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Continuous Path: The Evolution of Process Control Technologies in Post-War Britain

by

Ross Hamilton

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Abstract

Automation - the alliance of a series of advances in manufacturing technology with the academic discipline of cybernetics - was the centre of both popular and technical debate for a number of years in the mid-1950s. Alarmists predicted social disruption, economic hardship, and a massive de-skilling of the workforce; while technological positivists saw automation as an enabling technology that would introduce a new age of prosperity. At the same time as this debate was taking place, increasingly sophisticated control technologies based on digital electronics and the principle of feedback control were being developed and applied to industrial manufacturing systems. This thesis examines two stages in the evolution of process control technology: the numerical control of machine tools; and the development of the small computer, or minicomputer. In each case two key themes are explored: the notion of industrial failure; and the role of new technologies in Britain's industrial decline.

In Britain, four projects were undertaken to develop point-to-point or continuous path automatic controllers for machine tools in the mid-1950s - three by electronics firms and one by a traditional machine tool manufacturer. However, although automation was dominating popular debate at the time, the anticipated market for numerically controlled systems failed to appear, and all of the early projects were abandoned. It is argued that while the electronics firms naively misdirected their limited marketing capabilities, the root of the problem was the traditional machine tool manufacturers' conservatism and their failure to embrace the new technology.

A decade later, small computers based on new semiconductor technologies had emerged in the United States. Originally developed for roles in industrial automation, they soon began to compete at the low end of the mainframe computer market. Soon afterwards a number of British firms - electronic goods manufacturers, entrepreneurial start-ups, and even office machinery suppliers - began to develop minicomputers. The Wilson government saw computers as a central element of industrial modernisation, and thus a part of its solution to Britain's economic decline, so the Ministry of Technology was charged with the promotion of the British minicomputer industry. However, US-built systems proved more competitive, and by the mid-1970s they had come to dominate the market, with the few remaining British firms relegated as niche players. It is argued that government involvement in the minicomputer industry was ineffectual, and that the minicomputer manufacturers' organisational cultures played a major role in the failure of the British industry.

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A number of people read early drafts of the chapters and gave invaluable advice. Thanks go particularly to Nick Tiratsoo, Richard Coopey, Murray Laver, Steve Russ, Bill Aspray, and Malcolm Ogden. Thanks also to all of my friends who generously offered to proof-read the finished chapters.

For help in various archives during the course of my research I would like to thank Jon Agar, Tim Procter, Angela Stanfield, and Paula Gardner.

Of course, thanks are due to SERC (now EPSRC) for three years of funding, and to my parents for encouraging me to follow my heart rather than "get a real job" after completing my Computer Science bachelor's degree.

Finally, the historian G. R. Elton, in whose 1969 book, *The Practice of History*, can be found the apt line, "Marxist sociology, long since overtaken by more accurate and more subtle analyses, remains powerful among historians, and its influence is by no means confined to those aware of it; fragments of class-struggle theories and economic determinism are found curiously embedded in the work of scholars who at the conscious level do not believe in them but need them to satisfy their wish to be thought 'deep'."

Declaration

This thesis is presented in accordance with the regulations for the degree of Doctor of Philosophy. It has been composed by myself and has not been submitted in any previous application for any degree. The work described in this thesis has been undertaken by myself, except where otherwise stated.

Chapter 5, "The Minicomputer Industry" formed the basis of a paper published in *Business History*, Vol. 38, No. 2, April 1996.

Chapter 1 - Introduction

Overview

In the early 1950s Britain had a world lead in the emerging technology of automation, built largely on successes such as the first automated motor engine production line, the first operational stored program computer, and the first "automatic factory". Since the late 1940s automation had been a key research area for most large electrical equipment manufacturers in Britain. However, by the 1960s Britain had become a net importer of automation technology, and all of the world's significant international manufacturers were US firms. But, when the minicomputer was conceived in the early 1960s it looked as though once again British firms had a chance to enter at the forefront of a new automation-related market. Nevertheless, within a decade the world market was again dominated by US firms and the British innovators were nowhere to be seen.

Thesis Outline

My thesis follows a recent trend in British history of computing PhD theses to examine broad themes rather than individual cases. For example: Mary Croarken's *Early Scientific Computing in Britain* examines the role of L. J. Comrie in the mid-20th century establishment of British "computing centres", following on from Douglas Hartree's work in the 1930s on the development of Differential Analysers; Anthony Gandy's *The Entry of Established Electronics Companies into the Early Computer Industry in the UK and USA* examines the technical directions and the changes in organisational structures of various electronics companies as they became involved in the manufacture of mainframe computers in the 1950s; and finally James Small's *The Analogue Alternative* investigates the shift of emphasis from analogue to digital technologies in the development of computers around World War II.[1] There are two

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[1] Mary Croarken, Early Scientific Computing in Britain, Clarendon, Oxford, 1990; Anthony Gandy, *The Entry of Established Electronics Companies into the Early Computer Industry in the UK and USA*, (PhD Thesis), LSE, 1992; and James S. Small, *The Analogue Alternative: A Socio-Economic History of the Electronic Analogue*

key themes to my thesis: the notion of failure, and the position of the thesis within the genre of "failure studies"; and the role of control technology and its development in Britain's industrial decline. Both themes are investigated with particular regard to the influence of social factors on the direction of technological development.

Many British texts in the history of computing have been labelled failure studies, and it is a term that tends to be somewhat stigmatising. However it is a mistake to assume that industrial or commercial failures are clouds without any silver linings. Typically, the notion of failure is derived through the application of a simplistic definition of success: a domestic industry is only considered a success if it is a major player in the global market. However, in the case of high technology industries it is wrong to apply such a simplistic definition because it is clear that the widespread adoption of new technologies can in many cases be more important than its local manufacture. A particularly strong example is the case of computer technology, because an environment in which many companies are actively investigating and using new computer systems is of far greater significance than the fact that the computers are manufactured locally. Automation is another example of a technology that does not have to be manufactured locally for it to be regarded as a success. Computers and automation are enabling technologies, and so their benefits to the end users must be taken into consideration before an industry can be labelled a failure.

Britain's industrial decline, and in particular the "British problem" - the perceived failure to translate scientific discovery into product innovation - is the second theme of this thesis. Successive governments saw both industrial automation and the use of computers by small businesses as a means for countering Britain's relative economic decline.[2] A strong interest was shown in promoting the adoption of

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Computer in Britain and the USA, 1930-1975, (PhD Thesis), University of Manchester, 1994.

[2] See B. Collins and K. Robbins, *British Culture and Economic Decline*, Weidenfeld and Nicolson, London, 1990; B. Elbaum and W. Lazonick (eds.), *The Decline of the British Economy*, Clarendon, Oxford, 1987; Michael Dintenfass, *The Decline of Industrial Britain, 1870-1980*, Routledge, London, 1982; and M. Wiener, *English Culture and the Decline of the Industrial Spirit, 1850-1980*, Cambridge University Press, 1988.

the new technologies, both by industry and government. In chapters 3 and 5 the question is raised: Did the British governments handle the issues of industrial automation and the promotion of computing appropriately; and if not, what mistakes were made, and why?

The presentation and content of the thesis has been strongly influenced by the post-Kuhnian school of social constructivism. As well as considering the development of the control industry's supply-side, or technical and business direction, its demand-side and social environment are also taken into account.[3] In each case study described in this dissertation a number of principal social factors are taken into consideration, which include: the motivation behind the manufacturers' corporate and technical strategies; the demands placed upon the manufacturers by their customers; and the influences of government policy in both supply-side and demand-side measures.

There are four principal chapters to the thesis. Chapter 2 serves to introduce the technological and mathematical concepts of feedback control systems, and to give some historical background to the notion of the "automatic factory" as it was perceived in the early 1950s. Then in chapter 3 the furore that surrounded the establishment of automation as a topic of general debate is investigated. In chapter 4 one of the earliest applications of digital control technology - the numerical control of machine tools - is described. Chapter 5 continues to follow the theme of development in control technology by looking at the early 1960s general-purpose devices and the creation of the minicomputer. Three of these (chapters 3, 4, and 5) are based primarily on original research.

Chapter 2 - From Feedback Control to Automatic Factories

Before digital control technology was developed in the mid-twentieth century most industrial process control was achieved by analogue mechanical or electro-mechanical systems. In chapter 2 the origins of the modern concept of industrial automation are examined, beginning with the principle of "closed-loop feedback control" - systems

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[3] See particularly Donald MacKenzie, *Knowing Machines: Essays on Technical Change*, MIT Press, 1996; and Wiebe Bijker, Thomas Hughes and Trevor Pinch, *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, MIT Press, 1987.

that operate independently of human intervention (closed-loop), and in such a manner that any variation between the system's operating parameters and their desired values results in a corrective force being applied by some means (feedback control). There follows an explanation of the key elements of a control system - effectors, sensors, and comparators - along with a brief description of their origins and typical technologies.

The chapter continues with an examination of the influence of academic developments in the mathematics of control systems, which resulted in the genesis of the automation concept after World War II. In particular, during the late 1940s mathematicians such as Nyquist, von Neumann, Shannon, and Wiener formulated a general "control theory", which became known as "cybernetics", and which established automation as a distinct engineering discipline.[4] Furthermore, by showing that in a generalised model of a system employing feedback control there was always a potential to enter into a hazardous oscillatory state of increasing magnitude, the mathematicians effectively generated a requirement that future industrial cybernetic systems be examined analytically before they could be trusted in safety-critical applications.

The automation concept developed on the one hand from its academic roots in cybernetics, and on the other from a series of advances in manufacturing technology. Two seminal British manufacturing systems are examined: the transfer machine built for Morris Motors in 1923, and John Sargrove's 1948 Electronic Circuit Making Equipment (ECME). Although these developments were separated by twenty-five years, their influences were similar and significant. Both systems were hailed as "automatic factories" in the press, and both were ultimately deemed failures, being too ambitious for their time. Most significantly, both were also widely reported in the later British and United States' automation literature which played a major role in the "automation hysteria" of the 1950s, the subject of chapter 3.

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[4] The term "Cybernetics" was based on the Greek word for "steersman", implying some kind of controller, and was coined by Norbert Wiener in his 1948 book of the same name. (Norbert Wiener, *Cybernetics: Control and Communication in the Animal and the Machine*, MIT Press, 1948).

Chapter 3 - The Automation Hysteria

Wiener's technical warnings were accompanied with dire predictions of social disturbance, and these laid the foundations for a period of automation hysteria in the mid-1950s. Alarmists predicted social disruption, economic hardship, and a massive de-skilling of the workforce as a result of automation, while technological positivists saw automation as an enabling technology that would usher in a new age of plenty. In the United States, the books of Norbert Wiener and John Diebold are exemplars of the opposite sides of the debate, as alarmists and positivists respectively, but I argue that the debate in Britain was more concerned with the short-term effects of automation. The direction of technological development in the United States was strongly influenced by Cold War fears, but in Britain a perceived need to increase both domestic and international competitiveness - in order to combat Britain's economic decline - was more significant. In Britain, by publishing both the alarmists' claims that British industry would fall behind its competitors unless it embraced automation, and the positivists' claims that automation would lead to massively increased productivity – opposite sides of the same coin - the press encouraged industrialists to invest in modernisation. The most notable result was that a number of forward-looking electronics firms that were already involved in the development of automation technologies geared up for an anticipated surge in demand for general-purpose automatic control equipment.

Meanwhile, institutional interest in automation was growing in line with the amount of media attention the subject was attracting. The established engineering institutions struggled to integrate the new field into their organisational structures, while recently created interest groups tried to jump onto the bandwagon by forming completely new institutions. Typically, the existing institutions urged conservative, reflective analysis of the subject, and attempted to counter the subjective and uninformed debate that was dominating the popular media. They argued that because the alarmist predictions had no basis in hard data it was essential to commission further systematic case studies on the impact of automation. Meanwhile, many new journals were launched to address the new field, while others that were dedicated to related disciplines increased their coverage of automation issues. A few significant conferences were held to discuss the implications of automation and were widely reported in the popular press. By the late 1950s each of these measures, combined with the recognition that the alarmist predictions clearly were not being met, resulted in the dissipation of the automation hysteria.

Nevertheless, politically, automation remained a hot potato. With such a broad spectrum of opinions on its likely impact, it was difficult for any of the parties to find a single tenable standpoint on the subject. Even the trades unions could find no broadly defensible position - they were faced with the quandary that automation was essential to protect some of their members' interests, while it might ultimately prejudice the interests of others. In practice, throughout the 1950s political decisions were deferred while the political parties launched internal investigations and waited for the results of the reports which had been commissioned by bodies such as the Department of Scientific and Industrial Research (DSIR), the Board of Trade (BoT), and the European Productivity Agency (EPA). However, even when the results were forthcoming they were often contradictory. The chapter concludes by examining the controversy that erupted over the attempted cover-up of a European Productivity Agency report.

Chapter 4 - The Road to Numerical Control

While the automation debates had been raging in the popular media and political arenas in the mid 1950s, several UK and US electronics firms had been working on entirely new production technologies based on digital electronics and the principle of feedback control. There were many factors behind the companies' decisions to develop these new technologies, and the individual significance of each factor is hard to extract from the historical record. Several US scholars have examined the subject in the context of a Marxist class struggle between management and the workforce, and have concluded that the new technologies were encouraged as a means for management to appropriate control that was traditionally manifested at the shopfloor. However, within the context of the automation hysteria, particularly with regard to competitiveness fears, the impact of contemporary economic arguments on the direction of technological development seems to have been largely overlooked. The electronics firms could readily rationalise their decision to continue development of the new technology without recourse to control arguments. Furthermore, the US story, with its roots in military development - particularly the work on the APT tool control language sponsored by the USAF - is markedly different from what happened in Britain. The differences are explored, and crucial questions are raised regarding the validity of the Marxist control thesis.

Four principal research projects in the automatic control of machine tools were undertaken in Britain in the mid-1950s. Three of the projects were conceived and developed by electronics/engineering firms (Ferranti, British Thomson Houston, and Electrical and Musical Industries). The fourth was by a conventional machine tool manufacturer (Alfred Herbert). Each system used a different and unique technology, but they were all applicable to similar application areas, so we are afforded the opportunity to distinguish some of the critical factors in their successes or failures. Also, by comparing the efforts of the electronics companies and the machine tool manufacturer, some conclusions about how organisational cultures and capabilities affected technological developments can be derived. In particular, it is concluded that the machine tool manufacturer could be criticised for its conservatism, while the electronics firms appear to have misdirected their limited marketing capabilities.

The anticipated market for N/C systems failed to develop, and the result was that the electronics firms could not recoup their investment on the control technologies as quickly as they had anticipated. By the mid-1960s it was apparent that although the market was emerging, its growth was a great deal slower than had been predicted during the automation hysteria. Nearly a decade after the first development costs had been incurred and the type of control technology decided, the electronics firms were yet to show a profit on their work. The chapter ends with an examination of the reasons for the limited size and unexpectedly slow growth of the actual market. The conclusion is that the unrealistic early predictions had been poor estimates based on inappropriate statistics – it was not until the mid-1960s that there were accurate figures which separated automated machine tool sales from conventional sales on an industry-wide basis. Furthemore, it is argued that although the slow growth was partly due to managerial conservatism, it was more significantly due to the failure of the conventional machine tool manufacturers to introduce automated systems quickly enough to meet the early demand from companies that were interested in investigating the new technology.

