Activate M codes by pointing and clicking with mouse
- Standard or metric measurements
- Absolute and incremental position display
- Locate position to .0001 with fine resolution mode
- Undo command and edit function for both line and radius cuts
- Generation of NC codes from graphic drawings (CAD/CAM)

Options

SL-803 APPLE IIe™ MOUSE - Graphic input device for use with GAPP program on Apple IIe or II+™ computers (The Apple IIGS™ computer comes with a mouse).

SL-813 IBM PC COMPATIBLE MOUSE - Graphic input device for use with GAPP program on IBM PC or compatible computers.

Ordering Information

MODEL NUMBERS

SL-601 – Graphics-Aided Parts Programming package for the spectroLIGHT (Apple system SL-105) Requires 64K RAM and Apple mouse.

SL-602 - Graphics-Aided Parts Programming package for the spectroLIGHT PC (IBM PC system SL-104) Requires 256K RAM . Microsoft™-compatible mouse, and IBM color graphics adapter or equivalent

SL-603 – Graphics-Aided Parts Programming package for the spectroLIGHT II (Apple system SL-106) Requires 64K RAM and Apple mouse.

Specifications are subject to change without notice

LIGHT MACHINES CORPORATION

Relativity

Relativity Pty Limited
A-62 Telegraph Road
Pymble NSW 2073
Australia

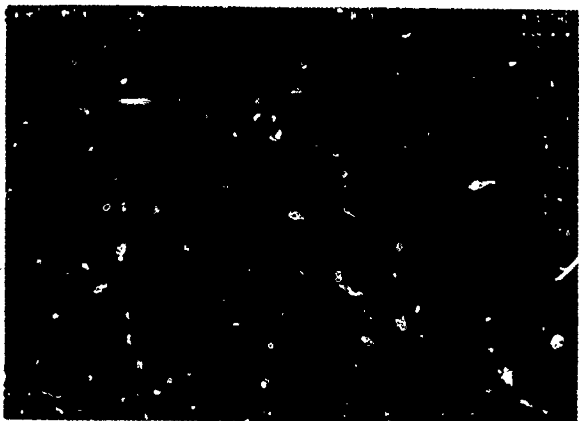
PO Box 288 Pymble NSW 2073

Telephone (02) 449 2575
(02) 44 7618
International +612 449 2575

Facsimile (02) 488 9967
International +612 488 9967

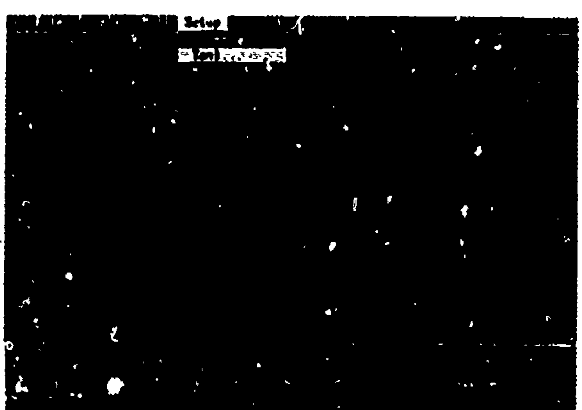
spectraCAM™

A CAD/CAM PART PROGRAMMING PACKAGE FOR THE spectraLIGHT™ CNC SYSTEM



AUTOCAD® DRAWING - Partially Dimensioned Autocad drawing with part geometry stored on different drawing layers. Part is saved in DXF file format

spectraCAM PART GEOMETRY - The DXF file is loaded into spectraCAM. The geometry is shown on different layers to be machined in different cycles



TOOL AND MATERIAL SELECTION - Using the mouse to select pop-up items, the tool and material are selected using the spectra- built in tool and material libraries

Overview

The spectraCAM™ CAD/CAM software package is a graphic oriented parts programming package that can import part geometry from popular CAD programs such as AutoCAD*, VersaCAD*, and CADKEY*, and output NC code compatible with the spectraLIGHT Lathe, Mill, and Mill Option.

The spectraCAM™ package runs on an IBM* PC XT™ or compatible computer. Part geometry for milling can be transferred using the popular DXF format from a CAD package. The program is extremely easy to use, and uses a Microsoft* compatible mouse for pop-up menus and graphic entry.

The mill CAM module automatically generates contour milling, pocketing, and facing with a sophisticated cutter-compensation algorithm for 2-1/2 axis milling from the part geometry. Lathe CAM generates roughing cycles and contouring.

Extensive help is available on line, and pop-up "dialog" boxes prompt the user for information when necessary.

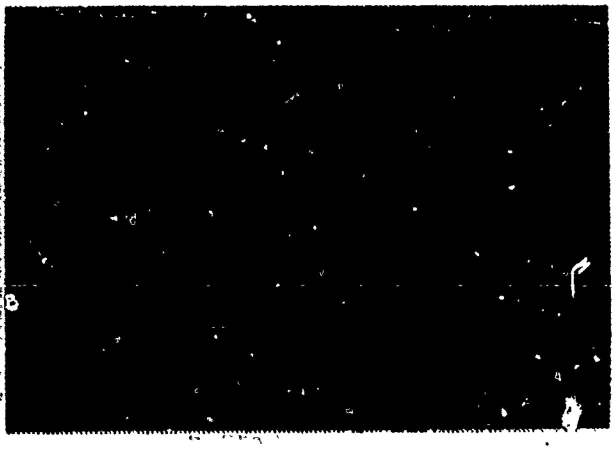
The spectraCAM™ package then outputs the NC code to a text file which can be graphically verified or run on the spectraLIGHT Mill or Lathe.

The spectraCAM™ software package is a powerful tool to provide total hands-on training from CAD to CNC and provide the missing link to convert CAD drawings into finished parts completely automatically. The spectraCAM™ package was designed specifically for educational and industrial users as a comprehensive CAD/CAM package that is very easy to use.

STEPS TO CREATE A PART USING spectraCAM

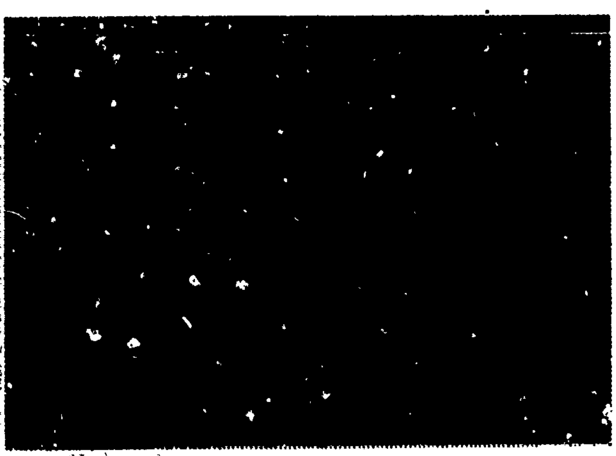
- Design part on CAD system such as AutoCAD, and save file in DXF format.
- Load part geometry into spectraCAM
- Generate toolpath using automatic contouring, roughing facing, and pocketing routines.
- Save toolpath as NC program.
- Run the spectraLIGHT control program to graphically verify the program, then machine the part.

LIGHT MACHINES CORPORATION



SETTING POCKETING PARAMETERS - The parameter dialog box for pocketing is used to select step size, cutter compensation and other parameters

FINISHED TOOLPATH - The finished tool path is shown for the two pocketting cycles. Tool motion can be simulated with the cutter m...ing along the path when the toolpath is generated



NC CODE LISTING - The toolpath is converted into NC code which can control the spectraLIGHT Mill to machine the part

System Requirements

IBM* PC XT™, AT™, PS/2™ or compatible with at least 512K RAM, floppy disk, hard disk, parallel port, 8087 (80287 on AT) numeric coprocessor, and EGA or CGA monitor and card (EGA recommended)

Features

Reads DXF file format for CAD Geometry.
Zoom and pan available in middle of program
Switch layers in middle of program
Assign Z depth for each layer (mill)
Contouring cycle with cutter compensation
Facing Cycle
Pocketing Cycle
Roughing Cycle (lathe)
Outputs standard G&M codes compatible with spectraLIGHT
Built-in tool and material library

Ordering Information

MODEL NUMBER
SL-654 - spectraCAM CAD/CAM package for the spectraLIGHT for IBM* PC or compatible computers.

Relativity

LIGHT MACHINES CORPORATION

With CAMM-1 you can write your own ticket!

Roland puts you at the cutting edge of technology with its desk top sign-maker, CAMM-1, the ultimate unit for both plotting and cutting functions. CAMM-1 quickly produces cut out characters, signs and advertisements for in-store merchandising and, simply replacing the knife with your selection of pens, provides a perfect method for drawing posters, price tags, announcements, letters and graphics.

Compatible with almost all popular CAD software, you can produce simple or intricate designs on your personal computer, safe in the knowledge that output to your CAMM-1 will ensure perfect, professional, eye-catching results. With CAMM-1, you can also edit or modify data for constant update requirements.

Features include:

- Inbuilt alpha-numeric fonts.
- A 1K data buffer.
- 8K re-plot buffer for repeat output.
- ...ation of configuration data even when ...r is off.
- Dimensions of 735mm (W) X 275mm (D) X 200mm (H), offering versatility and lightweight characteristics, ideal for counters, desktops and portability.
- Use of adhesive sheets, rolls of paper or similar material in widths up to 500mm for continuous operation.

CAMM-1 is the ideal choice when it comes to selecting your next sign writer. Call Roland for the name of your nearest Authorised Roland CAMM dealer, for a free demonstration NOW.

Your guarantee of quality: A full 12 month warranty on all products, covering both labor and parts, is given on all products.

Roland DIGITAL GROUP

Roland DG Australia Pty Ltd

Head Office:
50-52 Garden Street, South Yarra, Victoria 3141.
Telephone: (03) 241 1254. Facsimile: (03) 241 1257.

38 Campbell Avenue, Dee Why West,
New South Wales 2099.
Telephone: (02) 982 8266. Facsimile: (02) 981 1875.

Roland - Drawing ahead of the rest

* Sign configuration produced by SPACEWRITE LETTERING SYSTEMS utilising the IDOM system

RO DG 7323

Specifications

■ CAMM-1

Operational Method	Interactive using control panel keys and an LCD
Type	Moving paper
Adhesive Sheets	450mm to 500mm (17 3/4" to 19 11/16") in width (rolls may be used)
Paper Sheets	ISO A3 A2 (ANSI B C) (Pinch roller sheet feed)
Maximum Cutting/Plotting Range	X axis 800mm (31 1/2") Y axis 475mm (18-3/4")
Mechanical Resolution	0.05mm
Software Resolution	0.025mm step
Distance Accuracy	±0.2% or less of travelling distance or ±0.1 mm whichever is larger
Repeatability	±0.1 mm or less
Number of Pens/Cutters Used	1 (manually replaceable)
Cutters	Special CAMM-1 cutters only
Pens	Water-based fiber-tipped pens thick pens
Plotting/Cutting Speed	20 to 150mm (13/16" to 5-15/16")/sec (may be set in 14 steps of 10mm/sec increments)
Pen/Cutter Pressure	Continuously variable manually from 20g to 120g
Commands	CAMM-GLIII (Mode 1-compatible with commands for Roland DG's CAMM-2 CAMM-3 Mode 2—compatible with HP-GL commands)
Display	Back-illuminated LCD (20 characters x 2 lines)
Controls	4 cursor keys FUNC key ENTER key POWER switch CUTTER PRESSURE control
Interface	Parallel (Centronics) Serial (RS-232C)
Data Buffer	1K Byte
Replot Buffer	8K Bytes
Built-In Font	Outline Font Fixed Character Width Vector Font
Other Functions	Off-line cutting Cutter trail correction (may be used in the cutting mode)
Dimensions	735 (W) x 275 (D) x 200 (H) (28-15/16" x 10-7/8" x 7-7/8")
Weight	13.5 Kg (29 lb 76oz)
Operating Environment	Temperature 5°C to 40°C Relative humidity 35% to 80% (No dew forming)

RELATIVITY Pty Limited
A-62 Telegraph Road, Pymble
PO Box 266, Pymble NSW 2073
Phone (02) 44-7618 (02) 449-2575
Fax (02) 488-9967

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Roland - Drawing ahead of the rest

RO DG/7364/INN

Specifications

CAMM-3 MODEL PNC-3000

XY TABLE SIZE	500mm x 170mm (190-11/16" x 6-11/16")
AXIS TRAVEL (X-Y-Z)	180mm x 150mm x 150mm (7-1/16" x 5-7/8" x 5-7/8")
TOOL CHUCK	Collet Type (drill chuck optional)
PRECISION	0.01mm/step Internal Processing at 0.005mm/step
MAX. FEED RATE (SPEED)	1.2M/min (set either manually or by programming)
SPINDLE MOTOR	100W, AC Commutator Motor
WEIGHT	55kg (121.3 lbs.)
SIZE (W-H-D) (DIMENSIONS)	500mm x 580mm x 580mm 19-11/16" x 22-3/4" x 22-3/4"
SPINDLE RPM	3,000 - 10,000rpm (with manual control)
INTERFACE	Parallel (Centronics)/Serial (RS-232C)
DISPLAYS	X, Y and Z Axis Digital Coordinate Displays (unit-0.01mm) Table Feed Rate Spindle RPM Error Indicator
CONTROLS	Control-PAUSE, MOTOR ON/OFF, DISPLAY RESET, SENSOR, FEED RATE Data Input-ON/OFF, WRITE, START Positioning-Z0, Z1, Z2, P1, P2, HOME, ENTER JOG-Fast Feed Keys (X, Y, Z), Fine Adjust Dials (X, Y, Z), MANUAL ON/OFF Emergency Stop; Spindle Motor Control Power Switch
CONTROL COMMANDS	CAMM-GL1 (CAMM Graphic Language 1)
STANDARD ACCESSORIES	Ø6 Collet Chuck Collet Wrenches (2) AC Cord Carrying Bolts (4) Sensor Switch Fuses (2) AC Motor Brushes (4) T Nut Sets (2) User's Manual CAMM-GL1 Command Reference Manual

Specifications may change without notice.

RELATIVITY Pty Limited
A-62 Telegraph Road, Pymble
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Phone (02) 44-7618 (02) 449-2575
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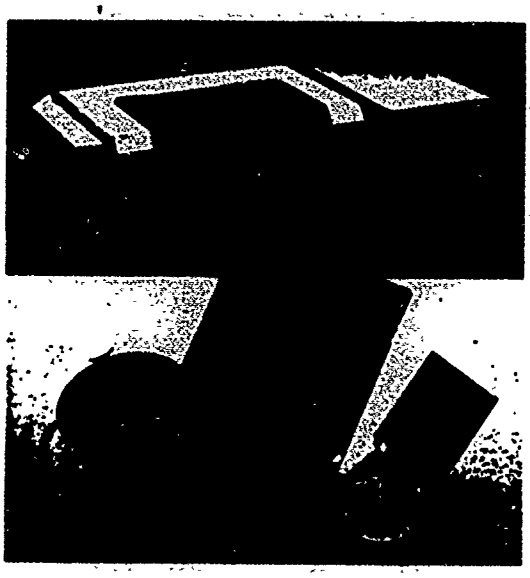
Roland - Drawing ahead of the rest

...with a little help from CAMM-2 and your PC

The art of engraving has entered the age of computers and Roland's CAMM-2 is at the forefront of this exciting technology. CAMM-2 will engrave any message or image onto soft metals, plastic, wood and perspex.

Using existing software with drivers written for Roland or H-P A3 size Plotters, simply type your name or scan a photograph and CAMM-2 quickly and efficiently converts it into an engraved reproduction. You can also change, enlarge, reduce or alter existing hard copy input through your graphics software to produce effective, eye catching results.

Plaques, labels, signs and luggage tags are only some of the miriad applications produced at a fraction of the time and money once spent on conventional methods.



Easy to use, lightweight and compatible with almost any type of computer, CAMM-2 is literally the breakthrough you've been looking for in the art of sign language.

- Engraving bed of 200mm x 140mm area with full clearance on front and sides for oversize sheets.
- Sign length is governed only by available material.
- Engraves to a maximum depth of 5mm.
- Use with the SYA-350 buffer for 'hands-off' operation.
- Comprehensive details available from all Authorised Roland Dealers.

Contact Roland today for further information about the revolutionary CAMM-2 and develop your own sign language.

Your guarantee of quality: A full 12 month warranty, covering both labor and parts is given on all products.