Chapter 5 - The Minicomputer Industry

In Britain and the United States in the late 1950s process control equipment manufacturers found that the development costs of new systems - which were traditionally developed from a clean slate - were becoming prohibitively high. Their solution was to create general-purpose, programmable controllers. These were effectively small computers, and became known as minicomputers. Although the first minicomputers were developed for use in industrial automation, similar systems were soon being aimed to compete - although only in small-scale application areas - with mainframe computers. Because minicomputers, unlike mainframes, were not capital- or resource-intensive, and did not require air-conditioned accommodation, or even full-time technical staff, they appealed to a completely new market of potential users. The minicomputer market expanded rapidly, and pushed US companies such as Digital Equipment Corporation and Data General to the forefront.

Chapter 5 centres on case studies of a number of British firms that entered into minicomputer manufacture in the 1960s. There were traditional electronic goods manufacturers (Ferranti, Elliott Automation, GEC, and Plessey), who entered the market through evolutionary advances of their existing process control technologies, and there were entrepreneurial start-ups (Computer Technology Limited, Digico, and Arcturus), who entered the market with the express goal of competing with the low-end mainframe computer market.

Within the context of its "white heat" policies, the Wilson government saw small computers as a central element of industrial modernisation and thus a part of the solution to Britain's economic decline. In the mid-1960s the Ministry of Technology was formed and initially given twin objectives with respect to the computer industry: to support industrial modernisation, and to promote the British small computer manufacturers. However, the US-built minicomputers proved too competitive on price alone, and by the mid-1970s they had come to dominate the industry, with the few remaining British firms relegated to niche markets. The chapter concludes by addressing a number of questions concerning the demise of the British minicomputer industry: What were the significant differences between the UK and US operating environments? Was the British manufacturers' tendency to niche specialisation appropriate, or inevitable? Was government policy responsible for the failure of the British minicomputer industry - indeed, was it actually a failure?

Position of the Thesis within the History of Computing

The history of information technology encompasses many fields, including computing, telecommunications, and broadcast technologies. It is a subject that has been increasing in its richness and sophistication in line with an improved quality of and access to source material. As Aspray has noted, the 1980s saw a dramatic rise of interest in the history of computing, with a corresponding increase in the systematic aggregation of historical artefacts, archives, and manuscripts.[5] Consequently there has been a move away from technical and intellectual history to a broader field in which the social and cultural contexts of the development of technologies are also being considered.[6]

History of computing literature can be broadly divided according to three types of author. First, there are computing professionals, who typically write internalist histories describing the development of a single project, or of a company with which they were involved, with the authority of a first-person account and a grasp of the technological issues which is often absent in histories written by non-technologists. Second, there are journalists, who typically write with the goal of entertainment and the popular dissemination of a story, often with some kind of implied moral. And third, there are the historians of technology and science, who are characterised by their more rigorous and holistic approach to scholarship, but which is often at the cost of accessibility to the layperson.

For various (mainly demographic) reasons, the history of computing has been dominated by English-language accounts. Aspray has suggested that there is a perceivable difference between European and US scholarship, which he attributes to European scholars making a greater effort to examine the history of computing from

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[5] William Aspray, "The History of Computing Within the History of Information Technology", in *History and Technology*, Vol. 11, 1994, pp. 7-19.

[6] See also Michael Mahoney, "The History of Computing in the History of Technology", in *Annals of the History of Computing*, Vol. 10, No. 2, 1988, pp. 113-125.

the social perspective that became fashionable in European history of science and technology during the late-1980s. However, what Aspray does not comment on is another significant difference between the two regional collections of scholarly work - the European studies tend to have a very different emphasis. In the United States historians have concentrated on success stories - for example, how Silicon Valley became the world centre for semiconductor development, how IBM came to dominate the world mainframe market, how DEC became the dominant minicomputer manufacturer, and how Microsoft came to dominate the microcomputer software industry. On the other hand, European scholars have been forced by circumstance to investigate the opposite - failure studies. Typical themes include: Why did "national champion" policies fail to establish viable domestic industries? Were US companies able to take the lead in the development of electronics technology because of endemic managerial conservatism in Europe? Why did early European technological breakthroughs fail to spawn successful industries? Were government policies responsible for lost opportunities, or was the European domestic market simply never large enough to sustain an independent world-class industry?

The European writers are divided into the same three types - computing professionals, journalists, and historians of science and technology - but their preoccupation with failure studies is marked, although unsurprising. For example, looking at journalistic works, on the United States' side we find books such as Rifkin and Harrar's *The Ultimate Entrepreneur*, which details the rise of DEC and its patriarchal founder Ken Olsen.[7] DEC's is an archetypal success story - the company was founded by a few Massachusetts engineers in 1957 with just $70,000 in venture capital funding from American R&D (ARD). By the mid-1980s it had become the second largest computer company in the world (behind IBM). Rifkin and Harrar's account is typically journalistic - largely based on hearsay and quite probably apocryphal stories, its background information was predominantly gathered by interviewing (often anonymously) an arbitrary group of senior DEC staff, most of whom had worked for the company since the 1960s. Rifkin and Harrar rarely attributed their sources, and clearly had an overt agenda to portray Olsen as an

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[7] Glen Rifkin and George Harrar, *The Ultimate Entrepreneur: The Story of Ken Olsen and Digital Equipment Corporation*, Contemporary Books, London, 1988.

anachronistic manager who was no longer capable of running a company which dealt in modern technologies that he did not understand, but who was unwilling to relinquish control of his creation. Nevertheless, although their analysis is shallow from both a technical and historical perspective, Rifkin and Harrar have followed the journalistic tradition of bringing to life the personalities behind the development of a major company. The result is that even though the book may not be intellectually demanding, it has an aspect of emotional engagement that is unfortunately often missing from academic scholarship.

Other prime examples of US journalism include: Tracy Kidder's award-winning *The Soul of a New Machine*, which is a fly-on-the-wall account of a year spent by Kidder working alongside a Data General team while they developed a new minicomputer, the first 32-bit system based exclusively on silicon chip technology, and intended to be a direct competitor to DEC's PDP-11; Wallace and Erickson's *Hard Drive*, which charts the rise of Bill Gates' Microsoft "empire", and its eventual domination of the world microcomputer software industry; and even David Sheff's *Game Over*, which although it is the description of a Japanese company (Nintendo), is predominantly concerned with its subsidiary Nintendo of America's marketing success in the United States.[8]

On the other hand, the European journalists have no success stories - at least on a global scale - to relate from the material at hand and so they inevitably write on the failures of domestic would-be global players. A typical British example is Rodney Dale's *The Sinclair Story*, which tells the story of Sir Clive Sinclair's rise from hobbyist electronics supplier to number one manufacturer of home microcomputers in Britain during the early 1980s (Sinclair Research), and the company's subsequent failure as it haemorrhaged funds into the misjudged development of a small business

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[8] Tracy Kidder, *The Soul of a New Machine*, Little, Brown, Boston, 1981; James Wallace and Jim Erickson, *Hard Drive: Bill Gates and the Making of the Microsoft Empire*, John Wiley and Sons, New York, 1993; and David Sheff, *Game Over: How Nintendo Zapped an American Industry, Captured Your Dollars, and Enslaved Your Children*, Random House, New York, 1993. There are many others, but these are good representative examples.

computer (the QL).[9] Other similar domestic stories include Tom Lloyd's paper, "Dr. Hermann Hauser, Chris Curry, and Acorn Computers" (which, incidentally tells the opposite side to Dale's *Sinclair Story*, detailing the controversial choice by the BBC to lend its name and support to Acorn rather than Sinclair), and John Harvey-Jones and Anthea Masey's "Apricot Computers", which describes the situation that faced management consultant Harvey-Jones when he was invited to advise the ailing Apricot Computers as part of a BBC documentary programme.[10] A final example is John Kavanagh's *Aliens' Guide to the Computer Industry*, which gives a fast-paced, but often superficial overview of the British industry within the world-wide context, and examines the principal issues that are regularly raised in this country: Why has ICL been unable to compete successfully with IBM in the mainframe industry? Are British businessmen doing their companies a disservice by buying British? (And notably, in the context of my thesis, "Who the hell are CTL?")[11]

The European concentration on failure studies is not restricted to journalism. Comparing US with European academic scholarship we see the same pattern. Representative US academic texts on the history of computing include Kenneth Flamm's two books, *Creating the Computer*, and *Targeting the Computer*, and Steven Usselman's paper "Fostering a Capacity for Compromise", all three of which examine the growth of the mainframe industry in the United States with respect to government policies, particularly defence and special projects funding.[12] Even though during the

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[9] Rodney Dale, *The Sinclair Story*, Duckworth, London, 1985. See also Ian Adamson and Richard Kennedy, *Sinclair and the Sunrise Technology*, Penguin, London, 1986.

[10] Tom Lloyd, "Dr. Hermann Hauser, Chris Curry, and Acorn Computers", in Tom Lloyd, *Dinosaur and Co.: Studies in Corporate Evolution*, Routledge and Kegan Paul, London, 1984; and John Harvey-Jones and Anthea Massey, "Apricot Computers", in *Troubleshooter*, BBC Books, London, 1990.

[11] John Kavanagh, *Aliens' Guide to the Computer Industry*, Reed Business Publishing, London, 1988.

[12] Kenneth Flamm, *Creating the Computer: Government, Industry, and High Technology*, The Brookings Institution, Washington, DC, 1987; Kenneth Flamm, *Targeting the Computer: Government Support and International Competition*, The

period covered by Flamm the industry leadership changed hands several times, it always moved from one US company to another, and the principal story is one of a national success. Flamm highlights two policy failures outside of the United States: the national champions model which dominated European governments' policies, and the deliberate fostering of a co-operative research environment, as favoured by the Japanese Ministry of Trade and Industry (MITI), both of which failed to achieve their desired catch-up with the US leaders.

Other prime examples include Richard Langlois' paper "External Economies and Economic Progress: The Case of the Microcomputer Industry", and AnnaLee Saxenian's *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, which both describe trends in technological development that resulted in a very localised industry infrastructure, ensuring that the United States would remain the centre of innovation even though individual companies might come and go.[13] Other US scholarship centres on specific case studies, in which the development of single organisations or products is considered, rather than the industry as a whole, but the success-story theme remains. For example, Gerald Brock's *The US Computer Industry: A Study of Market Power* and Steven Usselman's paper "IBM and its Imitators" describe how, through economies of scale, customer lock-in, and sheer marketing muscle, IBM and DEC managed to develop markets with prohibitive barriers to entry, while the United States' antitrust legislators were afraid to attack the monopolies for fear of destroying the United States' competitive advantage in computer technology.[14]

Brookings Institution, Washington, DC, 1987; and Steven W. Usselman, "Fostering a Capacity for Compromise: Business, Government, and the Stages of Innovation in American Computing", in *Annals of the History of Computing*, Vol. 18, No. 2, 1996, pp. 30-39.

[13] Richard N. Langlois, "External Economies and Economic Progress: The Case of the Microcomputer Industry", in *Business History Review*, Vol. 66, Spring 1992, pp. 1-50; and AnnaLee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Harvard University Press, 1994.

[14] Gerald W. Brock, *The US Computer Industry: A Study of Market Power*, Ballinger, Cambridge, MA, 1975; and Steven W. Usselman, "IBM and its Imitators:

By contrast, British scholars have looked for the reasons behind commercial failures. Taking the example of wide area analyses, we see John Hendry's *Innovating for Failure*, which complements Jill Hills' earlier *Information Technology and Industrial Policy* in asking whether government policy, particularly with respect to the role of the National Research and Development Corporation (NRDC), was to blame for the poor performance of the early British mainframe industry.[15] Similarly, Brian Oakley and Kenneth Owen, and Tim Kelly have investigated the theme, looking at the Alvey initiative of the early 1980s and the role of the National Enterprise Board (NEB) through the 1970s and 1980s in *Alvey: Britain's Strategic Computing Initiative*, and *The British Computer Industry: Crisis and Development* respectively. In *Technical Diffusion and the Computer Revolution*, Paul Stoneman used economic models in an attempt to pinpoint the mechanisms which enabled IBM to succeed against ICL in the British market, and concluded that by keeping hardware rather than software as the principal technological goal the large US manufacturers were able to maintain a barrier to entry which not only prevented new companies from competing on equal terms, but also forced existing competitors to fund massive R&D programmes just to keep up.[16]

Looking at the British scholarship of specific case studies the common theme remains clear. Martin Campbell-Kelly's *ICL: A Business and Technical History* tells the history of Britain's flagship mainframe manufacturer, and its government-encouraged creation through the merger of numerous office machine, electronics, and computer manufacturers in the late 1960s. Campbell-Kelly examines ICL's role as a national champion, its decision to compete head-on with IBM, and the impact of "Buy British" procurement policies, and asks if it was inevitable that it would be steam-

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Organisational Capabilities and the Emergence of the International Computer Industry", in *Business and Economic History*, Vol. 22, No. 2, Winter 1993.

[15] John Hendry, *Innovating for Failure: Government Policy and the Early British Computer Industry*, MIT Press, 1989; and Jill Hills, *Information Technology and Industrial Policy*, Croom Helm, London, 1984.

[16] Paul Stoneman, *Technical Diffusion and the Computer Revolutions: The UK Experience*, Cambridge University Press, 1976.

rollered by IBM.[17] Similarly, Mike McLean and Tom Rowland investigated the creation of Inmos by ex-CTL founder Iann Barron in *The Inmos Saga: A Triumph of National Enterprise?* Inmos was a clearly atypical example of government intervention in industry during the early 1980s laissez-faire Conservative government, and its story highlights the continuing debate about whether any government can rely on "picking winners" rather than providing broad support for an industry.[18]

Finally, and it is alongside these works that my thesis fits most comfortably, both John Hendry and Geoffrey Tweedale have investigated specific examples of products or companies which initially looked promising, but failed to live up to their expectations, in their papers "The Teashop Computer Manufacturer", and "Marketing in the Second Industrial Revolution: A Case Study of the Ferranti Computer Group, 1949-63" respectively.[19]

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[17] Martin Campbell-Kelly, *ICL: A Business and Technical History*, Clarendon, Oxford, 1989.

[18] Mick McLean and Tom Rowland, *The Inmos Saga: A Triumph of National Enterprise?*, Frances Pinter, London, 1985.

[19] John Hendry, "The Teashop Computer Manufacturer: J. Lyons, LEO, and the Potential and Limits of High-Tech Diversification", in *Business History*, Vol. 29, 1987, pp. 73-102; and Geoffrey Tweedale, "Marketing in the Second Industrial Revolution: A Case Study of the Ferranti Computer Group, 1949-63", in *Business History*, Vol. 34, No. 1, Jan. 1992, pp. 96-127.

A Note on Sources

My research has been based on published and near-published literature (see bibliography), British periodicals and trade journals, archival sources, and interviews. The principal trade journals examined (and dates covered) were as follows:

Automatica (1963-66)
Instruments in Industry (1954-56)
    which became *Automation* (1957)
    then *Automation in Industry* (1957-58)
    then *Instrument Review* (1958-60)
Instrument Practice (1954-60)
Process Control (1954-55)
    which became *Process Control and Automation* (1956-60)
Computer Surveys (1966-72)
Computer Journal (1972-75)
Computer Weekly (1970-75)
Computer Bulletin (1967-74)
Datamation (1959-75)
Data Processing (1968-75)

The principal archival sources were as follows:

The Board of Trade papers at the Public Records Office, London.
The TUC archives at the Modern Records Centre, University of Warwick.
The Institution of Production Engineers papers held by the IEEE Archives Department, Savoy Place, London.
The trade brochures and ephemera collection at the National Archive for the History of Computing, Manchester University.
The British Newspaper Library at Colindale, London.