Roland Corporation Australia Pty Ltd
50-52 Garden Street, South Yarra
Vic. 3141. Tel: (03) 241 1254.
Fax: (03) 241 1257

38 Campbell Ave, Dee Why West,
NSW 2099. Tel: (02) 982 8266.
Fax: (02) 981 1875. Telex: 27769

Roland DG New Zealand
9 Nugent Street, Grafton, Auckland 1.
Tel: (9) 39 9715. Telex: NZ (74) 60518

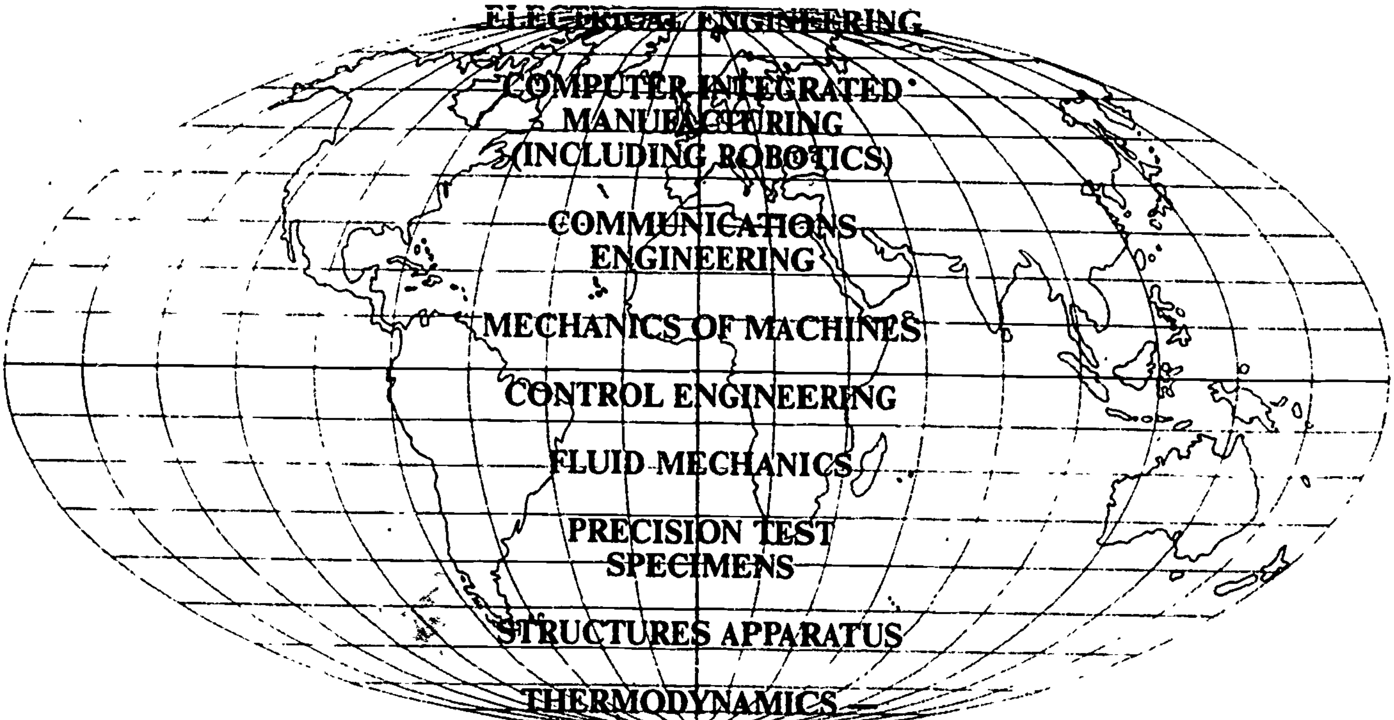
Roland
DIGITAL GROUP

Specifications

■ CAMM-2

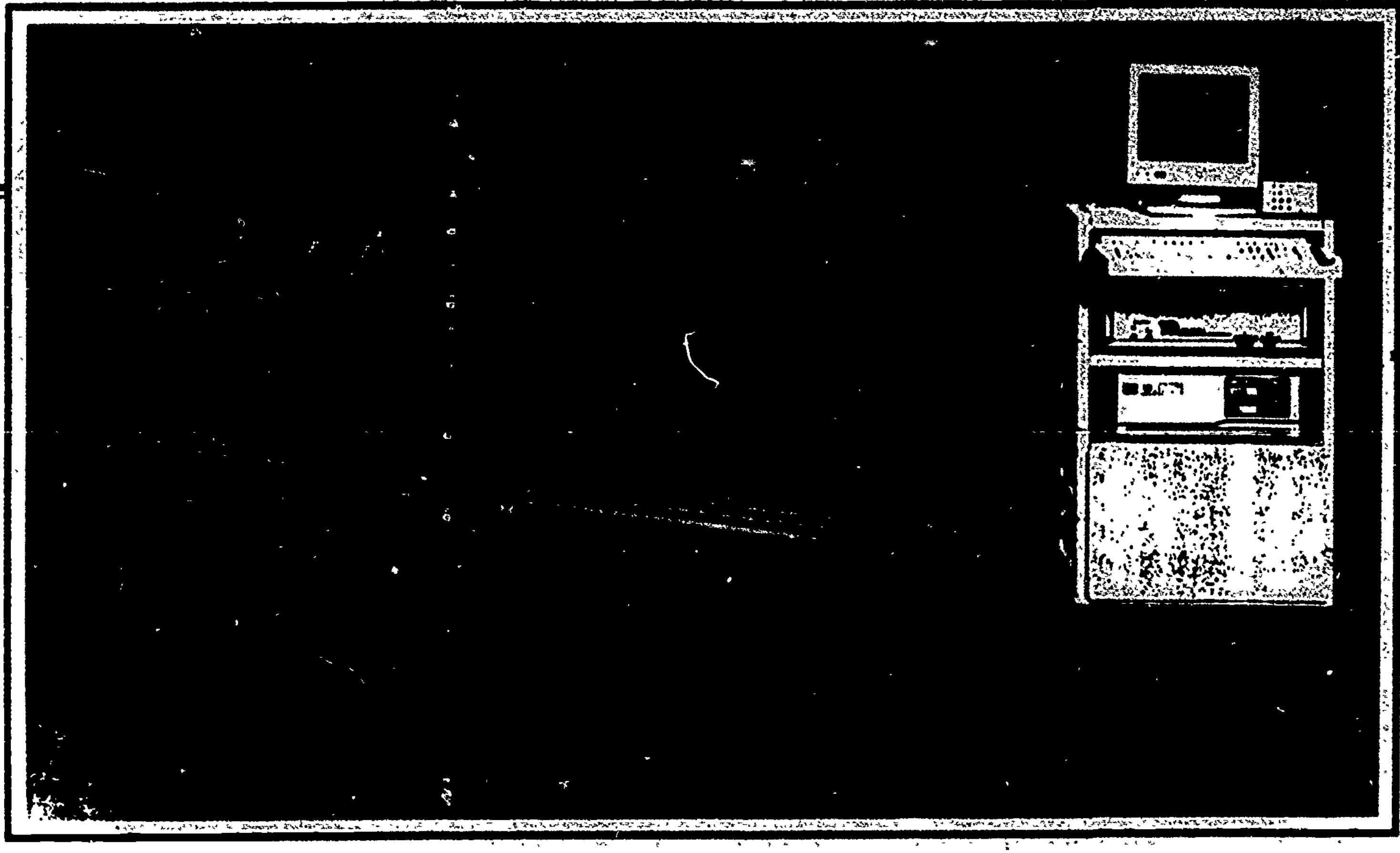
X-Y Table Size	200 x 140mm [7-7/8" x 5-9/16"]
Working Range	X axis : 200mm [7-7/8"] Y axis : 140mm [5-9/16"] Z axis : 10mm [7/16"]
Software Resolution	0.01mm/step
Operational Speed	X, Y axis 1.8m/min. [71"/min] max. Z axis 0.6m/min. [23-5/8"/min] max.
Spindle Motor	DC motor
Spindle Revolutions	11,000rpm
Operating Temperature	5°C~40°C
Dimensions	Engraving machine : 424(W) x 318(D) x 150(H)mm [16-3/4"(W) x 12-9/16"(D) x 5-15/16"(H)] Controller : 180(W) x 323(D) x 130(H)mm [7-1/8"(W) x 12-3/4"(D) x 5-1/8"(H)]
Weight	Engraving machine : 13kg (28lb. 66oz) Controller : 6kg (13lb. 23oz)
Display	LCD
Interface	Parallel (Centronics) Serial (RS-232C)

Specifications may change without notice



MA9000 SERIES

ROBOT TRAVERSE UNIT



MA 9060

The MA9060 Robot Traverse Unit is a 5-axis, servo-controlled robot fitted with an additional continuously variable sixth axis.

The high degree of flexibility afforded by this configuration, coupled with its powerful software, makes it ideal for integration with CNC machines and other CIM elements.

The MA9060 RTU is part of the TQ CIM Training System.

- Enlarged operating envelope
- Cost effective multi machine loading capability
- Powerful supervisory software
- Continuous variable traverse axis
- P.L.C. compatible
- Up to 28 software controlled input/output channels
- Floor or overhead mounted

▲ *The MA9060 Robot Traverse Unit with controller and computer housed in stacking workstation.*

International TQ

ROBOT TRAVERSE UNIT

MA 9060

Conventional robotic handling devices are inherently flexible and ideal for most machine loading applications. In an FMS cell, however, it is very likely that a robot will be required to service a number of machines and peripheral devices. The operating envelope of the robot can therefore become the limiting factor when considering a multi machine cell. The TQ MA9060 has been designed to overcome these limitations by adding an additional traverse axis to the MA3000 5 axis robot. This servo controlled traverse axis provides a further 1.7m of reach to the robot, giving an overall operating envelope of over 3.0m.

The design of the RTU is such that it can be supplied in an overhead or gantry configuration in situations where floor space is a constraint.

Up to 28 channels of I/O can be controlled via the robot software allowing it to interact with, and control, devices such as conveyors, buffer carousels, CNC machines, PLC's, inspection systems and AGV's.

The MA9060 is ideally suited for integration of existing C.N.C. machines where it can provide the necessary machine loading and supervisory sequence control.

MA9000 Series

- **MA2000** 6 Axis Servo Controlled Robot (1kg deadlift)
- **MA3000** Educational Robot (2kg deadlift)
- **MA9010** Robot/Saw F.M.S. Workcell
- **MA9012** Bandsaw F.M.S. Module
- **MA9020** Robot/Drill F.M.S. Workcell
- **MA9022** Drill F.M.S. Module
- **MA9031** Retrofit Kit for Bridgeport Milling Machine
- **MA9032** Milling Machine F.M.S. Module
- **MA9040** Robot Saw/Drill F.M.S. Workcell
- **MA9050** Robot/C.N.C. Lathe F.M.S. Workcell
- **MA9051** Micro Controlled C.N.C. Lathe Trainer
- **MA9057** Lathe F.M.S. Module
- **MA9060** 6 Axis Robot Traverse Unit
- **MA9061** Indexing Carousel
- **MA9062** 7 Axis Robot Traverse Unit
- **MA9070** Vision System
- **MA9071** Automatic Inspection System
- **MA9090** Automated Guided Vehicle (A.G.V.)

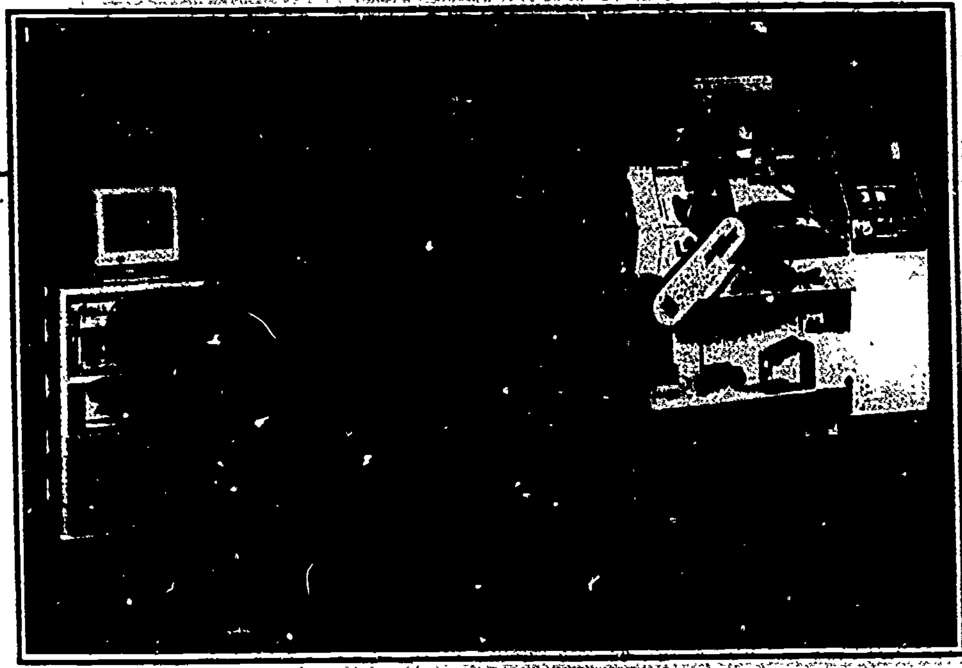
MA9000 SERIES

ROBOTICS AND COMPUTER INTEGRATED MANUFACTURING (C.I.M.)

- **Modular and expandable**
- **Unique integrated A.G.V. system**
- **In-process automatic inspection systems with S.P.C.**
- **IBM compatible**
- **High educational value designed for training**
- **Choice of machines and computers**
- **Integrated CAD CAM facility**
- **Networked**
- **Management systems software**
- **Choice of control: PLC or Cell controller**

▲ Typical CIM Training System comprising CNC milling machine, CNC lathe with CAD CAM facilities, four robots, an AGV system, vision inspection and in-process automatic inspection facilities, all connected on a computer network.

FLEXIBLE WORK CELLS



- Modular and expandable
- Industrial realism
- Choice of control method
- Safety
- Choice of machines and computers
- Designed for training
- High educational value

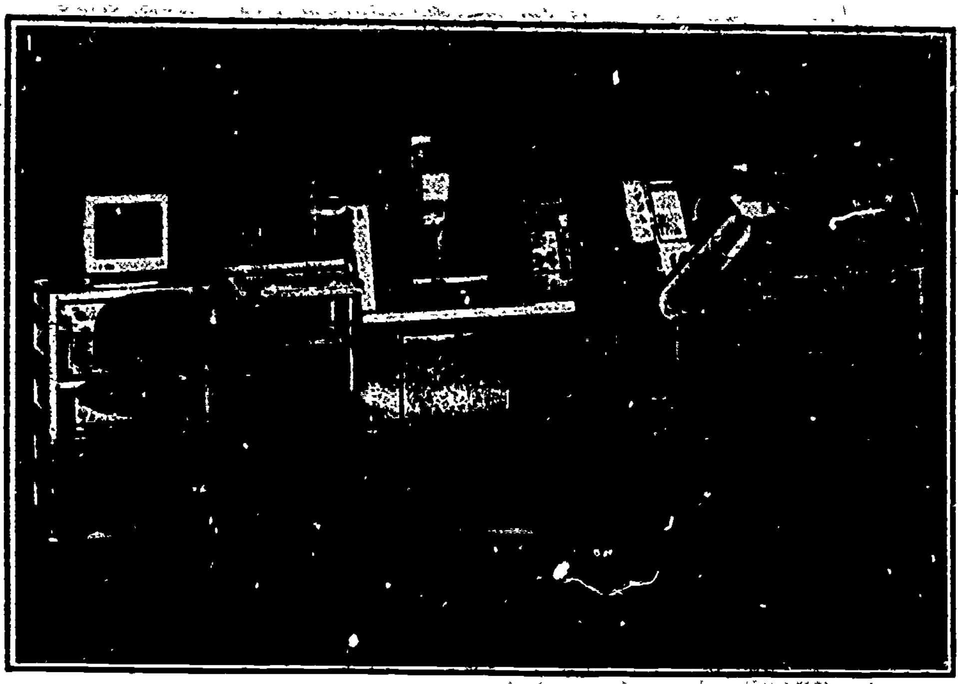
FMS The TQ MA9000 CIM training system is of modular design and open construction allowing it to be configured to exactly fulfil your current needs. The modular concept presents the option of on-going development in a planned and logical manner.

At the entry level, for example, a single C.N.C. machine can be integrated with the MA3000 robot to form a basic cell. This combination of C.N.C. machine tool and robot is a logical first step towards a fully integrated CIM training system. Expansion of the work cell at a later date may include the addition of further machines, an A.G.V., an inspection station, or integration of a CAD CAM system; all these options and many more are possible.

The scale of the specially adapted machine tools and robots ensures industrial realism without the disadvantages of the high capital and maintenance costs associated with full scale industrial systems.

The linking or integration of the machine and robot can be achieved in two ways, either by utilisation of the powerful robot software and its associated interface to supervise the functions of the machine tool, or by the use of a separate programmable logic controller (P.L.C.). Either way, the training capability and effectiveness of the cell can be further enhanced by the addition of off-line programming and CAD CAM packages.

1 *A basic AMT cell. comprising an MA3000 ...t interacting with a CNC lathe ... Fanuc control.*



The safety aspects of any machine based system cannot be ignored. The problems associated with industrial robots and large scale machines are well known to those lecturers who have tried to use them in a training environment.

The TQ MA9000 system solves these problems by providing an industrially realistic system, but in a format that is both safe for student use and economic on workshop area.

Automatic and interlocked guarding ensures that machines cannot commence their cycles until the robots are clear of the machines and interlocks checked.

TQ has experience of integration of many types of machine tools and their controllers. In most instances individual preferences, or existing machines, could be modified for inclusion into a work cell or complete CIM system.