Where possible my research has been backed up by contact with key figures who were active in the automation industry and/or the political sphere during the period under examination. Some of the participants have kindly offered advice by correspondence, while others have been generous enough to grant me an interview. These people were:

- Prof. Karl Åström (IFAC)
- Lord Avebury (Eric Lubbock) (Digico)
- Iann Barron (CTL)
- Denis Best (Ferranti)
- Dr Jeremy Bray, MP (Ministry of Technology)
- Laurie Bental (Elliott Automation, GEC)
- Prof. John Coales (IFAC)
- Bob Finch (CTL)
- Sir Godfrey Hounsfield (EMI)
- Dr Alexander King (DSIR, EPA, OECD)
- Murray Laver (Ministry of Technology)
- Sir Donald McCallum (Ferranti)
- Alan Sutton (English Electric)
- Sir Richard Young (Alfred Herbert Ltd.)

Chapter 2 - From Feedback Control to Automatic Factories

Introduction

This chapter briefly outlines some of the most significant British developments in control technology that preceded the invention of digital electronics, and considers the origins of the concept of the so-called "automatic factory". First there is an explanation of closed-loop feedback control, which is the underlying principle in most automated industrial processes. Next, the position of academic research within the development of early 20th century control technology is considered, concluding with the argument that the absence of a unified Control Theory held back the adoption of new control technologies until mathematicians such as Wiener, Shannon and Nyquist had developed general rules for the behaviour of dynamic control systems. Finally, there follows an analysis of the impact of two seminal developments in automatic manufacture, both of which were labelled automatic factories, and were widely cited in the automation literature of the 1950s.

Automation, Feedback and Closed-loop Control

Feedback control is the underlying concept of operation employed by post-1950s automated control systems. As a result of its broad range of possible applications it is a term that has been given a correspondingly large number of definitions. For the purposes of this discussion I propose to use the one published by the American Institution of Electrical Engineers in 1951:

> A Feedback Control System is a control system which tends to maintain a prescribed relationship of one system variable to another by comparing functions of these variables and using the difference as a means of control.[1]

The AIEE definition is rather neat because it encapsulates a broad range of applications of feedback, not just those in mechanical or electrical systems. While it uses the mathematical terminology of "functions" and "differences" to distance itself from any particular application areas, the use of the terms "system variable" and

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[1] AIEE, "Proposed Symbols and Terms for Feedback Control Systems", in *Electrical Engineering*, No. 70, 1951, pp. 905-909.

"control" reinforce the notion that automation is a concept which principally applies to physical systems. In fact, further examination of the definitions within the AIEE glossary reveals a strong emphasis on the concepts described in Norbert Wiener's *Cybernetics*, which was published three years before the AIEE glossary.[2]

The abstract concept of feedback predates the first use of the word itself. An inconclusive search for the first written description of a feedback mechanism has occupied a certain brand of scholars for many years. It is interesting to note the wide range of subjects that have conceptualised feedback - from engineering to sociology. For example, Adam Smith's *Wealth of Nations* was based on the concept of a closed causal loop - which represented an economy with a system of free enterprise - within which deviations from an optimal state would be inevitably corrected by supply and demand, or in other words a system governed by a feedback mechanism.[3] While the original concept of feedback is notoriously difficult to pinpoint, the first use of the word in the field of control technology has been unequivocally attributed by Bennett to a series of technical reports published by Bell Telephone Laboratories in the 1920s, in which it was used to describe systems whereby the output of an amplifying unit was added to the input of the same unit, that is, fed back into the system.[4]

The "closed-loop" aspect of a closed-loop feedback control system implies that the control system works independently of human intervention. However, some closed loop systems incorporate feedback but should not be considered feedback-*controlled* systems. One such example is the weir - as the water level above the weir begins to rise, so the amount of water flowing over the weir increases. Accordingly, the water level (under normal circumstances) never significantly exceeds the height of the weir.[5] In order to exclude such variants from the set of feedback-controlled systems, Mayr

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[2] More on Wiener and Cybernetics follows in this chapter and in chapter 3.

[3] For further details of Smith's work in the context of the history of the feedback concept see Otto Mayr, *The Origins of Feedback Control*, MIT Press, 1970, p. 128.

[4] Stuart Bennett, *A History of Control Engineering, 1800-1930*, Peter Peregrinus Ltd., Exeter, 1979, p. 1.

[5] See Mayr, *Origins of Feedback Control*, for the definitive pre-history of feedback control systems.

has provided a simple rule - a feedback-controlled system must contain distinct units for sensing and comparing the system variables.[6] A good example of an early feedback controller which conforms to Mayr's rule was a system applied to the control of a steamship rudder by J. McFarlane Gray in 1866 (it was first installed in the S. S. Great Eastern).[7] The controller performed a comparative operation, measuring the distance between the actual position of the rudder and its desired position, as set by the ship's pilot. The difference between the control variable (the position set at the tiller) and the system variable (the actual position of the rudder) was fed as input to a control unit that attempted to adjust the rudder accordingly.

"Automation" is another term which has been given many different definitions, and once again there is some controversy over its origins.[8] While it is universally attributed to Del Harder, a senior automobile industry executive in the mid-twentieth century, the date of its first reported use varies from 1936 to 1947. Goodman claims that according to correspondence with Harder the word was coined in 1936 when he was a manager at General Motors, and that he had used it to denote "The automatic handling of parts between production processes."[9] However, Noble claims that Harder coined the phrase early in 1947, while working at the Ford Motor Company, and notes that by October 1948 the Ford Automation Department (of which Harder was the head) was merely 18 months old.[10] On the other hand, Bright claims that Harder coined the phrase in late 1946 at an engineering conference where he was discussing the layout and equipment plans for two new Ford engine plants. But Bright corroborates at least part of Noble's story when he notes that Ford's Automation

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[6] Mayr, *Origins of Feedback Control*, p. 8.

[7] Bennett, *History of Control Engineering*, p. 99.

[8] For an interesting, although not comprehensive, overview of some of the definitions of "automation" see Eugene M. Grabbe, "The Language of Automation", in Eugene M. Grabbe (ed.), *Automation in Business and Industry*, John Wiley and Sons, New York, 1957, pp. 18-32.

[9] L. Landon Goodman, *Man and Automation*, Penguin, London, 1957, p. 24.

[10] David F. Noble, *Forces of Production: A Social History of Industrial Automation*, Oxford University Press, 1984, p. 66.

Department was formed in April 1947.[11] Finally, Bennett claims that Harder coined the phrase in 1946.[12]

Bright is the only scholar who also attempts to attribute the first publication of the word, claiming that it first appeared in print in an article in *American Machinist*, by Rupert Le Grand, "Ford Handles by Automation". However, it would appear that what Le Grand called automation - "the art of applying mechanical devices to manipulate work pieces into and out of equipment, turn parts between operators, remove scrap, and to perform these tasks in a timed sequence with the production equipment so that the line can be put wholly or partially under pushbutton control at strategic stations"[13] - is a kind of activity which today would be carried out by transfer machines, and thus would probably be considered mechanisation rather than automation.

Effectors, Sensors and Comparators

While the actual technologies employed in automated control systems have changed markedly, from analogue (predominantly) mechanical to digital electronic methods, the basic principles of operation have remained fairly constant. A feedback control system has three key elements: the effector, or output device; the sensor, or input device; and the comparator, or control unit.

First we have the effector, a device that, when triggered, will exert a force of some description - it may be physical, electrical, or magnetic, for example - which will tend to reduce the deviation between a system variable and the control variable. The most common type of effector is the servomotor, often referred to simply as the servo. (Besides servos, other common effectors include heater elements, solenoids, and cutting tools).

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[11] James R. Bright, "The Development of Automation", in Melvin Kranzberg and Carroll W. Pursell Jr. (eds.), *Technology in Western Civilization, Vol. II*, Oxford University Press, 1967, p. 635.

[12] J. M. Bennett, "History and Definition - The Future", in G. W. Ford (ed.), *Automation: Threat or Promise? Impact and Implications in Australia*, Australian and New Zealand Association for the Advancement of Science, 1969, p. 18.

[13] Quoted in Bright, *Development of Automation*, p. 635.

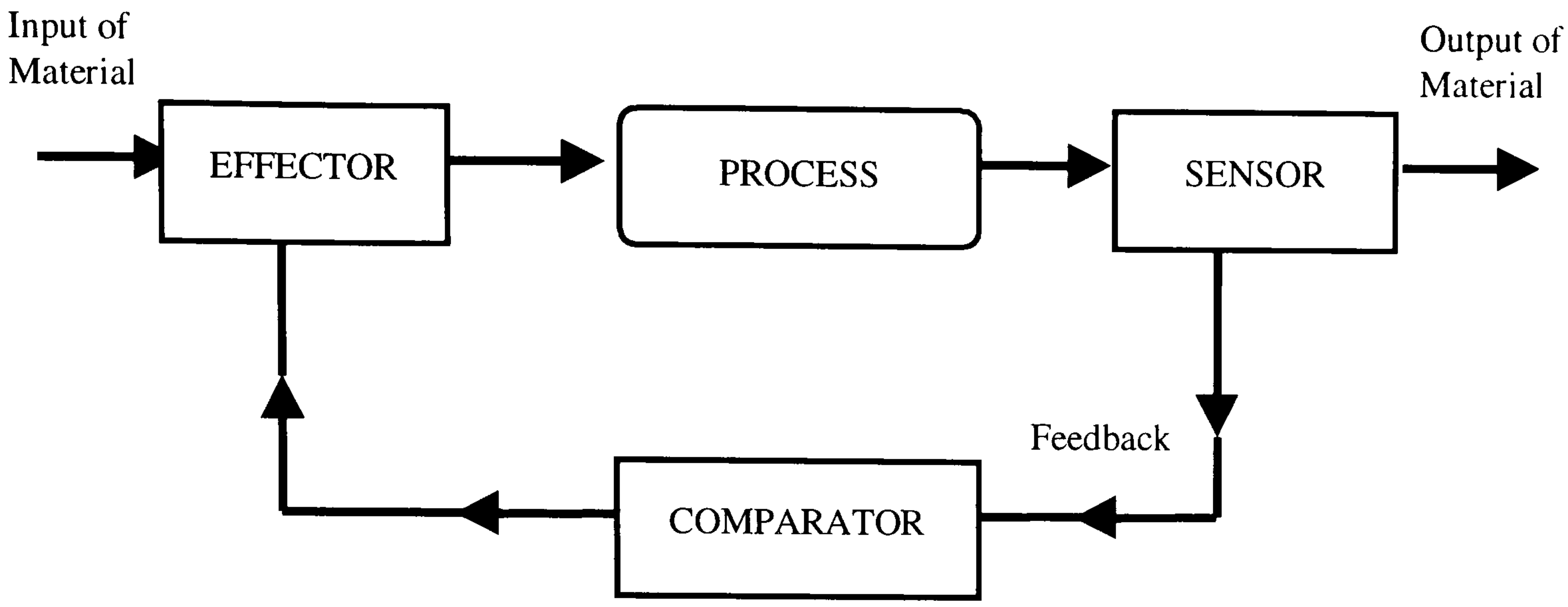

Figure 2.1 A Closed-Loop Feedback Control System

The name "servomotor" was coined by Joseph Farcot, whose 1872 text described "Le Servo-moteur ou Moteur-Asservi".[14] In fact, the servo is a general term used to describe a family of devices whose basic principle as described by Farcot is:

> Any motor at the absolute command of an operator, whose hand acts directly or indirectly upon the control member of the motor, which moves so that the two go, stop, proceed and reverse together, the motor following at every step the operator's finger, imitating like a slave its every gesture.[15]

Obviously this is a rather loose definition, and it should be noted that the set of devices called servos is a matter of some controversy – as I. A. Gettings wrote in 1945, "It is nearly as hard for the practitioners of the servo art to agree on a definition of a servo as it is for a group of theologians to agree on sin."[16]

Servos were first developed for use in steamship rudder control because, while a sailing ship has a high metacentric height, and thus requires little movement of the rudder to effect steering, a steamship sits lower and more squarely in the water, so the force required to control its rudder is much greater - more than a single person could exert without mechanical assistance. Farcot devised a system whereby a controller on the ship's bridge was connected to a powerful motor that operated the rudder. By

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[14] English translation: the servo- or enslaved-motor.

[15] Quoted in R. H. MacMillan, *Automation: Friend or Foe?*, Cambridge University Press, 1956, p. 12 [the quote has been translated from Farcot's original French text by MacMillan].

[16] Quoted in Bennett, *History of Control Engineering*, p. 96.

transmitting the desired position as set by the controller on the ship's bridge to the motor on the rudder, the pilot was relieved of the physical effort.[17]

Next we have sensors, which provide the input to a feedback-controlled system. A sensor converts a physical signal to an appropriate representation as a system variable, perhaps a varying analogue voltage, a force or degree of torque, or a discrete digital representation. In fact, many sensor technologies were available long before they were put to use in automation systems – for example, photoelectric cells were only first used in control applications in the early twentieth century, even though their principle (that the conductivity of selenium varies according to the amount light falling on it) had been discovered in 1873.

Finally, the comparator, or control unit is the heart of an automation system. It evaluates the control and system variables in order to generate the control signals, which are then transmitted to the effector. In the context of this thesis the comparator is the electronic controller or minicomputer as described in chapters 4 and 5. The addition of sensors and comparators to existing mechanised processes is the central aspect of the development of automation. Broadly speaking, when a mechanised process is given the capability to react in different ways to its environment it becomes an automated system. For example, looking at the field of computer-controlled machine tools (the subject of the following two chapters), the primary change that occurred in machining techniques during the inter-war period was the addition of automatic stops which enabled a lathe to be set to keep working until the tool had reached a set point, and thus require less supervision.[18]

Nyquist, von Neumann, Shannon and Wiener: The Mathematical Foundations of a General Control Theory.

By the 1940s control technology had become too complicated to be applied according to rules of thumb and experience. There was an obvious void between practice and

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[17] For details on Farcot's work see Bennett, *History of Control Engineering*, pp. 99-101; and MacMillan, *Automation: Friend or Foe?*, pp.10-11.

[18] S. Lilley, *Men, Machines, and History: The Story of Tools and Machines in Relation to Social Progress*, Lawrence and Wishart, London, 1965, p.158.

theory. Automatic control systems were notoriously difficult to build because they were prone to positive feedback – without proof of stability a system based on closed-loop feedback control could not be trusted in safety-critical, or even economically important, applications because there was a possibility that it could enter into a dangerous oscillatory state. So, in 1932 when Harry Nyquist, a researcher at Bell Telephone Laboratories, published an article on servomechanisms and stability criteria in which he outlined a means for finding stable solutions to certain types of control problem it was well received.[19]

Following Nyquist's research, Shannon's work of 1949 developed the theory further. Shannon claimed that his approach was based on earlier work by Boltzmann in 1894, who had observed in the field of physics that entropy was related to a notion of "missing information", or the number of alternative states which remain open to a physical system after all the macroscopically observable information concerning it has been recorded. Shannon broadened the application of Boltzmann's work by applying it to the communication of information.[20] He outlined three principal types of problem in communications, which he labelled levels A, B, and C. Level A referred to technical problems, or how accurately the symbols to be communicated could be transmitted. At level B the problem was semantics, or how precisely the transmitted symbols could convey a desired meaning. Finally, the level C problem was that of effectiveness, that is, how effectively the received meaning would affect conduct in the desired way. Shannon devised terminology and nomenclature to represent the three types of problem, and proposed the basis of solutions to parts of them.