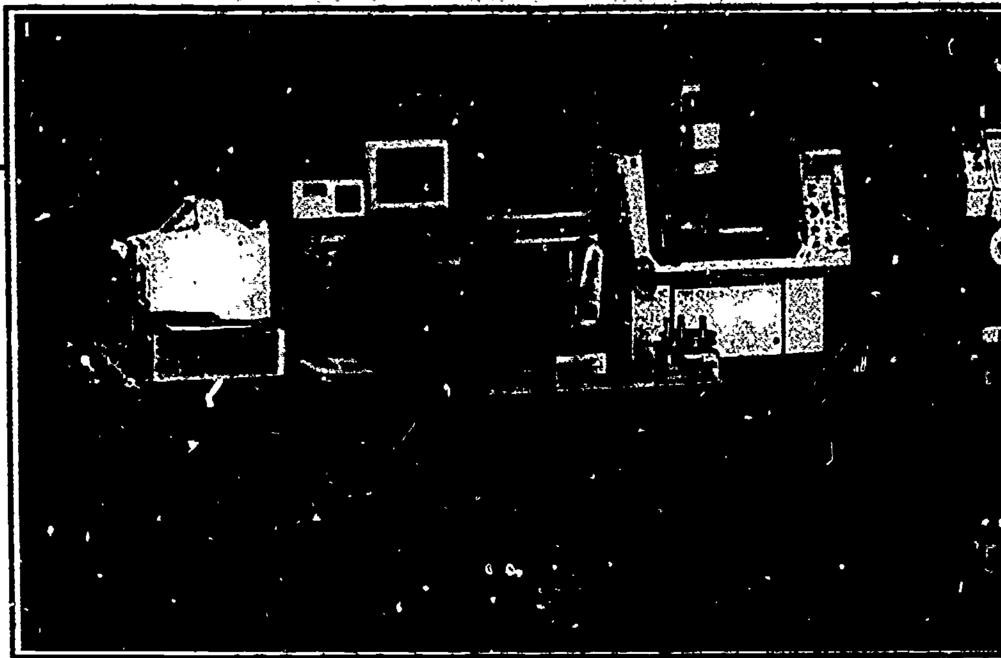
Choice over the controlling computers is also available. IBM XT, AT or compatibles, as well as Acorn BBC computers can be used.

The benefits of the modularity and flexibility of the TQ MA9000 range becomes increasingly clear as the system is expanded to include two machine tools. In this configuration, the MA9060 Robot Traverse Unit with its large operating envelope has the ability to span the two machines and service intermediate buffer storage carousels such as the MA9061, or receive material from an A.G.V. (the MA9090). As with a single machine cell control can be either by the robot's software acting as a supervisor or by a separate P.L.C. In both cases, information received from the sensors within the cell can be acted upon in a logical manner and in accordance with the program written by the students. The status or condition of the machines, the availability of parts awaiting machining or raw material arriving into the cell via an A.G.V. are all detected and appropriate action taken.

As the complexity of the cell increases, the requirement for higher levels of control comes into play. The ability to remotely program and monitor the machines in the cell, therefore, becomes important. The concept of a cell controller can then be introduced in which a separate computer acts as the supervisor to the system. This adds a further dimension to the educational capabilities of the system and, again, matches industrial practices.

A multi-machine cell, comprising an MA9060 Robot Traverse Unit. CNC lathe and mill with a buffer storage carousel.

COMPUTER INTEGRATED MANUFACTURING



- Modular and expandable
- Fully integrated
- Cell supervision
- MAP connectivity
- Distributed student workstations
- Simulation and off-line programming capability
- Integrated CAD CAM
- Highly flexible materials handling devices
- Unique integrated AGV system
- In-process automated inspection system
- Comprehensive courseware

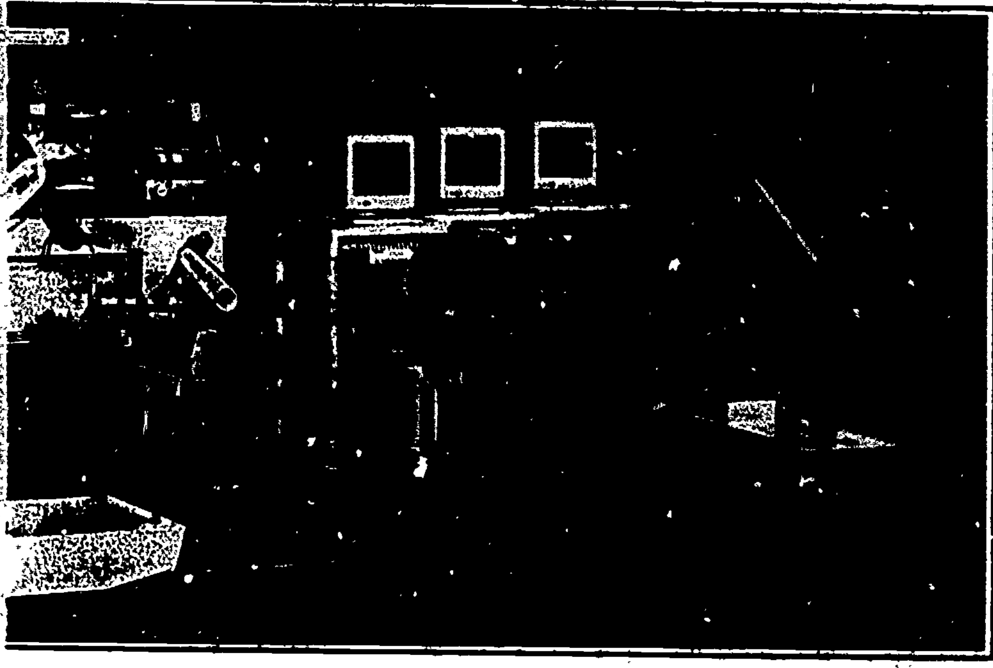
The TQ route towards complete CIM training continues in a logical manner by the addition of further modules that can be integrated into the system.

For example CAD CAM, software and hardware packages can be added enabling component design to be created remotely from the cell before being checked using tool path graphics simulation and then directly downloaded to the CNC machine tools.

The very important area of automatic inspection is covered by two modules in the MA9000 range: one, the MA9070, includes an adapted industrial machine vision system which can be used for stand-alone training or can be integrated with an MA2000 robot to form a functional inspection station. The second system, MA9071, utilises an automatic precision micrometer that combine with an MA2000 robot to provide an in-process inspection station. Statistical Process Control (S.P.C.) software is also available in which data is downloaded to a remote computer for subsequent analysis.

The capability of the MA9000 system is expanded considerably by the inclusion of TQ's unique automated guided vehicle (A.G.V.). This provides a completely flexible materials handling capability enabling the production cell to be linked with raw material and finished stock stores.

1 Typical CIM training system comprising CNC milling machine, CNC lathe with CAD CAM facilities, four robots, an AGV system, vision inspection and in-process automatic ...n facilities: all connected ...puter network.



Even other machines elsewhere in the workshop can be readily reached by the A.G.V. which tracks easily installed metal tape fitted to the floor. When combined with the MA9060 robot traverse unit, the A.G.V. produces an unrivalled flexibility of materials handling enabling every possible workshop configuration to be accommodated.

As the number of elements in the system increases, the required level of control and communication also increases. The accepted way of dealing with this in industry is to install networked communication systems and cell controllers.

In line with this industrial practice, TQ are able to offer Local Area Network Systems (LANS) which link together the controlling computers. At one level this might include an IBM PC local area network with central file server whilst at the highest level the network configuration would include a full IBM PC LAN utilising netbios and including a cell supervisor capable of communicating to other higher networks such as MAP, IBM token ring and Ethernet.

The ability to provide a networked system has many benefits to the lecturer. Firstly, it represents faithfully what is happening in industrial installations where factory communications from management to shop floor level are achieved utilising networks. Secondly, the distributed computers can be used as stand-alone workstations, each student working on a particular part of the cell — for example, CNC programming, AGV and robot programming.

This approach maximises the utilisation of the equipment and allows courses to be offered on the individual elements of the cell as a lead into the fully integrated system.

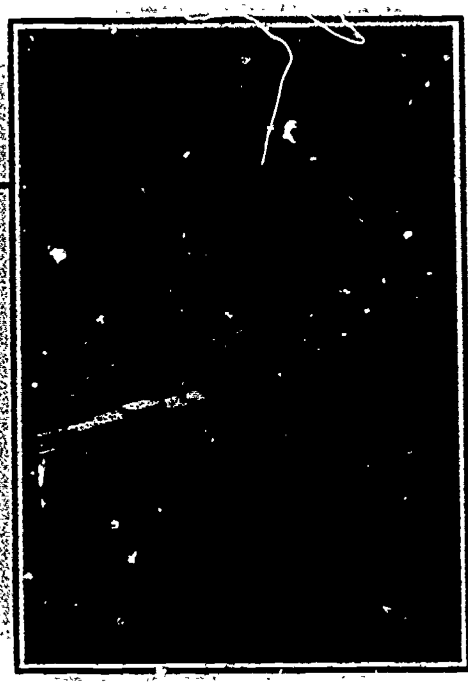
At the leading edge of the developments in CIM is the use of sophisticated off-line software packages which provide animated 3D graphics to simulate not only the individual elements of the FMS cell such as robots, AGV's CNC machines but also the total control of the system. Packages of this type running on higher level computers and workstations can be incorporated into the MA9000 providing a true state of the art training system.