Building on the work of Nyquist and Shannon was a group of academics who Heims calls the "cyberneticians". [21] They met regularly in the United States in the late 1940s, and attempted to tie together what had been viewed as the disparate subjects of

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[19] See particularly Harold Chestnut, "Feedback Control Systems" in Grabbe, *Automation in Business and Industry*, John Wiley and Sons, New York, 1957, pp. 41-88 (esp. p. 48).

[20] Claude Shannon and Warren Weaver, *The Mathematical Theory of Communication*, University of Illinois Press, Urbana, 1949.

[21] Steve Joshua Heims, *Constructing a Social Science for Postwar America: The Cybernetics Group, 1946-1953*, MIT Press, 1991.

engineering and biology. Their approach was to throw out the traditional biological notion that the actions of an entity were solely reactions to external stimuli, in favour of a theory of goal-directed actions. In the new system, entities, whether biological or mechanical, would seek to achieve goals, acting with a purpose, and their reactions would depend on the evaluation of stimuli with respect to the goal.[22] The cyberneticians labelled this "circular causality", which is equivalent to a system of closed-loop feedback control. It was found that modelling circular causality required the analysis of non-linear mathematics, whilst the simpler existing concept of cause and effect could be modelled linearly. Norbert Wiener provided a mathematical basis for the cyberneticians' model. While Shannon had been more concerned with the theory of communication in engineering applications, Wiener's model was more generalised, although in his texts he tended to stick to biological examples. [23] Most importantly, Wiener's work led to the possibility of a systematic approach whereby the stability of industrial processes could be assured by rigorous mathematical means rather than rules of thumb. However, Wiener also set the stage for the extended social debate concerning automation by making alarmist predictions of the negative social effects which would follow the widespread adoption of automation technologies (see the next chapter).

The Automatic Factory

In the mid-1950s the new concept of automation became intertwined with the existing idea of the automatic factory. In this section one of the first systems to be referred to as an automatic factory is briefly discussed, followed by a more in-depth analysis of the first system that arguably deserved the label. However, it is necessary to draw the distinction clearly between automation and mechanisation because the first systems to be labelled automatic factories were merely mechanised systems, most often large transfer machines, and their technology is incidental to the subject of this thesis.

The history of transfer machines – systems whose definition sits uneasily between that of mechanised and automated processes – is another area in the history of technology that has produced interminable priority issues. Once again the confusion

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[22] Heims, *Constructing a Social Science for Postwar America*, pp. 15-16.

[23] Wiener, *Cybernetics*.

results from a lack of accepted definitions. Probably the first transfer machine was a system built in Britain for Morris Motors in the early 1920s to machine engines from rough castings. Most significantly however, it was described in contemporary reports as an automatic factory. Herbert Taylor, the chief engineer at Morris, designed it and supervised its production, as described in his 1922 paper, "Factory Planning".[24] It was 181 feet long, consisting of 53 stations connected by transfer machines, and had a complete cycle time of approximately four minutes – that is, every four minutes all of the stations would have completed their current operation and each of the workpieces could be transferred to the next station. The total time from when a newly cast cylinder was placed at the start of the line to when it reached the end was 224 minutes. However, because of its pipeline mode of operation, after the first 224 minutes another finished cylinder block would be ready every four minutes.

The capital cost for the system was said to have been considerably less than it would have been for a group of normal machine tools to do the same task. Furthermore, the 53 stations could be operated by a total of just 21 men.[25] The system proved very successful, although its efficiency was improved by splitting it into two separate systems because the complete system proved too complicated to keep in operation, and Morris went on to commission a number of other similar systems, including ones for gearbox casings and flywheels.

Nevertheless, clearly the Morris machine was not a true example of an automatic factory, or even one of automation. For the first such example we have to step forward 25 years to examine John Sargrove's ECME.

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[24] Herbert Taylor, "Factory Planning", in *Proceedings of the Institution of Production Engineers*, Vol. 2, 1922-3; See also Frank G. Woollard, "Some Notes on British Methods of Continuous Production", in *Proceedings of the Institution of Automotive Engineers*, Feb. 1925; and Frank G. Woollard, *Principles of Mass and Flow Production*, Iliffe and Sons, London, 1954.

[25] My use of the word "men" is obviously not sexist in the context of early-20th century automobile manufacture.

Sargrove's ECME

The Electronic Circuit Making Equipment (ECME), designed and built by John Sargrove in 1947, was an automated system which could produce a complete circuit board for a radio receiver every 40 seconds. Although it proved to be a commercial failure, for reasons to be explored later, its primary significance lies in the way it was represented in the automation hysteria literature (alongside the Morris Motors transfer machine). However, its technical achievement – pre-dating any comparable systems by about a decade – was undoubtedly one of the earliest examples of automation, and warrants a description here.[26]

Sargrove had previously been the Chief Engineer at British Tungsram Radio Works Ltd, a position he held for 11 years before leaving the company to form Sargrove Electronics Ltd. It was one of many companies that he would found, and was started expressly for the development of ECME, which he had already conceived and designed. Sargrove had thoroughly searched the technical and patent literature – in an IRE Journal paper in which he described ECME he cites 26 related patents.[27] He also knew about some of the less well-known developments in World War II military electronics technologies, including the use of printed wiring techniques in proximity fuses, although his sole wartime experience had been in the use of photoelectric devices at the Electro-Physical Laboratories and with Mervyn Sound and Vision Ltd.

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[26] I am indebted to Ken Beauchamp (formerly of Lancaster University) for the loan of his papers on the history of Sargrove and ECME, which included private correspondence and background information. Beauchamp's papers form the basis of his paper, "John Sargrove – Innovator and Pioneer of Automation", presented at the *8th IEE Weekend Meeting on the History of Electrical Engineering*, Imperial College, London, 1980; and K. G. Beauchamp, "John Sargrove – inventor of the first PCB", in *Electronics and Power*, June 1981, pp. 477-483.

[27] John A. Sargrove, "New Methods of Radio Production", in *Journal of the British Institution of Radio Engineers*, Vol. VII, No. 1, Jan.-Feb. 1947, pp. 2-33. (Sargrove won the first Institute of Radio and Electronics Engineers Clerk Maxwell Premium for this paper).

Sargrove's primary motivation was his recognition that the labour cost of electronic goods such as radios was so high that following any manufacturing failure it was necessary to reclaim the unit, at further cost, rather than abandon it. By designing an automated manufacturing process, he hoped to reduce the labour cost, in particular by eliminating wiring mistakes - a common cause of rejected circuits in conventional manufacture – but also by automating testing at the point of manufacture. Furthermore, there were obvious benefits if the rate of production could be controlled and absolutely predictable, enabling production to continue around the clock at a uniform rate. He wrote, "Electronic control assures complete safety and, at the same time, maintains maximum economy in consumption of material and power."[28]

The ECME machine cost over £100,000 to build, but according to Sargrove's calculations it could make 50,000 radio sets a year, and would become profitable after a run of 20,000 sets (he told reporters at a press conference that the ECME effectively did the work of 600 technicians). Each ECME radio contained two separate circuit boards, costing about £1 to make the pair. The complete circuit consisted of 30 individual components and would have required 80 soldered connections if made by hand. [29]

Sargrove's manufacturing process was innovative: each board was initially sandblasted, then sprayed with a film of zinc. After the metallising process, a milling operation removed all of the zinc except in certain recessed areas on the circuit board – at this point the circuit board would closely resemble a modern printed circuit. Resistors were then made by spraying graphite onto defined areas of the boards. Likewise, by spraying a layer of lacquer with high dielectric coefficient between two deposited metal films capacitors could be made. Finally, inductors were ingeniously made by spraying metal spirals onto opposing sides of the circuit board.[30]

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[28] Sargrove, "New Methods of Radio Production", p. 33.

[29] The Science Museum in Kensington, London, has a set of ECME-produced radio circuits in its collection.

[30] The details on the ECME manufacturing process come from Beauchamp "John Sargrove – Innovator and Pioneer of Automation", and Woollard, *Principles of Mass and Flow Production*, p. 161-164.

The design innovations were not restricted to the manufacturing process, but also extended to automated testing. Photoelectric cells were used to check that the metallising process had been performed correctly, and any boards that were not sufficiently coated would be automatically rejected. Furthermore, if two faulty boards were detected one after the other the whole preceding section of the production line would be halted so that the problem could be rectified, but the remaining section of the machine would continue operating.

Sargrove's circuit design used a small number of cheap, multipurpose valves (incidentally, it was the UA55, which he had designed for Tungsram in the 1930s). The radio was aimed at the Asian market – the circuit was a simple single-channel short-wave receiver, while at that time the Western markets demanded super-heterodyne receivers. Two large orders were placed for the system - one from the Chiang Kai-shek government in China, for 25,000 sets, and one from the Indian government for 20,000 sets. However, ECME never operated for more than a few minutes, and the total number of boards produced using the system was less than one hundred. [31] The Indian order was withdrawn following the partition of India and Pakistan in 1947. It is not clear what happened to the Chinese order – presumably it was dropped during the struggle between the Chinese Nationalist and Communist forces - it was certainly never fulfilled.

The teething troubles when ECME was first tested had taken too long to overcome - typically the sprayed resistors needed to be altered by hand to make their values correct.[32] Sargrove later cited materials shortages and difficult financial obligations as the major problems that he had failed to resolve.[33] And while Sargrove grappled with the technical issues, his funding ran out. His principal financial backer

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[31] Details from correspondence between Edward Sargrove (son of John) and Ken Beauchamp, dated 11th April 1980.

[32] The need for hand-correction was outlined in correspondence from John Sargrove to D. Chilton (a curator at the Science Museum) dated 5th August 1967.

[33] Beauchamp claims that the financial problems were exacerbated by the frequent cuts to the electricity supply in the winter of 1946-47, during a coal shortage, which occurred at exactly the time the ECME needed to be making an uninterrupted production run in order to sustain orders.

got cold feet, and decided to abandon the venture, but first negotiated the sale of the system to the radio manufacturer A. C. Cossor.[34] To Sargrove's dismay, A. C. Cossor had no interest in using the machine, perhaps because it would have made Cossor's own production system obsolete - ECME was cut into several pieces in order to be transported away, and it was distressingly clear to Sargrove that the machine would never work again.[35] The story might have ended there, but Sargrove was a master of publicity, and had managed to awaken the interest of many of the technical writers who would become the major contributors to the automation hysteria of the 1950s.

Conclusion - the Enduring Significance of ECME and the Morris Motors Transfer Machine

In 1947, while trying to drum up support for ECME, Sargrove had gone to the length of commissioning a short colour 35mm film to be made of the system in operation, which he titled "The First Automatic Factory". The result was a seminal popular press article on ECME, with the same title, which appeared in *Fortune* in August 1948. Sargrove was, for a short time, a well-known figure outside of the field of electronics – within his papers we find a letter from Lord Mountbatten, in which he was congratulated on a recent visit to Paris, where he had presented a talk on the ECME to the Societe des Radioelectriciens. Mountbatten wrote:

> I hold the strongest possible views on the subject of international radio and contend that not only should traffic channels be common to all countries, but also that scientific data should be freely interchanged.

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[34] The original backer for the ECME project was the chairman of a large company with no connection to the radio industry, who requested anonymity - a request which remains observed to this day. After his death, Sargrove's wife still withheld the name of the backer when asked to recount the story by Ken Beauchamp. Details are from correspondence from Mildred Sargrove to Beauchamp dated 17th March 1980.

[35] Correspondence from Mildred Sargrove to Beauchamp dated 17th March 1980.

> It is much to your credit that the B.I.R.E. are the first to set an example on this exchange of data.[36]

While ECME and the Morris transfer machine clearly had great contemporary significance, the influence of both systems on the automation hysteria of the 1950s (the subject of the next chapter) is perhaps even more important - both systems were widely cited in the automation literature. A key point to note, which speaks volumes about the nature of the automation hysteria, is that they were often used to support both sides of an argument. For example, take Woollard's description of the Morris transfer system. He enthused, "The machine was eminently successful. [...] It substantially reduced the machining costs while providing the operators with an equal or even higher remuneration." And, "It survived well beyond the normal period of obsolescence, in fact it outlived the engine for which it was made. A section of it was still at work in 1949, that is 25 years after it was first commissioned."[37] On the other hand, one of the most commonly levelled criticisms of the Morris transfer machine was that its capital cost had proved to be so much higher than anticipated that it had to be used for many years longer than was originally expected, to recover the cost.

Similarly, Woollard cited ECME as an example of a successful manufacturing process due to the product and the production line being designed at the same time.[38] Diebold also applauded Sargrove's work, although clearly he had never seen it, nor even read its description thoroughly, because he too cited it as an excellent example of a method of circuit board production that allowed for simple product change.[39] Obviously Woollard's and Diebold's definitions of success were very generous, but they contradict with, say, Lee's analysis – he noted that one of the principle reasons for ECME's failure was the inflexibility of the manufacturing process, and that it was

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[36] Letter from Lord Mountbatten of Burma to John Sargrove, dated 28th July 1947. There is a copy in the IEE archive, NAEST 130/5.3.

[37] Both quotes are from Woollard, *Principles of Mass and Flow Production*, pp. 26-27.

[38] Woollard, *Principles of Mass and Flow Production*, p. 163.

[39] (Diebold features strongly in the next chapter). See John Diebold, *Automation: The Advent of the Automatic Factory*, Van Nostrand, New York, 1952, pp. 38-41.

simply too difficult to adapt it to make a more marketable product.[40] Nevertheless, the net result was that throughout the 1950s there was a general awareness of both ECME and the Morris transfer machine, although the specifics of each system tended to be concealed by hyperbole as they were used to argue for a wide range of propositions.

Finally, it is important to note the continuing influence of Sargrove himself. He went on working in the automation industry, and became in the 1950s a leading figure in the development of automated inspection devices. [41] He also served on the IRE council from 1965 to 1968, and was elected its Vice-President in 1966. Above all, however, he was influential as a voice of reason and experience during the automation hysteria of the mid-1950s, as we shall see in the following chapter.

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[40] L. K. Lee, "Automatic Production of Electronic Equipment", in Grabbe, *Automation in Business and Industry*, pp. 361-418.

[41] The most significant of Sargrove's later papers on automatic inspection are: John A. Sargrove, and P. Huggins, "Automatic Inspection (The Anatomy of Conscious Machines)", in *Journal of the Institution of Production Engineers*, Vol. 34, No. 9, Sept. 1955, pp. 563-74; Sargrove, "Automatic Inspection - Cybernetic Machines", in *Journal of the Institution of Radio Engineers*, Vol. 24, No. 3, Sept. 1962, pp. 241-9; and Sargrove, "Automatic High-speed Measuring Systems for Complex Products and Shape: Interdependent Computation and Cybernetic Inspection Machinery", in *The Radio and Electronic Engineer*, Vol. 27, No. 5, May 1964, pp. 337-48.

Chapter 3 - The Automation Hysteria

The Automation Hysteria of 1954-57

In the mid-1950s automation became a major issue of popular interest, largely due to a flood of publications and an unprecedented degree of media attention. A period of "automation hysteria" was experienced which continued for several years. It was a time when information and misinformation appeared at such a rate that few people could remain reliably informed of the day to day developments in control technology. Because it was a new term, Bright writes,

> "automation" became synonymous with any and every kind of technological change. [...] Any kind of machinery affecting labor was labelled as automation, whether or not it was automatic. [...] In general, automation covers *anything significantly more automatic than previously existed.* [1]

Or, as Lockwood wrote ironically in 1968, "It has been said that in the last fifteen years the weight of paper used to sell and explain the numerical control of machine tools exceeds the weight of installed machines."[2] While journals promoted the imminent, or even supposedly existent "automatic factory", alarmists warned of the catastrophic human consequences which would inevitably follow any hasty automation of production industries. As Bright notes, a major increase in any one of three fields - machines to perform production operations, machines to move materials from one work station to the next, and control systems that regulate the performance of production and handling systems - was often enough for observers to use the label of "automatic factory".

The "Second Industrial Revolution"

Two US writers, John Diebold and Norbert Wiener, gained reputations as authoritative expert witnesses and pundits on developments in the field of automation. Wiener's *The*

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[1] James R. Bright, "The Development of Automation", in Melvin Kranzberg and Carroll W. Pursell Jr. (eds.), *Technology in Western Civilization, Vol. II*, Oxford University Press, 1967, pp. 635-655, (the quote is from p. 640 [his italics]).

[2] F. B. Lockwood, *Fundamentals of Numerical Control*, The Machinery Publishing Company Ltd., Brighton, 1968, inside back cover.

Human Use of Human Beings and Diebold's seminal 1952 text, *Automation: The Advent of the Automatic Factory*, were undoubtedly the most widely read and influential books of the decade on the subject of automatic control.

Wiener was an eminent professor of Mathematics at MIT. Although his original work in control had concentrated on the mathematical theory of feedback systems, he became preoccupied with automation's social impact, and warned of the dangers inherent in relying on autonomous technology and with the replacement of human workers by machines.[3] Wiener viewed social factors, particularly the motives of power and profit as fundamentally destabilising forces, that is, the social embodiment of a positive feedback mechanism.[4] He made an alarmist prophecy in 1948 which is often considered the trigger of the automation hysteria:

> The first industrial revolution [...] was the devaluation of the human arm by the competition of machinery. [...] The modern industrial revolution is similarly bound to devalue the human brain, at least in its simpler and more routine decisions.[5]

Diebold, on the other hand, was a technological positivist, keen to promote the potential benefits that automation might bring. He was the editor of *Automatic Control*, a new 1950s technical journal, and a member of the prolific Harvard Business School's Research Group on Automatic Control Mechanisms. Diebold described automation as "denoting both automatic operation and the process of making things automatic [...] the systematic advantages and the study of which will yield fruitful results."[6] He deliberately distanced himself from the alarmists, but also from what he perceived to be over-enthusiastic predictions of an anticipated "second industrial revolution", and the "glowing pictures painted by those who say that smaller

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[3] Norbert Wiener, *Cybernetics: Control and Communication in the Animal and the Machine*, MIT Press, 1948.

[4] Noble emphasises Wiener's politics in David F. Noble, *Forces of Production: A Social History of Industrial Automation*, Oxford University Press, 1984, p. 72.

[5] Wiener, *Cybernetics*, p. 27. The social implications of automation became the central theme of his next book, *The Human Use of Human Beings*, MIT Press, 1950.

[6] John Diebold, *Automation: The Advent of the Automatic Factory*, Van Nostrand, New York, 1952, p. ix.

computers will soon be available much more cheaply."[7] Although he agreed that many of the suggested technological developments could eventually happen, he considered that the pace of change outlined in most ostensibly serious writing on automation was more suited to science fiction:

> Writers such as Norbert Wiener, by emphasising the similarity of automatic control systems and the nervous systems of humans and animals, have made the world of science fiction seem indeed to be upon us, with a race of human-like robots already in the making. No interpretation of the facts could be more perverse - or disturbing.[8]

To Diebold the essence of automation, and the reason that its introduction would be slower than Wiener feared, was the need to design manufacturing processes around the new control technologies rather than the reverse.[9] In some cases this might even require the re-design of products, at the very least to provide reference points for machine handling.[10] In general, Diebold's predictions were down-to-earth assessments of automation's potential to increase productivity in manufacturing operations, and of its knock-on effect on the standard of living. However, he noted that some manufacturing processes could never be altered simply to increase productivity, and cited an example of a pretzel company which had made a machine to stamp pretzel-style shapes but had then discovered that consumers did not like the traditional tied pretzel shape to be changed. On the whole, Diebold encouraged experimentation in control technologies, which he saw as a force for social improvement, whereas Wiener

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[7] Diebold, *Automation*, p.5. Nevertheless, he was well aware of the trends in research in electronics technology. For example, he foresaw the minicomputer nearly a decade before it became reality, writing "as transistors [...] replace vacuum tubes in the construction of computers, the heat problem will become insignificant [...]. The computers will also occupy far less space; a computer built entirely with transistors rather than vacuum tubes will occupy about the same cubic volume as a normal office desk." (p. 28).

[8] Diebold, *Automation*, p. 154.

[9] Diebold, *Automation*, pp. 20-32. Although Diebold used the example of ECME, Sargrove's automated radio-manufacturing system (see Chapter 2), it is clear from his description that he had never seen the system in operation (p. 39).

[10] Diebold, *Automation*, p. 37.

argued that scientists should try to err on the side of caution by taking more time to assess the impact of new technologies. Wiener warned,

> Let us remember that the automatic machine, whatever we think of any feelings it may have or may not have, is the precise economic equivalent of slave labor. Any labor which competes with slave labor must accept the economic conditions of slave labor. It is perfectly clear that this will produce an unemployment situation, in comparison with which the present recession and even the depression of the thirties will seem like a pleasant joke.[11]

However, Diebold countered Wiener's claim by suggesting that 56% of the (US) workforce was not, and perhaps never would be, in a position to embrace automation. He listed examples of difficult to automate (rather than mechanise) processes, which included agriculture, services, construction and mining. Diebold claimed that the fields which were generally considered ripe for automation, such as printing, petroleum refining, and communications, accounted for a mere 8% of the labour force.[12] According to Diebold, Wiener had made the mistake of assuming that there was a fixed amount of work to be done, so automation would cause the human workforce to be made obsolete, and had ignored the fact that increased production might be matched by increased consumption.

The debate between US scholars centred on heavyweight social issues, and was divided into two camps which Herbert Simon later categorised as Radicalists and Conservatives.[13] Using Simon's categorisation Wiener was clearly an archetypal radical while Diebold was a conservative. However, as Simon (writing in 1965) noted, the 1950s literature had been dominated by informed technological debate but supported by uninformed economic analysis.[14] When it came to assessing the social

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[11] Norbert Wiener, quoted in Bright, "The Development of Automation", p. 636.

[12] The 56% figure excluded people in military service. Diebold, *Automation*, pp. 148-149.

[13] Herbert Simon, *The Shape of Automation for Men and Management*, Harper and Row, New York, 1965, (introduction, p. xi).

[14] Simon's *Shape of Automation*, and in particular its first section, "The Long-Range Economic Effects of Automation" was the first scholarly economic analysis of automation.

implications of automation, the writers during the period of automation hysteria had been starved of facts and figures, and their predictions were uniformly based on rhetoric rather than analysis.

While many of the US-originated fears carried across to the debate in Britain, local issues tended to be more practical, tending to focus on the potential short term economic consequences of automation in industry rather than its long term social effects. For most British observers, their impression of automation came from media reports, the mood of which was captured in L. Landon Goodman's contemporary Penguin publication, *Man and Automation*.[15] Goodman was a Fellow of the Royal Society, a freelance consultant on industrial production and design, and an associate of most of the major British manufacturing and engineering institutions. Like Diebold, Goodman was optimistic about the potential benefits that would accompany increased automation. He too argued that automation was as strongly connected to managerial philosophy as to new technologies, and he frequently criticised the misrepresentation of automation by the popular media, emphasising that at the time he was writing, in 1957, there were no fully automatic chemical factories in existence - even though media reports had suggested otherwise.[16] Goodman's 1957 book, and other similar works, mark a turning point in the automation hysteria - when the fear that automation would create massive unemployment began to subside as it became clear that the adoption of automation was proving to be a gradual process rather than overnight.[17]

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[15] L. Landon Goodman, *Man and Automation*, Penguin, London, 1957.

[16] Goodman, *Man and Automation*, p. 90.

[17] Other key mid- to late-1950s "gradualist" accounts which predicted that the uptake of automation would be a much slower process than had been warned by the alarmists include R. H. MacMillan, *Automation: Friend or Foe?*, Cambridge University Press, 1956; Simon Ramo, "Automation in Business and Industry", in Eugene M. Grabbe (ed.), *Automation in Business and Industry*, John Wiley and Sons, New York, 1957, pp. 9-17; the 1956 DSIR report, *Automation: A Report on the Technical Trends and their Impact on Management and Labour*, HMSO, London; Frank G. Woollard, *Principles of Mass and Flow Production*, Iliffe and Sons, London, 1954; and the 1957 PEP report, *Three Case Studies in Automation*, Political and Economic Planning, Metchim and Son, London.

However, obscuring the rational assessments of the potential impact of automation was a wealth of science fiction accounts published in the mid-1950s. Undoubtedly the most well-known of these was Kurt Vonnegut's 1953 classic, *Player Piano*,[18] which epitomised the popular perception of automatic control technology (it was not yet widely known as automation). Vonnegut worked as a technical writer and publicist at General Electric's Schenectady factories, the loosely disguised centre of the action in the novel. The story, set in the near future, revolves around Paul, a factory manager who recalls the days before automation and the development of completely automatic factories. At one point in the book, in response to his secretary remarking, "Actually, it is kind of incredible that things were ever any other way, isn't it?" Paul replies that relying on human mental and physical processing power was "Expensive, [...] and about as reliable as a putty ruler." Paul goes on to describe the problems of pacing, and how seasonal changes such as workers slacking off towards Christmas could influence the output rate of an entire production line.[19] Later in the book Paul discovers that his chief engineer, Bud, has devised a new machine that eliminates his own job - and those of the nation's 72 other chief engineers.[20] However, although the theme of engineers making themselves obsolete was common in contemporary science fiction, and clearly struck a chord with readers who were regularly presented with exaggerated stories of fully-automatic factories in the popular media, the science fiction of the period was dominated by positivist accounts.[21]

The pessimistic predictions from Wiener, Vonnegut, and the other radicalists (as Simon would describe them) appear to have carried weight only during the early years of the automation hysteria, say from 1954 to 1957. Afterwards, the optimistic messages of Diebold, Goodman, and the other conservatives are more representative of the general trend. But, as we shall see in the next chapter, which looks at the

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[18] Kurt Vonnegut, *Player Piano*, Macmillan, London, 1953.

[19] Vonnegut, *Player Piano*, p. 17.

[20] Vonnegut, *Player Piano*, p. 60.

[21] Other similar contemporary cautionary tales include Cordwainer Smith's short story, "Scanners Live In Vain"; and Walter M. Miller's *A Canticle For Leibowitz*, C. Chivers, 1959. For an informed analysis see John Clute and Peter Nichols, *The Encyclopedia of Science Fiction*, Orbit, London, 1993.

development of the numerically controlled (N/C) machine tools in Britain, radicalist predictions were pervasive just at the time when British research interests in N/C systems were formed, and their influences were significant. The radicalist perspective was grounded in anxiety over the impact of new technologies; the fear generated by the Cold War; and the notion of relative economic decline.

Competitiveness Fears and the Limits to Organised Resistance

US scholars such as Noble, Melman and Braverman have attributed much of the technological direction during the early development of automation to the influence of Cold War fears and a perceived need, at least in the United States, for manufacturing industry to be geared for rapid defence mobilisation.[22] In the United States, particularly following the USSR's launch of Sputnik on 4th October 1957, proponents of automation managed to tie the need to modernise industry to the perceived Communist threat, and they swept aside arguments - such as Wiener's - that new technologies should be thoroughly assessed before being put into general use. The fear was raised that the USSR would overtake the United States in military and manufacturing technologies. Premier Kruschev played against this fear, reportedly saying that, "[automation] is good. It is the means we will use to lick you capitalists."[23] The result was the unprecedented growth of the United States' Cold War military economy.[24]

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[22] See Noble, *Forces of Production*; David F. Noble, *America by Design: Science, Technology, and the Rise of Corporate Capitalism*, Knopf, New York, 1977; Seymour Melman, *Profits Without Production*, Knopf, New York, 1983; Seymour Melman, *Pentagon Capitalism; The Political Economy of War*, McGraw-Hill, New York, 1970; and Harry Braverman, *Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century*, Monthly Review Press, New York, 1974.

[23] Quoted in John Diebold, *Beyond Automation: Managerial Problems of an Exploding Technology*, McGraw-Hill, New York, 1964, p. 10. Diebold argued that automation, or "increasing output per manhour worked", was an essential defence "against the aggressive powers of communism." Diebold, *Automation*, p. 170.

[24] For an explanation of the origins of the United States' Cold War economy, and its influence on technological development programmes the essential references are Michael S. Sherry, *Preparing for the Next War: American Plans for Postwar*

Because the rate of technological change and systems obsolescence in military technology had become so high, it was no longer sufficient for the country to merely stockpile equipment. The United States' manufacturing industry was urged to increase its productivity so that at any given time it would be capable of turning out massive quantities of modern military hardware.[25] Given the spirit of the times it was inevitable that automation would be considered the means to achieving the required increase in productivity.

These very US-centric scholarly analyses make an interesting contrast with the British story, which has had little analysis. In mid-1950s Britain, the United States' defensive response was generally considered excessive. Anti-communist sentiments were considerably weaker here - the mood being excellently captured in this excerpt from a November 1957 column by MP and automation pundit Frank Beswick, who was a regular contributor to *Process Control and Automation*:

Defense, 1941-45, Yale University Press, New Haven, 1977; and Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford*, Columbia University Press, New York, 1993. See also James L. Penick Jr., Carroll W. Pursell, Jr., Morgan B. Sherwood, and Donald C. Swain, *The Politics of American Science, 1939 to the Present*, MIT Press, 1965.

[25] See for example, L. K. Lee, "Automatic Production of Electronic Equipment", in Grabbe, *Automation in Business and Industry*, pp. 361-418, which describes Project Tinkertoy, a research project into mass production techniques for electronic goods.

> Let us be clearer about this. The United States may not yet have staked a claim in outer space but she has more vacuum cleaners to the square mile, and more elaborate motor cars than any other society in the world. The U.S.S.R. has caught up with the U.S.A. in fission and fusion weapon design, and passed her in the development of ballistic rockets and satellites - but standards in other things are pretty spartan. The Russian worker may have a part share in a Sputnik but more likely than not he has no refrigerator, nor washing machine, nor even a decent kitchen in which to put them.[26]

In mid-1950s Britain the Communist threat was less important than the notion that the country was becoming less competitive than other Western nations.[27] The suggestion of industrial decline was fuelled by examples in the field of automation such as those provided by Diebold which showed that the United States' textile industry averaged one operator per 104 looms, while in Britain the ratio was only one operator per eight looms. Industrialists asserted that the solution was for British industry to increase its competitiveness through massive modernisation programmes. For example, the March 1958 issue of *Instrument Review* included a "Special Supplement on Scientific and Technical Education" in which Viscount Chandos (Chairman of AEI) wrote:

> In this country we live by our brains and by our ability to manufacture. I have described engineers as the aristocrats of the twentieth century, for they are the people who lead our industrial development. Anyone who contributes to the reduction of manufacturing costs contributes to our survival. Those responsible for the development of automatic control of machine tools are doing just this.

However, industrial competitiveness was not only considered within an international context. Fears were raised that British companies which failed to adopt automation rapidly would find themselves left behind by their faster moving domestic

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[26] Frank Beswick, "Westminster Commentary", in *Process Control and Automation*, Vol. 4, No. 11, Nov. 1957, p. 412.