No CIM system is complete without the inclusion of management software tools that link the various elements of a manufacturing organisation from sales through production control to despatch.

Software packages can be supplied which cover these areas and provide further scope for widening the appeal of the MA9000 system to include courses such as business and management studies.

CAD CAM

SIMULATION



- Choice of packages
- Industrial capability
- Direct file transfer to CNC controllers
- Tool path graphics simulation
- Stand-alone or networked

The combination of Computer Aided Design and Computer Aided Manufacture is a vital element of an integrated system. In the TQ MA9000 context CAD CAM can be used to generate component designs using stand-alone or networked systems.

Drawings can be created and edited interactively on a graphics monitor, translated via the CAM package into a format that, after post processing, allows direct downloading to the CNC machine tool.

A CAD CAM package running on a network with a number of workstations has the advantage of providing student facilities which do not depend directly on the availability of the machine tool. This off-line technique represents a very cost effective way of providing hands on training and also mimics industrial practice where CNC machine utilisation has to be maximised.

TQ are able to provide and integrate most of the standard P.C. based CAD and CAM packages available on the market including Superdraft, Auto CAD, PEPS 2, MLD and others. Existing packages can also be integrated into the CIM system.

- Off-line programming
- Design and verification of systems
- Visualisation and animation
- 2D and 3D packages

Simulation is a technique in which computer hardware and software is used to model and graphically represent real physical systems.

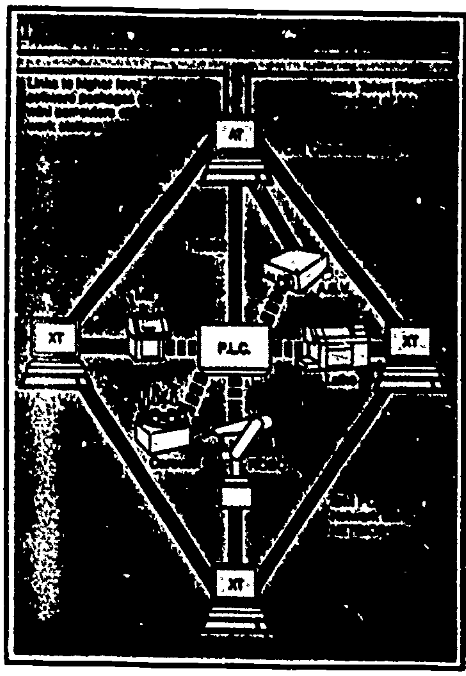
TQ are able to offer a basic simulation package which runs on IBM or compatible PC's and provides simple 2D graphical representation of the MA2000 and MA3000 robots. The full features of the robot software can be exploited and checked off-line prior to downloading to the robot. A multi-user licence for this package will allow a class of students to develop robot programming skills off-line in a cost effective way.

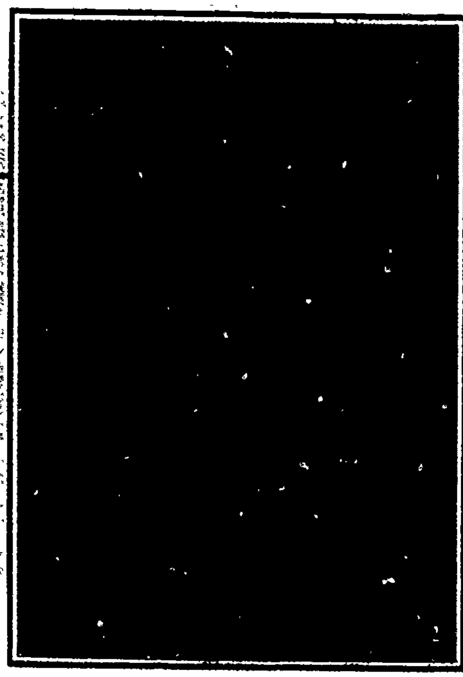
Higher level 3D graphical simulation packages with the capability of modelling complete workplaces and FMS cells including machine tools, robots, A.G.V.'s and conveyor systems are available. These provide animated displays in both wire frame and full colour shading with verification and collision avoidance features.

Software of this type can be used to effectively model a fully integrated MA9000 CIM system.

1 Example CAD CAM screens showing tool path simulation graphics.

2 A 3D animated simulation of an MA3000 robot ...ed by the GRASP software ...e.





NETWORKING

MANAGEMENT SYSTEMS SOFTWARE

- Introduction to Local Area Networks, LAN's
- Provides route to MAP/TOP compatibility
- Provides inter-machine communication using IBM Netbios
- Enables linking to off-line programming facilities

MA NETWORKS

An essential part of any industrial CIM system is a computer network. TQ has recognised the importance of networking in CIM training in two ways. Firstly as a fundamental requirement to reflect industrial practices and teach the concepts of data management and file transfer. Secondly, as a valuable tool for departments and lecturing staff involved in delivering cost effective CIM training. A networked system is ideal for linking existing computing facilities which can be used for off-line programming of the various elements contained in the production cell. For example, off-line C.N.C., robotics, A.G.V. and P.L.C. software packages can be used to develop programs prior to downloading to the relevant hardware controller.

The TQ MA9000 offers networked systems which can be configured according to the particular installation requirements. At the highest level this could include a full IBM P.C. local area network utilising netbios and including a cell supervisor capable of communicating to other higher networks such as MAP, IBM token ring and Ethernet. At a lower level a network may involve a number of computers equipped with simple file handling facilities and serial ...ions to the relevant machines.

- Production planning
- Capacity planning
- Material requirements planning
- Stock control
- Quality control, and shop floor data collection

MA SOFTWARE

Vital to any CIM system is the associated management software tools that allow efficient control of the data flow from receipt of customer order through production control, engineering, manufacture to final despatch.

Concepts such as capacity planning, material requirements planning (MRP), inventory control are essential in the education of personnel involved in CIM and AMT systems.

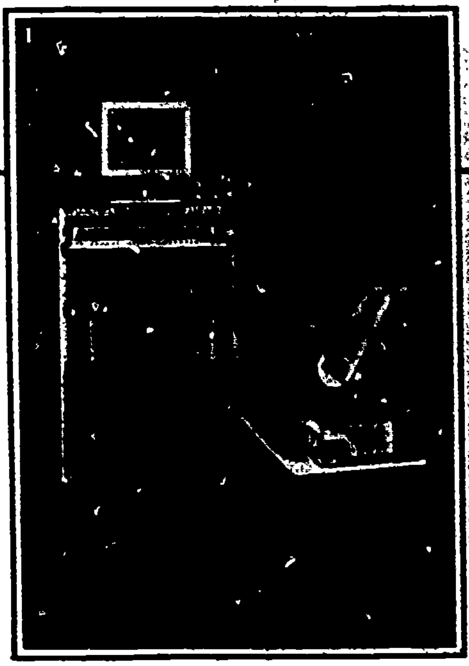
TQ can provide software packages which can be used to provide effective training in these areas with the added advantage of relating to an actual physical model of a manufacturing situation.

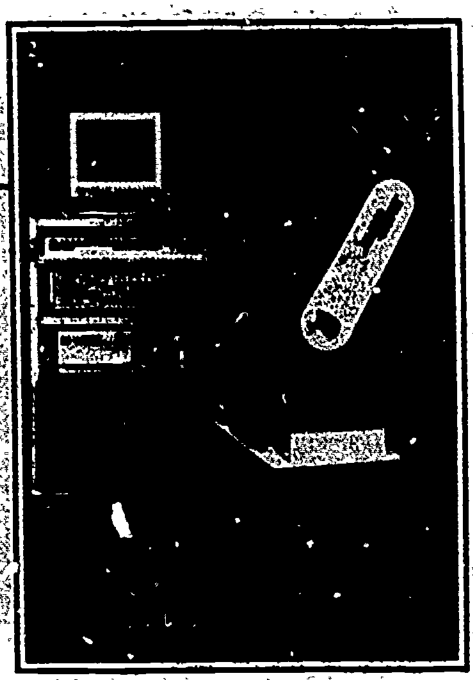
The benefits of having management software that relates to the physical manufacturing cell are that the scope of courses can be widened to include those with a management or business bias. Up-date courses for production control, quality, and inventory control personnel can all be developed.