[27] See for example Michael Shanks, *The Stagnant Society*, Penguin, London, 1961; and more recently, Michael Dintenfass, *The Decline of Industrial Britain, 1870-1980*, London, Routledge, 1982; B. Collins and K. Robbins, *British Culture and Economic Decline*, Weidenfeld and Nicolson, London, 1990; B. Elbaum and W. Lazonick (eds.), *The Decline of the British Economy*, Clarendon, Oxford, 1987; and M. Wiener, *English Culture and the Decline of the Industrial Spirit*, 1850-1980, Cambridge University Press, 1981.

competitors.[28] For example, a report published by the Association of Supervisory Staffs, Executives and Technicians (ASSET) in 1956 called the introduction of automation technologies "The Compulsory Revolution" precisely because it was seen as the solution to increasing competitiveness.[29]

Thus, the automation hysteria in Britain was far more concerned with the issues of international and local competitiveness. While the hysteria lasted, industrialists were spurred on by alarmist economic arguments to explore the possibilities of the new technologies, even though there were few tangible case studies on which to base rational assessments. An excess of unsupported predictions of economic decline and social upheaval fuelled the hysteria, but as we shall see in the next section, it waned as observers began to realise that the alarmist predictions were not being fulfilled.

The Institutionalisation of Automation in Britain

The late-1950s general trend away from radicalism to conservatism in the perception of automation was largely due to the broadly publicised activities of a number of trade and technical institutions. Critics of the radicalist position invariably pointed out that there was insufficient hard data on which to base alarmist projections of the social and economic impact of automation. The institutions reacted to the massive demand for systematic studies on the effects of automation by publishing reports and launching new, specialised periodicals.

Existing Institutions and New Journals

Both in Britain and the United States a number of technical journals were launched, while several established ones in related fields changed their titles to reflect the increasing interest in automation. For example, looking at the developments in Britain, in June 1954 *Instruments in Industry* was launched, a trade journal with the brief to "provide information [to design engineers] on the application of industrial instruments and instrumentation." Later that year (October) *Process Control* was launched, aimed

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[28] For a typical example of the pro-modernisation argument see Shanks', *Stagnant Society*.

[29] ASSET, *Automation - A Challenge to Trade Unions and Industry*, G. F. Tomkin Ltd., London, 1956.

at the users rather than the developers of automatic control technology. From 1955, as the awareness of automation grew, the journals responded swiftly. In January 1955, *Instruments in Industry* gained the subtitle "The British Journal of Instrumentation, Automation and Process Control". Then, early in 1956, *Process Control* became *Process Control and Automation*, soon followed by the merger of *Instruments in Industry* with the recently launched *Automation* to become *Automation (incorporating Instruments in Industry)*. A similar pattern could be observed in the United States during the years 1955-57.

Alongside the growth of trade publications there were widespread organisational changes as institutions interested in the newly recognised field tried to accommodate automation as a distinct discipline. The earliest British institutional response was the formation of the Control Section of the Society of Instrument Technologists in 1950. It had followed consultations with the Interdepartmental Committee on Servomechanisms and Related Devices (ICSR), a Ministry of Supply committee that wanted to extend its remit from being an advisory panel to the armed services to becoming a promoter of education and research programmes in automatic control.[30] Similarly, the Institution of Radio Engineers (IRE) formed a Servo-Systems Committee in 1951, which became the IRE Feedback Control Systems Committee the following year. The new committee went on to form the IRE Professional Group on Automatic Control in 1955, the first significant professional group of any British institution to be dedicated exclusively to the topic of automatic control. The Institution of Electrical Engineers (IEE) on the other hand, chose not to create a new section but merely extended its Measurement Section to become the Measurement and Control Section in 1955. Even so, the IEE's minor reorganisation makes a marked contrast with the activities of the American Institution of Electrical Engineers (AIEE) which had been grappling with organisational reform for several years. During the 1940s and early 1950s the AIEE had at least 11 committees and 16 sub-committees that overlapped in the field of automatic control, a situation which was only partly remedied in 1944 by the formation of an Industrial Control Devices Committee, and later a Feedback Control Systems Committee in 1950.

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[30] Stuart Bennett, "The Emergence of a Discipline: Automatic Control 1940-1960", in *Automatica*, Vol. 12, 1976, pp. 113-121.

For some of the more conservative British engineers, however, the pace of change was too rapid. An interesting example can be found in the late 1955 Council Minutes of the Institution of Production Engineers (IPE).[31] The IPE was probably the institution that dealt most coherently with the early automation hysteria by scheduling its "Automatic Factory" conference in Margate in the summer of 1955 (see section 2.2). Although the IPE was traditionally involved with the more down-to-earth aspects of manufacturing technology, it had become deeply involved in the popular media's presentation of automation through hosting the first major conference on the subject. Because automation attracted wide interest and was a somewhat ambiguous term, it was seen by some IPE Council members as a frivolous and distracting topic which should have been accorded less attention. So, in October 1955 the IPE council debated a motion to reduce the Institution's recent emphasis on "automation issues". [32] One member warned that:

> The present phase of over-popularisation of automation will have a national reaction in debunking. These swings should be compensated by accurate statistical and technical studies of the impact of automation in the U.K., Europe and the world at large, promoted strongly by the I.P.E., and constantly published through its Journal and publications channels.

The ensuing debate centred on comments made by Lord Halsbury who, as managing director of the National Research and Development Corporation (NRDC), represented the link between government and trade interests in high technology ventures. Halsbury expressed concern that too much of the current research into automation in Britain was concerned with its technical aspects, and suggested that the IPE should try to redress the balance by setting up a body to explore human-relations implications (to which the NRDC would gladly co-opt a staff member to contribute or observe). Halsbury's comments were endorsed by Sir Walter Puckey, president of the IPE, who observed that since speaking at the Margate conference he had been offered

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[31] IPE Council Minutes 2.1.6, 1953-56. (The IPE papers are held in the IEE Archive, at Savoy Place, London).

[32] The following details and quoted references are from IPE Council Minutes 2.1.6, 27th Oct 1955, p. 161, (paras. xi-xiv).

> 57 invitations to address meetings in the U.K. and abroad on automation [... The IPE is] better able than the majority to understand and interpret [automation] to those other 16 million people [in service industries], most of whom at the present time, in my experience have not the faintest idea what it is all about.

Conservatism held sway, however, and the council voted by a slim majority to form an ad hoc committee to further investigate the automation issues. The committee would report back to the council at a later date, and a discussion would be held to determine the institution's position with regard to automation. However, it appears that this was a political concession made to silence the critics - the report was never forthcoming, and automation issues continued to increase in prominence in the IPE publications over the following months.

For the most part, professional engineers who opposed the popularisation of automation voiced concerns about its ambiguous definition. "Just what does automation mean?" was the question asked repeatedly in published discussion articles. It was often suggested that the lack of standard terminology throughout the range of applications that used automation technologies was holding back technical progress. Consequently, most institutional activity until the early 1950s, both in the United States and Britain, was concerned with the clarification of automation nomenclature. However, these efforts were uncoordinated, resulting in a huge number of incompatible definitions - by 195~~7, in~~ the United States alone, there were over one hundred proposed standards, papers and articles which dealt with the terminology.[33]

The IPE's Margate Conference in 1955

It has been said that between 1952 and 1955 almost every professional engineering society held seminars on the subject of automation.[34] Undoubtedly the most significant single example of institutional involvement in Britain was the IPE's conference in June 1955, in Margate. In fact, significant proportions of the delegates were journalists and

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[33] An ASME committee collected the data for a report in 1957. For further details on the compilation of bibliographies in automation see Bennett, "Emergence of a Discipline", pp.114-117. I have been unable to find a comparable UK-only survey, but inspection of the trade journals suggests that the British figure would be similar.

[34] A claim made by Bright in "Development of Automation", p. 638.

curious outsiders rather than the typical group of engineers to be expected at an IPE conference. As the editorial of *Instruments in Industry* noted:

> If this month of June were to be recorded in history for any other reason than the Rail Strike it would surely be for the English use of the word Automation. The subject has been written about in every section of the press, from The Times, to Tribune; P.E.P. have issued a booklet; [...] there have been discussions on the radio and television [...] and nearly 1,000 engineers attended *that* conference in Margate.[35]

The conference title, "The Automatic Factory - What Does It Mean?", was inspired by John Diebold's seminal 1952 book, *Automation: The Advent of the Automatic Factory*.[36] The concept of a fully automatic factory - one in which raw materials were fed into one end of the factory and finished goods would emerge at the other, untouched by human hand - had become firmly established in the early 1950s. But, as Coales reminisces, the conference seems amusing with hindsight because the majority of the delegates were truly convinced that the fully automatic factory was indeed "just around the corner", whereas just a few years later the recognition of unforeseen technical problems and skills shortages had put paid to such thoughts.[37]

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[35] Instruments in Industry, Vol. 2, No. 13, (Jun 1955), p. 147 [their itals.]. The booklet referred to was a feature edition of PEP's journal, Planning, titled "Towards the Automatic Factory". (*Planning*, Vol. XXI, No. 380, 13th June 1955).

[36]. In his keynote address, Walter Puckey, President of the IPE, immediately cited Diebold's book. Puckey, "The Automatic Factory - Dream or Nightmare?", *IPE Automatic Factory Conference*, Margate, June 1955.

[37] Interview with John Coales, 30th April 1996. Not least of the technical problems was the fact that management decisions were often ignored or altered at the shop floor. For example, when a data processing system was introduced by Tube Investments in the early 1960s it was found that shop foremen typically ignored any technical directions coming from management, preferring to rely on their experience with the equipment as recorded in private pocketbooks, referred to as the "back pocket syndrome". (See R. D. Young, "Data Processing in Tube Investments Ltd.", in Ronald S. Edwards (ed.), *Business Growth*, MacMillan, New York, 1966; and interview with Sir Richard Young, 28th May 1996.)

At the Margate conference, speakers were invited to talk on a broad range of themes, encompassing the social, technical, and managerial aspects of automation. Papers were presented in four parallel sessions, and were of a high technical quality. Walter Puckey, President of the IPE, gave the opening address, "The Automatic Factory - Dream or Nightmare?", which was perhaps memorable for its hackneyed conclusion:

> One of the most spectacular exhibits at the conference [...]comes in a variety of sizes and specifications, weighing in its medium size about 160 lb. It has a built-in computer complete with a fine memory unit and feed-back controls. I would particularly ask you to examine its servo-control system and the ease with which it can be adapted to a wide range of jobs. Unfortunately it does require some skill to get full output from it, but once set and reasonably maintained it performs a fine job. It has, too, the advantage that it can be reproduced by comparatively unskilled labour. Its name? A three-letter word beginning with 'M'!

Puckey was followed by Lord Halsbury on the "Technical and Human Problems of the Automatic Factory". Halsbury criticised the uninformed debate on automation, arguing that it was merely a subset of mechanisation, and should be treated as an incremental advance to existing technologies, rather than a completely new development. He said,

> A picture of the push-button factory, with a river of castings flowing in and a river of finished engines flowing out, is false. Push-button factories are like space-rockets, and push-button manufacture is like space travel. There are no realisations of such fictional concepts even if industrial journalists cannot resist the temptation to dramatise them in advance of achievement.[38]

Other notable speakers, in a series of parallel sessions, included Pierre Bezier (of Renault), on the design and use of transfer machines in automobile manufacture, and John Sargrove, on automatic inspection systems. Of particular relevance to chapter 4, which looks at the development of automated machine tool control systems, were the papers presented by D. T. N. Williamson of Ferranti on "Computer Controlled Machine Tools", and by J. A. Stokes of British Thomson-Houston (BTH) on "Automatic Electronic Control of Machine Tools", and Edwin Fletcher, of the TUC, on "The Automatic Factory: How will the Trades Unions React?" (see also section 3.3).

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[38] Halsbury's speech was summarised in *Instruments in Industry*, Vol. 3, No. 24, May 1956, pp. 100-103. (The quote is from p. 100).

With the strong media interest that the conference engendered, it could quite possibly be regarded as the institution's finest hour - no future IPE conference ever matched Margate's broad appeal or timeliness. Following on the success of the Margate conference, the IPE Summer School (a regular event typically held for 30-40 visiting engineers) of 1956 was titled "Education for Automation", with speakers including John Sargrove, and T. Burns of the DSIR.[39] The 1956 Summer School was a success, and massively oversubscribed, but by 1959 the IPE Summer Schools had to become biannual events because of reduced enthusiasm.[40] The appeal of automation had waned and there was no substitute topic with a similarly broad appeal.

It is interesting to note that there was a US conference contemporary with the IPE's at Margate that enjoyed similar success.[41] This was hosted by UCLA in 1955, and was well attended, with 735 engineers and journalists present. The tone of the Margate conference had been broadly optimistic, but at UCLA the speakers were positively exuberant when discussing the potential benefits of automation. The speakers included many industrialists, such as Simon Ramo (of Ramo-Wooldridge, one of the principal US companies involved in the development of automation), John Mauchly (Remington-Rand UNIVAC), and Harold Chestnut (General Electric). Ramo joked:

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[39] For brief details see IPE Archives, Education and Training Committee 4.2.3 Minutes, 1955-60, pp. 11-16. No papers appear to have been published to accompany the talks.

[40] IPE's Education and Training Committee discussed the lack of interest in succeeding summer schools in 1959. See IPE Archives, Education and Training Committee 4.2.3 Minutes, 1955-60, p. 155.

[41] Grabbe, *Automation in Business and Industry*, is an edited volume of the most significant papers presented at the conference. (Grabbe was a staff consultant on automation to Ramo-Wooldridge, and a professor at UCLA.)

> Anyone who is foolhardy enough to challenge the idea that the replacing of man's brains will be the top industry in the nation some years hence is in danger of having his brains among the first to be replaced.[42]

However, although their predictions were almost uniformly optimistic there was a general acknowledgement, which was yet to be widely voiced in Britain in 1955, that the uptake of automation would probably be delayed by social and technical factors.

IFAC, Automatica, and Pergamon Press

While the old institutions were struggling with the task of defining their policy towards automation, a growing movement of academics and engineers was proposing new institutions for what was perceived to be a new field in manufacturing technology, rather than simply making ad hoc changes to existing organisations. One such group of engineers and academics came together during the 1956 International Conference on Automatic Control, in Heidelberg, to form the International Federation of Automatic Control (IFAC) in response to the "enormous growth in both the theory and practice of automatic control."[43]

A provisional IFAC Committee was elected at the conference, and within a year twelve countries had pledged to recognise and financially support the organisation. Most countries created national member organisations, such as the United Kingdom Automation Council (UKAC).[44] It was formed in April 1957 under the leadership of John Coales, who was one of the wartime pioneers of radar.

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[42] Grabbe, *Automation in Business and Industry*, p. 9.

[43] Quoted from Bennett, "Emergence of a Discipline", p. 113.

[44] In fact, UKAC grew out of the British Conference on Automation and Computation (BCAC). BCAC had been recently formed, after the IEE had convened a meeting for representatives from the 30 main engineering-related institutions, to consider (and ultimately criticise) the recent formation of an Institution of Automation. The Institution of Automation was an ill-starred organisation based in London that appeared in early 1957 but never achieved significant recognition and faded into obscurity within a few years. At the IEE meeting the represented institutions agreed that Britain required an association of existing institutional and trade organisations

In September 1957, a meeting was held in Paris to approve IFAC's proposed constitution, and Harold Chestnut (of General Electric, Schenectady) was elected the first president. The official language at IFAC conferences was English, and so it sought a British publisher, eventually choosing Robert Maxwell's Pergamon press. In 1963, Pergamon introduced *Automatica*, "The International Journal on Automatic Control and Automation", as the official IFAC journal. Maxwell hoped to make Pergamon the principal scientific publisher in Europe, so he considered his association with IFAC prestigious and valuable (more about Maxwell's involvement in the history of digital control, particularly minicomputers, follows in chapter 5). In fact, Maxwell had pressed for the launch of *Automatica* when IFAC was first founded, but had been blocked by Coales and Eckman of the IFAC Committee who had objected that there were too many journals in the field already. But when Coales became the president of IFAC 1963 he relented as Maxwell once again suggested that Pergamon publish a dedicated IFAC journal.[45] *Automatica*'s editorial policy was "to foster international co-operation and research by publishing papers on the theory and experimental research in control systems technology." Articles published in *Automatica* were peer-reviewed and generally of a highly analytical content, reflecting the maturing understanding of the underlying principles of automatic control.

The Politics of Control

British politicians in the 1950s were almost as responsive as the engineering institutions to the surge of interest in the subject of automation. Although the Eden and MacMillan governments' responses to the automation hysteria could easily be overlooked because there were few significant policy changes tied directly to automation, at the same time many politicians were both affected by, and contributors to the hysteria.[46] Of course, just as we shall see in the following chapter on the

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rather than a new institution, and so the BCAC was formed. (For further details see IPE Council Minutes 2.1.7, April 1957 (Secretary's Report); and interview with John Coales, 30th April 1996.)

[45] Details from interview with John Coales, 30th April 1996.

[46] For instance, a report published in 1956, and authored by eight conservative MPs, examined their expectations of the impact of automation. Anon, "Automation

minicomputer industry, for every MP who knew a little about automation there were a host of others who were either uninformed or misinformed because the onset of the automation hysteria had been so sudden - over the course of one year, 1956, the situation had changed from few having even heard the word automation, to almost everybody having an opinion on the subject. For example, at the Labour Party Conference in July 1956 there were twenty-nine resolutions on the agenda that mentioned the word automation in their titles, while the year before there had been none. Furthermore, they represented a full spectrum of opinions, from those welcoming modernisation and technical change to those who asserted that automation could be “a menace to the well-being of working people”.[47]

The DSIR Report and its Successors

In a move to combat uninformed speculation, the Eden government commissioned a survey in late 1955 from the Department of Scientific and Industrial Research (DSIR). The result was a best-selling report, *Automation*, produced by a team led by Dr. Alexander King, the DSIR’s Chief Scientific Officer, published in 1956. Serendipitously, *Automation* was published at the same time as a widely reported industrial action was taking place at Standard Motors, which the press had dubbed the “Automation Strike”. As King recalls, “the government was surprised and delighted at this evidence of [its] prescience and concern”.[48] The report tied together findings from the few existing studies of experiments in factory automation, and aimed to address a series of principal questions that were of importance to both management and the workforce. The questions included: Will automation be limited to large firms? Will it be difficult to raise enough capital? Will machinery or materials be scarce? Will there be a shortage of manpower? And, will there be social resistance to automation?

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and the Consumer”, distributed by the Conservative Political Centre, London, 1957. And, as we have already seen, one MP (Frank Beswick) was a regular correspondent for one of the trade journals.

[47] Quoted from a report on the 1956 Labour Party Conference in *Instruments in Industry*, Vol. 3, No. 26, July 1956, p. 151.

[48] Alexander King, private correspondence with the author, 26th May 1996.

King and his team aimed to dispel the widely held belief that automation could only be economically adopted by large firms, by arguing that even small firms could make use of the new technology if they were prepared to change their working practices.[49] It was suggested that N/C technology might even encourage the growth of a new type of small firm with a high ratio of capital to labour, although it was conceded that "the newer industries are likely to be more interested in automation than the old ones, partly because they are expanding, but also because they are less likely to be hampered by conservative management or by a labour force that fears to lose its traditional skills."[50] Finally, it was argued that the social impact of automation would probably be small given the prevailing climate of full employment - displaced workers, it was claimed, would be able to find other jobs elsewhere.[51]

The DSIR report was soon followed by a host of complementary reports from government, trades unions, and trade organisations: most significantly from the Board of Trade (BoT), the Machine Tool Trades Association (MTTA), Political and Economic Planning (PEP), the European Productivity Agency (EPA), and the International Labour Organisation (ILO).[52] Virtually every report had a common message - that the automation of industry would be gradual, and that the slowness of progress should in itself be a cause for concern.

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[49] However, King suggested elsewhere that the cost of capital equipment might prove prohibitively high, and it was possible that the UK market for manufactured goods might not be large enough to justify massive expenditure on automation. See Alexander King, "Investing in Automation – The Technical Trends", in *Instruments in Industry*, Vol. 3, No. 24, May 1956, pp. 106-109.

[50] DSIR, Automation, p. 47.

[51] The argument only works if one assumes that the full employment was expected to continue indefinitely.

[52] Of these the most significant were PEP, *Three Case Studies in Automation*; Seymour Melman, "Report on the Productivity of Operations in the Machine Tool Industry in Western Europe", PRO BT 258/998 (unpublished); MTTA, *The British Machine Tool Industry*, Machine Tool Trades Association, 1959; ILO, *Automation in the Metal Trades*, International Labour Organisation, Geneva, 1956; and Anon, *The United Kingdom Machine Tool Industry*, Pidgeon and Stebbing, London, 1956.

No doubt as a direct consequence of the volume of contradictory information, Conservative government policy on automation was confused throughout the 1950s, and companies interested in the subject found themselves operating in a policy vacuum. However, the Labour opposition was equally confused, most notably as the party performed a U-turn regarding its policy toward the machine tool industry. Policy in the early- to mid-1950s had been towards the nationalisation of the machine tool industry. In 1953, the policy document, *Challenge to Britain*, had stated that

> Labour will acquire in the public interest a number of the key machine tool firms. These will act as centres for technical rationalization and expansion and will be closely integrated with the state sponsored research organisation.[53]

But by 1960 the explicit policy for the machine tool industry had lapsed, to be replaced by a vague general statement in *Industry and Society*:

> What can be done [with major industries]? The first requirement is that where an industry is falling down on its job a careful and full enquiry should be made and its defects critically appraised. Secondly, when the problems have been fully investigated the most appropriate remedies must be sought.[54]

The Melman Report

With such strong interest and a diverse range of opinions on the subject of automation it comes as no surprise that a single incident became the focus for a controversy involving the Conservative government, Labour, and the trades unions. The cause was a report commissioned by the European Productivity Agency (EPA) in 1956, even though it was never actually published.[55]

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[53] Anon, *Challenge to Britain: A Programme of Action for the Next Labour Government*, Labour Party, London, Dec. 1953, p. 14.

[54] Anon, *Industry and Society: Labour's Policy on Future Public Ownership*, Labour Party, London, July 1957, p. 45.

[55] The principal sources for this section are the Board of Trade papers at the PRO, the TUC Production Department papers at the MRC, and Jonathan Zeitlin, "Growth, Competition, Concentration - II: Aircraft, Machine Tools and Shipbuilding", in Zeitlin, *Between Flexibility and Mass Production*, (forthcoming). I am indebted to Zeitlin for the loan of a draft chapter.

The EPA had arranged for Seymour Melman, a professor of engineering from Columbia University, New York, to visit a number of European machine tool manufacturers in order to assess their competitiveness and compare them with their counterparts in the Soviet Union. Melman sent a draft of the report to the EPA, in which he had set out a scathing attack on the technical direction of the European industry. His report criticised European manufacturers for failing to embrace automation and mass production techniques - Melman claimed that the technology and techniques he had observed in Soviet factories were far in advance of anything being used in Europe. His main recommendation was that the European manufacturers should immediately try to increase standardisation of parts across their product lines on an industry-wide basis, in order to achieve mass production and combat the Soviet threat. Melman also criticised the fact that trained scientists and technologists were scarce throughout the European machine tool industry because by the time such people had completed both university and military service they would, aged 23, be too old for the apprenticeship which the industry seemed to consider essential.

A special meeting of the European Committee for Co-operation in the Machine Tool Industry (CECIMO) was held to discuss what should be done with the draft report. The tone of the meeting is revealed clearly in its minutes: G. Fischer, the Chairman, opened the discussion by discrediting Melman as being more of a journalist than an academic, and certainly not a machine tools expert. He added that Melman was too concerned with the Soviet threat, and had been ill-informed.[56] The other members of the committee echoed his sentiments and supported Fischer when he concluded, "I

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[56] Melman's preoccupation with the Soviet threat is highlighted within correspondence with Fletcher (in MSS.292/615.61/2). In a letter to Fletcher dated 27th June 1959, Melman wrote that he had heard that agents for Russian machine tool manufacturers were in the UK seeking buyers. He added, "Clearly, the Soviet moves are at a faster tempo than I anticipated." Later he urged a Prof. John Ullman of Stevens Institute, Hoboken, NJ, to write to Fletcher, including a clipping of a New York Times article about Melman's Soviet threat warnings (*The New York Times*, Monday 26 Oct. 1959).

am instructed to request that the Melman Report be buried as quickly and discreetly as possible."[57]

The story might have ended there, except the minutes of the CECIMO meeting were leaked to the OEEC's Trade Union Advisory Committee. Fletcher and Melman were already acquainted, and over the following months they corresponded regularly. A hand-written letter from Melman to Fletcher describes his understanding of the events carrying on in Europe after he had submitted the report (Melman had returned to the United States):

> Word from Paris is that all hell broke loose after that press conference on Sept. 21, and that [CECIMO] protested in the strongest terms to the Sec. General of OEEC [...] and demanded that OEEC should not issue any word from me in any form whatever. [...] The game is clear and I hope you can put some heat on to restore the previous decision to publish.[58]

On the advice of CECIMO the EPA decided not to publish Melman's report, but the leak had ensured that the subject was already being followed closely by observers throughout the industry, government and media. Soon Melman was invited to give a BBC Radio broadcast on the subject. On Saturday 21st November 1959, from 6.55-7.15pm he delivered a talk on "The Machinery Makers" in which he reiterated the most controversial claims he had made in his EPA report, particularly with regard to the Soviet threat. His broadcast was deliberately provocative, as illustrated in further extracts from the letter to Fletcher:

> Perhaps to be kept quiet for a while? - have prepared BBC address and will tape it on Weds - for broadcast Nov. 21. You may expect quite an outcry from the Neanderthals after that one.

The British machine tool industry, presumably via the MTTA, had approached the BBC to protest about the forthcoming broadcast, but the only result was that Melman received even more publicity - which was ironic, because the broadcast had been scheduled at a time when it would ordinarily have attracted a small audience.

Melman was clearly being used as a pawn to further the goals of Labour and the TUC. Fletcher wrote about the events to Victor Reuther, the Administrative

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[57] MSS.292/615.61/2, minutes of the European Committee for Co-operation in the Machine Tool Industry.

[58] MSS.292/615.61/2, (manuscript) letter from Melman to Fletcher, dated 26th Oct. 1959. Note that the date coincides with the New York Times article.

Assistant to the President of the (United States') UAW, saying that "With this background we are glad to have Seymour Melman provoking controversy."[59] However, behind Melman's back Fletcher was critical of his academic achievements, writing in a letter to the assistant editor of the Guardian, "I expect you know Melman's two books, "Dynamic Factors in Industrial Productivity" and "Decision Making and Productivity". Don't be discouraged by the fact that neither is brilliant: both are very useful."[60] The inference was that both books were politically useful, although of dubious academic quality.

As leaked and sanctioned copies of the report began to be circulated more widely its content came under vociferous criticism, particularly by the machine tool manufacturers and their trades associations. The MTTA claimed that Melman had not visited any British machine tool factories, had not met with the MTTA, and had rejected an invitation to address the MTAC - the President of the Board of Trade was briefed to this effect.[61] However, a letter from Fletcher to W. J. Carron, president of the AEU, suggests that no such invitation was ever issued, and that Melman's proposed visit had never been welcomed by the British machine tool manufacturers. Fletcher's records in the TUC archives reveal a memo from the Board of Trade which confirms that Fletcher had attended a meeting at the BoT - before Melman had begun his tour - where he had heard that the MTAC was actively opposed to Melman visiting any British firms because it did not recognise him as an expert on the subject.[62]

Succumbing to the pressure from Labour, the press, and the TUC, the BoT advised the MTAC to set up a sub-committee to look into Melman's report and publish a report on it. Sir Steuart Mitchell, a well-respected Ministry of Aviation

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[59] MSS.292/615.61/2, letter from Fletcher to Victor Reuther, dated 24th Nov. 1959.

[60] MSS.292/615.61/2, letter from Fletcher to John Anderson, dated 28th Sept. 1959.

[61] PRO/BT/190/38 document 52A, "Brief for the President's Meeting with Lord Hailsham on 29th January and for the N.P.A.C.I. on 5th February 1960."

[62] MSS.292/615.61/2, letter from Fletcher to Carron, dated 16 June 1959. The claim is confirmed in a letter from Miss E. Ackroyd of the BoT to Fletcher, dated 12th June 1959.

official and a politically safe choice, was chosen to chair the committee, whose members were principally representatives of most of the larger British machine tool manufacturers (Asquith, Alfred Herbert, Vickers Armstrong, Thomas Ryder and Son, and Joseph Lucas) plus observers from the Board of Trade and the Amalgamated Engineering Union.[63] Significantly none of the manufacturers of electronic control systems were represented.

Labour also investigated the content of Melman's report, concluding that Melman had overstated his case, and that there was little evidence for many of his claims. The results of the investigation were circulated as a confidential Labour Party memo in February 1960.[64] Describing the state of the British machine tool industry, the report disagreed with Melman's call for the industry to restructure its R&D in order to further the development of automated manufacturing techniques, concluding that "it seems that at least in the application of electronics to machine tools the failure of the machine tool industry may not matter as a number of large electrical firms [...] are tackling the problem." Nevertheless, the contents of the internal report were kept quiet, and Labour continued to pressure both the EPA to publish Melman's report, and the government to issue a statement on it.

The Mitchell Committee's report was published in 1960 even though the Melman report had never been published.[65] Not surprisingly, given the background of the committee members, it largely defended the methods employed by the European manufacturers - its principal conclusion was that Britain should compete in quality, rather than quantity. However, a small concession was made, with the committee

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[63] An amusing memo from J. B. L. Munroe of the BoT to Sir Leslie Armstrong reads, "Good - the party is now complete except for the Vicker." (The BoT was still waiting for Metropolitan Vickers to nominate its representative). BT/258/998 "Machine Tool Advisory Council Mitchell Sub-Committee", document 62.

[64] Labour Party Home Policy Committee, "The Machine Tool Industry", RD.25/Feb. 1960. (There is a copy in MSS.292/615.61/2).

[65] MTAC, "Report by the Sub-Committee of the Machine Tool Advisory Council Appointed to consider Professor Melman's Report to the European Productivity Agency on the Machine Tool Industries of Western Europe" (hereafter: *Mitchell Committee Report*), 1960.

noting that the conventional machine tool manufacturers would be well advised to at least turn their attention to electronic control systems.[66] The report claimed that British developments were "still ahead of any foreign competitors". However, because it was recognised that there was "a good *prima facie* case supported by actual tests to show that within a wide field of batch production substantial savings in costs can be obtained with these controls even at their present high prices"[67], the committee tried to decide why investment levels in automated systems had been low. Three conclusions were drawn: the still prohibitively high price of control units; a general lack of belief in its reliability; and a lack of empirical data on the cost of its use. It was noted that the industry was well aware of the first problem, the excessive cost, and that the electronics manufacturers were working to solve it. However, the other two problems were the result of years of misinformation and speculation, and would be harder to address.

Having recommended that the conventional machine tool manufacturers should look into the integration of electronic control systems into existing products, the report went on to echo the findings of Labour's internal report, agreeing that the conventional machine tool manufacturers should not have to develop the electronics expertise in-house.