1 *Diagram of a networked system showing integration of all components in the FMS cell, with a gateway to higher CIM functions.*

2 *Screen layouts of typical integrated management software package.*

ROBOTS





- D.C. servo controlled 6 axis plus gripper
- Emulates industrial robot programming methods
- X-Y-Z real world transformation software
- Open construction both hardware and software
- Simulation and off-line programming software

MA 2000

The TQ MA2000 6-axis, d.c. servo controlled robot has all the features of an industrial robot with added benefits of safety and flexibility. The standard software allows programming by the teach pendant in point to point, lead by nose and continuous path modes as well as direct keyboard entry. Additional software provides transformation from robot joint space to real world x, y, z co-ordinates.

The off-line programming package allows a class of students to develop their own programs without tying up the robot hardware. Simple graphics are used to simulate the robot's movement and input/output commands prior to downloading to the robot's controller. This presents a breakthrough in robot training as the net cost per student seat is greatly reduced.

The MA2000 has many other unique features including condition monitoring of motor powers and positional error, control of P.I.D. algorithms, operation as a P.L.C. and the ability to integrate the software with vision systems and user written programs.

- D.C. servo controlled 5 axes plus gripper
- Readily interfaced to machine tools
- P.L.C. compatible
- 2kg lift capability
- Off-line programming and simulation software
- Large operating envelope

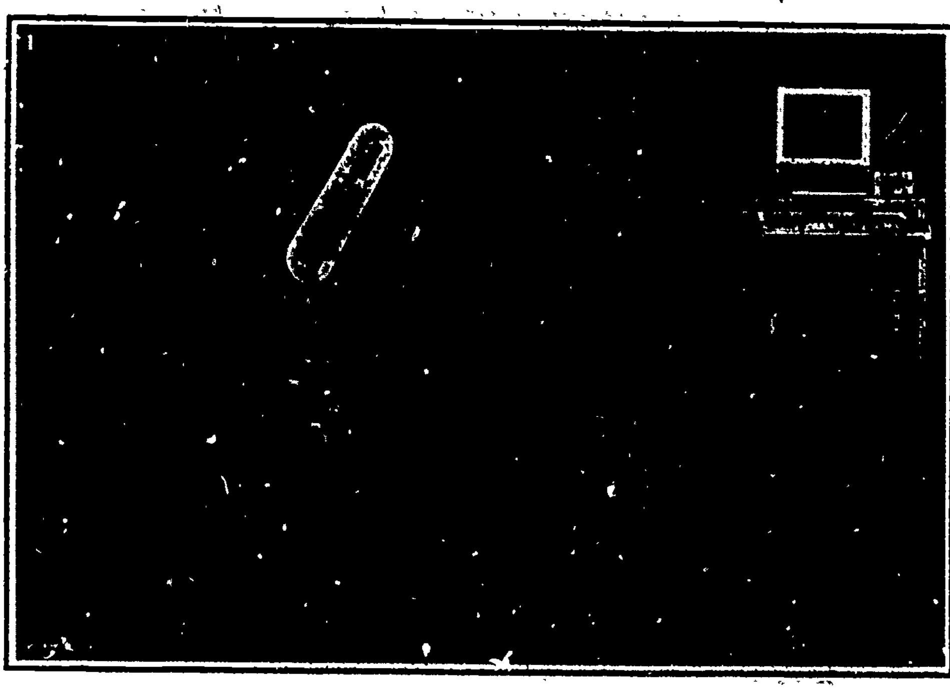
MA 3000

The TQ MA3000 has a reach of 750mm and a dead lift capability of 2kg which make it ideal for integration with industrial scale machine tools. The sophisticated software enables the robot to be programmed by a number of methods all of which accurately match the techniques used by full scale industrial robots. A teach pendant can be used for programming using either robot joint position data or x-y-z cartesian data. Alternatively, off-line programming software with graphical simulation is available for development of robot sequences remotely prior to downloading to the robot. A multi-user site licence for this package provides a cost effective way of delivering robot training and accurately represents industrial practice.

As with the MA2000 various modes of operation are provided. The ability to use the robot controller as a P.L.C. (programmable logic controller) is particularly useful when interfacing the robot to machine tools and other devices.

1 *MA2000 robot with controller and computer housed in stacking workstation.*

2 *MA3000 robot with controller and computer in stacking workstation.*



TRAVERSE UNITS

- Enlarged operating envelope
- Cost effective multi machine loading capability
- Powerful supervisory software
- Continuous variable traverse axis
- P.L.C. compatible
- Up to 28 software controlled input/output channels
- Floor or overhead option

MA 9060 Conventional robotic handling devices are inherently flexible and ideal for most machine loading applications. In an FMS cell, however, it is very likely that a robot will be required to service a number of machines and peripheral devices. The operating envelope of the robot can therefore become the limiting factor when considering a multi machine cell. The TQ MA9060 has been designed to overcome these limitations by adding an additional traverse axis to the MA3000 5 axis robot. This servo controlled traverse axis provides a further 1.7m of reach to the robot, giving an overall operating envelope of over 3.0m.

The design of the RTU is such that it can be supplied in an overhead or gantry configuration in situations where floor space is a constraint.

Up to 28 channels of I/O can be controlled via the robot software allowing it to interact with, and control, devices such as conveyors, buffer, carousels, CNC machines, PLC's, inspection systems and AGV's.

- Enlarged operating envelope
- Cost effective multi machine loading capability
- Interfaces to existing desktop machine tools
- P.L.C. compatible
- Off-line programming

MA 9062 In the same way that the addition of a traverse axis to the MA3000 increased its capabilities, the addition of a seventh axis to the 6 axis MA2000 robot allows many more interesting applications to be considered. Within the MA9000 CIM system the MA9062 can be utilised as a cost effective way of providing robotic handling; for example, for the inspection stations allowing two systems to be spanned by a single robot.

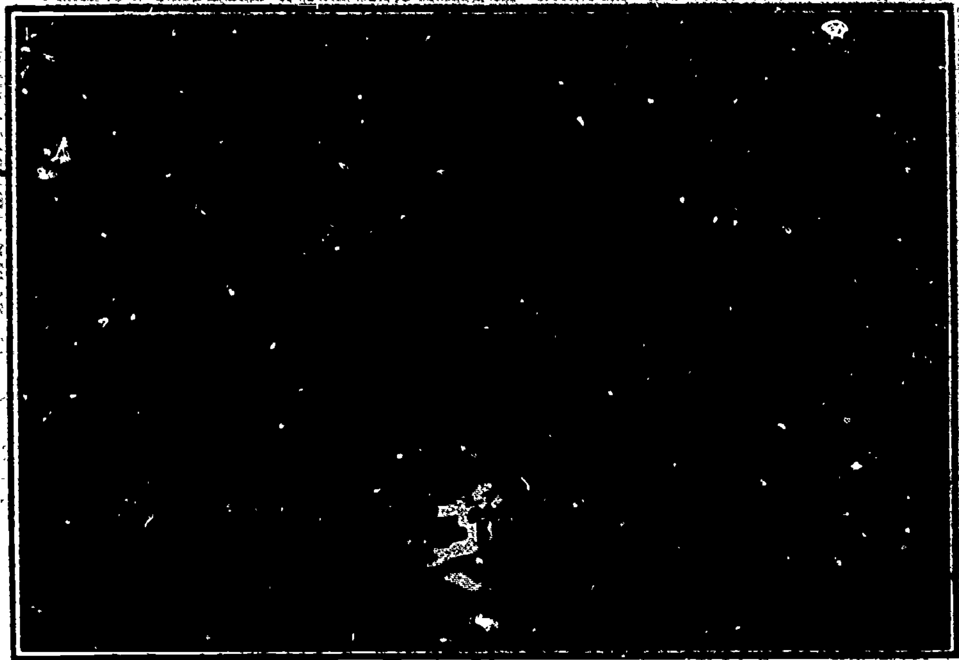
A further application is as a machine loading device for desk top C.N.C. machines. In this case the input/output capabilities of the robot can be used to control the sequencing of the machines and associated devices.

The traverse axis for the MA9062 takes the form of a slide assembly with control to pre set locations. Movement can be controlled either by the robots own input/output channels or an external programmable logic controller (P.L.C.).

The facility for off-line programming the traverse robot allows students to develop their programs remotely before downloading to the robot controller.

1 *MA9060 robot traverse unit with controller and computer housed in stacking workstation.*

AUTOMATED GUIDED VEHICLE



- Flexibility of material handling
- Stand-alone or part of CIM system
- Designed for education and training
- Off-line programming capability
- On-board computer
- 25kg lift capability
- Automatic docking and recharging

MA 9090

Industry has recognised the need for improved productivity and has closely examined all areas to which automation can be applied.

Whilst robotic handling devices have been successfully used within production cells themselves it is only relatively recently that the effect of improving material flow on a macro scale has been realised.

The ability to transport stock from raw material stores to a given production cell and later to either a second cell or to finished stores is now relatively straightforward using Automated Guided Vehicles. A.G.V.'s can be programmed to carry out material delivery tasks in line with production requirements. This flexibility is essential in a true flexible manufacturing system. A.G.V.'s also find use in automated warehousing for finished stock retrieval and as mobile workstations.

From an education and training viewpoint it is impractical for teaching staff to consider the use of full scale A.G.V. systems. Both cost and space rule out this possibility.

The TQ MA9090 is a working A.G.V. with a lift capacity of up to 25kg which has been specifically designed for education and training. Its scale and facilities make it ideal for integration to CIM systems.

As a stand-alone unit, the MA9090 offers a facility which can be used as a practical example of microprocessor control, computing, sensors, pneumatics and communication techniques.

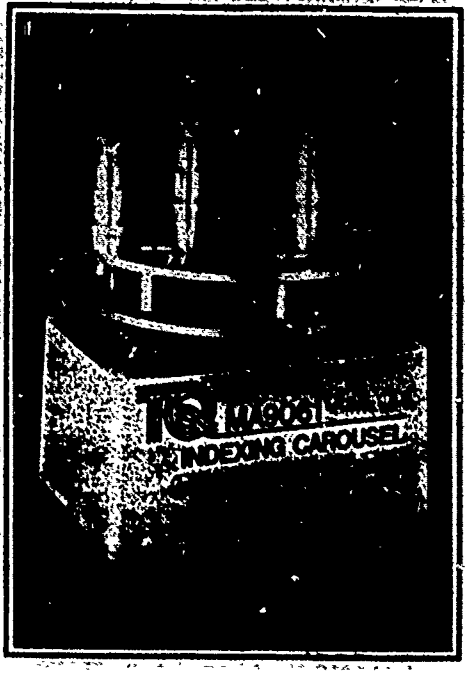
The vehicle is programmed by the "mission method" in that it receives information about its tasks from a ground station with which a host computer is communicating. Simple graphics are used to plan the A.G.V. route and any interaction with other devices that may be necessary during its mission.

On completion of a mission, the A.G.V. automatically docks with its base station to recharge its batteries and await further mission instructions from the host computer.

An off-line programming package is available which allows a class of students to develop missions remotely from the A.G.V. prior to downloading to the host computer and to the A.G.V. itself.

Any number of A.G.V. missions can be compiled and stacked in the host computer. This facility, together with the off-line programming capability, is a key factor in providing a system which is genuinely flexible and integrated with the overall system.

1 *MA9090 automated guided vehicle returning to its base to receive its next mission.*



INDEXING CAROUSEL

CONVEYOR SYSTEMS

- Six station buffer storage system
- Bi-directional indexing
- P.L.C. compatible
- Interfaces to robot I/O
- Optical component sensors

MA 9061

In a true flexible manufacturing cell there has to be provision for buffer storage of the components as they pass through the various machining and inspection operations. These can take many forms, from simple magazine arrangements to complex storage systems. For the TQ MA9000 CIM system a carousel has been designed which represents many of the features of the more complex industrial systems. The MA9000 is a rotary 6 station indexing carousel which utilises optical sensors for component recognition. The unit can be interfaced to any of the TQ robots or to a standard programmable logic controller. TTL level signals are used to index the carousel in either direction.

From an education and training viewpoint the concepts of logic control via either robot I/O or P.L.C. optical sensing and integration with other devices can be effectively taught with the MA9061.

- Flexible
- P.L.C. or robot controlled
- Multi-level capability
- Choice of width and configuration

MA CONVEYORS

Conveyor systems have been included in the TQ MA9000 CIM system as they represent a valuable, though less flexible, method of transporting components through the manufacturing cell.

They are of particular interest, however, where a large system involves two or more F.M.S. cells.

Conveyors can be readily integrated into the TQ system and control can be achieved by use of the input/output facilities of either the TQ robots or by a separate programmable controller. Component sensing for counting and system monitoring can be added.

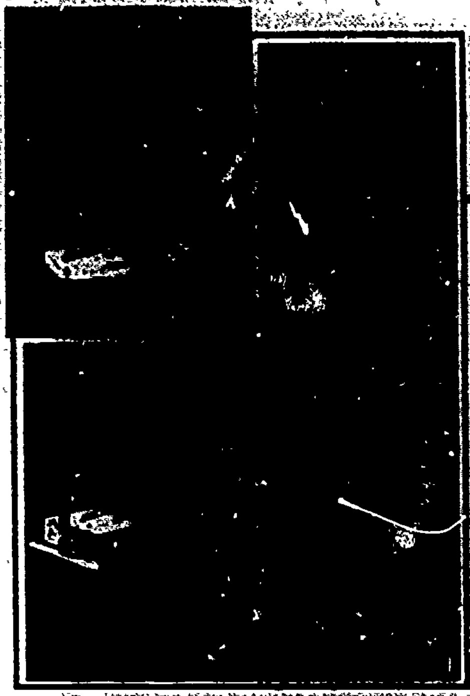
The length and width of track can be tailored to suit the particular cell configuration.

1 MA9061 6-position indexing carousel, containing partly machined workpieces.

2 An example layout of a conveyor system showing a two-level configuration.

VISION INSPECTION SYSTEM

AUTOMATIC INSPECTION SYSTEM



- Serial communications link
- Interfaces to robots and other devices
- Adapted industrial system
- Stand-alone or part of CIM system

MA 9070

The use of vision systems in industrial applications is increasing rapidly. Machine vision is used for checking of products for quality, accuracy and completeness as well as providing a valuable sensor for robots, automated guided vehicles and other robotic systems.

The technologies involved in vision systems is of great interest to those providing education and training in computer integrated manufacturing and AMT in that it represents a combination of opto electronics, electronics, mathematics, computing and mechanical technologies.

The TQ MA9070 system has been developed for teaching the concepts of machine vision and also as a working system in the MA9000 CIM environment. The system is based on an industrial unit utilising a solid state camera which captures the image of the component being inspected.

The stored image is processed by the on-board processor and the data compared with that relating to a previously stored image. In this mode of use outputs are communicated to an associated robot which takes appropriate action. The vision system can also be used as a control sensor to provide feedback data for robot control functions.

- Stand-alone or part of integrated system
- Industrial capability
- Multiple measurement head facility
- Statistical process control software for IBM and BBC computers

MA 9071

In recent years the nature and emphasis of inspection and quality control has changed significantly. No longer is it viewed as a 'last in the line' process to catch out of tolerance components. Today inspection takes place continuously throughout the production stages. Accumulated data is used as a control element to take corrective action when a process is found to be drifting out of limits. This latter technique, referred to as statistical process control is fast becoming the norm in manufacturing industry. It is against this backdrop that TQ has developed its MA9071 Automatic Inspection System.

In line with the modular concept of the MA9000 range, inspection stations can take several forms from stand-alone single measurement devices to fully integrated systems with a number of measurement inputs interfaced to robot handling devices and via a multiplexer interface to a host computer for data processing. The S.P.C. software package receives the data down an RS232 serial link and via menu control produces control charts, histograms and other data related to the performance of the manufacturing process.

1 A vision inspection system integrated with an MA2000 robot and MA9061 carousel to form an automatic component recognition system. Insert shows vision light table, camera and recognition unit.

2 Typical configuration of an integrated inspection station comprising an MA2000 robot, two indexing carousels and the automatic inspection system (see insert).

COURSEWARE

GLOSSARY OF TERMS

- Integrated courseware
- Over 20 practical assignments
- Wide educational range

The modular design of the TQ MA9000 CIM Training System extends into the supporting courseware which includes training manuals for the individual component modules, such as MA2000 robot, automatic inspection and S.P.C., automated guided vehicle, vision inspection and many more.

In addition, there are over 20 integrated practical assignments that have been specially written by practicing lecturers and tailored to meet the requirements of all levels of education ranging from Short Courses, National, Higher National, Diploma through to degree level courses.

MA GLOSSARY

AGV	Automated Guided Vehicle
AMT	Advanced Manufacturing Technology
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CIM	Computer Integrated Manufacturing
CNC	Computer Numerical Control
Ethernet	A probabalistic network standard
FMS	Flexible Manufacturing System
I/O	Input/Output
LAN	Local Area Network
MAP	Manufacturing Automation Protocol
MRP	Material Requirements Planning
NC	Numerical Control
Netbios	Network Basic Input/Output System
OSI	Open Systems Interconnection
PC	Personal Computer
PID	Proportional, Integral, Derivative
PLC	Programmable Logic Controller
RTU	Robot Traverse Unit
SPC	Statistical Process Control
Token ring	A deterministic network standard
TOP	Technical and Office Protocol