> We do not recommend that machine tool firms should become manufacturers of electronic control equipment but are strongly of the view that each firm manufacturing machine tools of a type to which electronic controls of inspection could advantageously be applied should have on its staff sufficient engineers with the necessary qualifications to understand fully what electronics can and cannot do, to form a link in a joint activity with an electronics firm and to handle the subsequent technical sales problems.[68]

Melman later regarded the government and industry response as indicative of an "old boy" network closing ranks and rejected his comments, and criticised the lack of foresight that they had displayed.[69] It is ironic that Melman's central message - the warning of an imminent massive influx of Soviet machine tools and the call for European manufacturers to radically alter their product lines to combat the threat -

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[66] *Mitchell Committee Report*, para. 58, part A.

[67] *Mitchell Committee Report*, para. 58, part D [their ital.].

[68] *Mitchell Committee Report*, para. 59, part E.

[69] Melman, *Profits Without Production*, p. 13.

proved to be unfounded, but served to draw attention away from his valid arguments for greater investment in R&D and the development of automation technologies. As we shall see in the next chapter, by the mid-1960s the traditional machine tool manufacturers had indeed woken up to the need to modernise, and were doing exactly what Melman had proposed as early as 1959.

Automation and the Trades Unions

Calls to modernise manufacturing techniques and change factory working practices by introducing automated manufacturing techniques were, of course, a major cause of concern for the trades unions. As Christensen has noted, the trade unions were really only interested in two main questions, both sides of the same coin: "Are we going to see a new golden age of leisure and plenty for everybody?" or "Are we facing the greatest threat to our standard of living and way of life since the industrial revolution?"[70] But, while organised labour's rhetoric spelled out its fears in black and white, its actions were grey. In practice, the trade unions were reactive rather than proactive, fighting individual cases where insensitive management could be blamed for disaffected workers, but not actually confronting the principle of automation.

In Jan 1955, during a meeting of the TUC's Scientific Advisory Committee, the TUC General Secretary (Sir Vincent Tewson) had warned against making rash pronouncements with regard to the TUC's policy on automation, saying that "much harm could be done by exaggerated and ill-informed publicity on automation; such reports could be used as an excuse for slacking-off trade union support for improved efficiency in industry."[71] During the discussion the committee acknowledged that there was no evidence so far that automation had caused any redundancies. It appeared that in factories where large-scale automation had been introduced normal labour turnover and temporarily reduced recruitment seemed to have absorbed any workforce displacement. The committee's chief concerns were the effects of changing

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[70] Erik Christensen, *Automation and the Workers*, Labour Research Department Publications, London, 1968, p. 8.

[71] MSS.292/571.81/5A (Trade Union Policies on Automation, 1955-62), Scientific Advisory Committee Minutes, 31st Jan. 1955, discussing the Committee's report 1/1, "Automation".

manufacturing techniques on group and social relationships within the workplace. It was feared that increased automation might have a net result such that "production operatives or machine-minders may be few in number and be drawn into a 'vertical' group structure - mainly staff and management - with promotion opportunities limited for want of early technical training and qualifications." The committee concluded that fear of automation was merely the fear of the unknown, and that it should be addressed by instigating further cases studies - the unions were extremely sensitive about their position with regard to technological progress for fear that they would be accused of Luddism.

Fletcher attempted to outline the TUC's position with regard to automation at the IPE's Margate conference in 1955, but because no policy had been decided upon his presentation was vague, and in parts even contradictory. He told the assembled engineers and press that the trade unions were not necessarily against automation, but warned that "Even with full employment, organisational and social changes within industry will necessitate early management action if unnecessary build-up of hostility is to be avoided."[72] Following his inconclusive remarks, Fletcher fell back on the TUC's traditional failsafe position of being in the business of protecting its members' interests. He said that trade unions would certainly make claims that their members should share in any productivity benefits achieved through automation, particularly in cases where some of their members had been disadvantaged by its introduction.

By the time the Scientific Advisory Committee met again a year later in January 1956 the published literature on automation had mushroomed, and it became clear that there was little, if anything, that the unions could do to slow technical progress. The committee reported that "Essentially, [the] unions have no desire (even if they considered it possible) to prevent the introduction of automation; its continued

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[72] Edwin Fletcher, "The Automatic Factory: How will the trades unions react?", IPE Conference, Margate, June 1955. As Sir Walter Puckey later told the IPE Council, "You know as well as I do that today one of our biggest problems is to put over a development like this [automation] constructively, and thank goodness organised labour has so far been most constructive in its reactions to automation." (IPE Council Minutes 2.1.6, 27th Oct. 1955, p. 161).

application is regarded as inevitable."[73] It was recommended that the TUC should adopt a policy which aimed to ensure the spread of the benefits of automation, rather than to hold back its introduction, but there remained the problem that the literature on automation did not answer all of the committee's questions:

> The alarmist nature of some of the publicity has indeed been a source of concern to trade unions. [Trade unions] aim to safeguard and to advance the interests and well-being of their members, a role best performed in the light of reliable information and facts - not on emotion or hypothetical situations and trends.[74]

By the summer of 1956 the Scientific Advisory Committee was suggesting that the TUC should recognise that automation might offer a broad range of benefits.[75] By wholesale adoption of automation, it was argued, industries would achieve higher efficiency and standards of production, which would lead to improved competitive position (in international terms) and greater stability and security. Furthermore, the Committee recognised that there would be knock-on effects to society (better living standards, material wealth, leisure, opportunities) and to workers (higher wages, shorter working week, extended holidays, improved working conditions, less heavy/fatiguing and more satisfying jobs). And because during the full-employment of the mid-1950s the unions were not particularly troubled by the spectre of unemployment, any change in manufacturing processes that benefited consumers was in turn good news for the union members. However there were clearly many potential pitfalls to be avoided wherever automation was introduced: labour displacement and transfer; changes in training and skills structures; changing wage rates; reduced promotion opportunities; and increased responsibilities. In April 1956, urged on by the Science Advisory Committee, the TUC Congress carried a resolution which defined its

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[73] MSS.292/571.81/5A, Scientific Advisory Committee Report 1/4, "Trades Unions and Automation", 5th Jan. 1956, para. 22.

[74] MSS.292/571.81/5A, Scientific Advisory Committee Report 1/4, "Trades Unions and Automation", para. 7.

[75] The following sentences in this paragraph paraphrase the list of issues that the committee debated. See MSS.292/571.81/5A, Scientific Advisory Committee Report 1/4, "Trades Unions and Automation", paras. 16-17.

position with regard to automation and which became the basis of policy decisions for the following decade:

> This congress believes that the introduction of automation into industry and commerce provides the possibility of better living standards and greater leisure. It is not opposed to automation developments which are recognised as inevitable, but it is resolved that the interests of trade union members shall be safeguarded against any ruthless application of automation by employers, and that the wages and conditions of workers in occupations not easily converted to automatic processes shall not lag behind those in manufacturing industry.

However, even though the principle of automation was not directly resisted because it was difficult for the unions to separate its costs from its benefits, the issue of automation's effect on skill levels did provide a focus for debate. All of the major mid-1950s reports on automation had suggested that automation was being held back by a national shortage of engineers and technologists.[76] Consequently, in 1956, at the height of the automation hysteria, the trades unions criticised the government for failing to provide the resources to increase the number of skilled scientists and technologists. First, at the April 1956 Scottish TUC Congress, the Association of Scientific Workers had tabled a resolution which warned that automation would cause a scarcity of technicians unless the government put forward more money for the development of scientific and technical education programmes. Later, in September 1956, the annual report of the TUC General Council reiterated the claim that the effects of automation would be gradual because of a shortage of scientists and technicians.

The action to highlight the skills shortage was one of the few automation policy successes for the unions in the 1950s. It was a non-contentious issue on which the General Council could take an easily defensible position. In February 1957, the Macmillan government, in a popularly received move, granted an indefinite deferment of National Service to scientists and engineers who graduated from university with first class honours degrees. Its timing was doubly significant because the decision was taken prior to Melman's visit to Europe, so to some extent it contradicts his claim that the

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[76] A skills shortage was also recognised in the United States at the same time. Simon Ramo had argued at the 1956 UCLA conference that rapid change was out of the question because of a shortage of skilled technical workers. He anticipated that the spread of the new technology would probably take place over a twenty to thirty year time scale.

machine tool industry was being hampered because graduates who had been on National Service would be too old for apprenticeships, thus adding credence to the criticisms of his scholarship.

The de-skilling issue, however, had another aspect, which was a great deal more difficult to resolve. During the second World War, the trade unions had lost ground to the proponents of mechanised and automated manufacturing processes, even though many of the new systems had been designed to accommodate the de-skilling of operators, because manufacturing efficiency had been considered a necessary part of the war effort. But, after the war the continuation of de-skilling programmes was regarded as a threat to workers' interests. The trades unions saw a clear trend of demand for manual skills declining in favour of knowledge-based skills - in 1956, at the height of the automation hysteria, reports began to arrive that white-collar workers were now outnumbering blue-collar workers in the United States' workforce.[77]

The proponents of automation argued that there was nothing to worry about, and that on the whole workforces would become more skilled, even if certain specialist skills became obsolete. As was noted in the DSIR's 1956 *Automation* report, increased automation in a manufacturing plant tended to result in a lower skills requirement for general operators, but at the same time their responsibility, in terms of the volume of finished goods which they individually oversaw, tended to increase. A series of case studies published by PEP in 1957 supported the claim that automation would increase the average skills level by demonstrating that it had the knock-on effects of increasing the numbers of managerial staff, supervisors, and maintenance workers, and of increasing the autonomy of the workers who operated the new equipment.[78] These observations were to have considerable implications for training - in particular a reassessment of the need for vocational training in the form of apprenticeships - and in the payment mechanisms used throughout manufacturing industry.

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[77] For the background on knowledge workers see Fritz Machlup, *The Production and Distribution of Knowledge in the United States*, Princeton University Press, 1962; and Marc Uri Porat, *The Information Economy: Definition and Measurement*, United States Department of Commerce, 1977.

[78] PEP, *Three Case Studies in Automation.*

Conclusion

Automation remained an emotive subject from the mid-1950s well into the 1960s. Contradictory claims were made, almost invariably with assumed authority, creating both politically and economically a culture of confusion and uncertainty. At the height of the automation hysteria, from 1955-56, companies were being encouraged to invest in modernisation and to increase their productivity for a host of reasons: to protect their domestic markets; to ensure their future success; and even to combat the Soviet threat. The proponents of automation saw it as a necessity for the continued economic (and in the United States military) well-being of the country, while its opponents saw it as a destructive force which would destroy social structures, reduce the skill level of the nation's workforce, and cause massive unemployment.

The trades unions were unique in keeping the alarmism of the automation hysteria at arms length until there had been time to assess its implications, but as a result, by the end of the 1950s they had found themselves in the position of having to fight cases individually rather than adopting general policies because the costs and benefits of automation were so difficult to separate. The British trades unions had been presented with a quandary that they never managed to fully resolve: that modernisation was both the means to protect some members, while the cause of the disaffection of others.

By the start of the 1960s automation was no longer the political hot potato that it had been. The wealth of surveys into its application had stifled the alarmist predictions. Automation had become recognised as an inevitable, but surprisingly slow avenue of technological development, and the sense of urgency towards its adoption had waned. As we shall see in the next chapter, by the early-1960s even conservative industries had lost their fear, and were beginning to gingerly test the potential of the new technologies.

Chapter 4 - The Road to Numerical Control

Introduction

In the 1950s the spearhead of industrial automation was the use of automatic control systems applied to metal-cutting machine tools. This chapter examines some early British innovations in numerically-controlled machine tools in the light of the automation hysteria. It is argued that the direction of technical development was affected more by the social and political environment than by managerial desire to extend its control over the workforce. It is also concluded that the first companies to develop numerical control systems mistakenly tried to market them to end-users when they should have been approaching the conventional machine tool manufacturers.

Pre-Digital Control Technology

To set the stage for the story of automated machine tools in the 1950s and early 1960s we must first consider the development of control technology in the inter-war period. By the 1920s the automobile industry in particular was increasingly encouraging research into sophisticated mass production technologies which were aimed at the rapid manufacture of large numbers of identical parts. Henry Ford's revolutionary invention of the moving assembly line in 1913, with its emphasis on continuous production and standardised parts, led to an increasing demand for new types of specialised machines, and by the late 1920s the automobile industry had become the largest market for metal-cutting machine tools.[1] Research was concentrated on

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[1] E. Sciberras and B. D. Payne, *Machine Tool Industry: Technical Change and International Competitiveness*, Longman, Harrow, 1985, pp. 27-9. For an analysis of British companies' development with respect to flexible manufacturing techniques see also Paul Hirst and Jonathan Zeitlin (eds.), *Reversing Industrial Decline? Industrial Structure and Policy in Britain and Her Competitors*, Berg, Oxford, 1989; Jonathan Zeitlin and Steven Tolliday (eds.), *Between Fordism and Flexibility: The Automobile Industry and its Workers*, Berg, Oxford, 1992; and Wayne Lewchuk, *American Technology and the British Vehicle Industry*, Cambridge University Press, 1987, esp. chapter 9, "The collapse of the British system of mass production, 1930-1984".

technologies that augmented a worker's ability to manipulate workpieces - mechanisation - rather than control technologies, or automation, which would actually replace skilled workers. For example, electrical and electromechanical handling systems which made use of automatic stops, detectors, and servomotors were developed to speed up production by removing the physical burden from the production line workers, but without changing the manufacturing process itself.

The simplest form of automation - as opposed to mechanisation - to be applied to machine tools was the tracer system. A stylus would trace the shape of a template while the machine tool replicated the movements of the stylus - a simple everyday example is the key-cutting machine. The first tracer systems were developed in the 19th century, but were of limited success because the physical contact between the stylus and the template caused wear, soon resulting in a poor quality copy.[2] Tracer technology first became viable for use in mass production in the early 1940s when fully electronic systems appeared which made use of detector heads that did not touch the surface of the template.[3] A number of British companies developed contact-less tracer systems during the 1940s: for example, Metropolitan Vickers introduced a sophisticated contouring tool in 1947 which used an electromagnetic tracer head to hug the profile of the template, and which could follow into re-entrant cavities in the template.[4]

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[2] For details see L. T. C. Rolt, *Tools for the Job: A History of Machine Tools to 1950*, B. T. Batsford Ltd., 1965. For a contemporary account see Charles Babbage's "The Economy of Manufactures", in Martin Campbell-Kelly (ed.), *The Works of Charles Babbage (Vol.8): The Economy of Machinery and Manufactures*, William Pickering, London, 1989.

[3] General Electric made the first such contact-less system in the United States. For further details see David F. Noble, "Social Choice in Machine Design: The Case of Automatically Controlled Machine Tools", in Andrew Zimbalist (ed.), *Case Studies on the Labor Process*, Monthly Review Press, 1979, pp. 18-50.

[4] See John Dummelow, *1899-1949*, Metropolitan Vickers Electrical Company Limited, Manchester, 1949, p. 229. MetroVick's involvement in the development of Douglas Hartree's Differential Analyser, one of the precursors to the computer, is

However, tracer technology had many drawbacks even after the problem of stylus wear had been solved. When machining complicated parts it was often necessary to use a sequence of templates, so the process would have to be stopped frequently while templates were changed, thus reducing the total time spent machining metal. Furthermore, there were clerical and storage overheads because the templates had to be indexed and stored for subsequent re-use. In practice, tracer systems were more expensive to use than conventional hand-operated tools, only becoming economically viable when used in long production runs. However, the significant improvement that tracer systems offered over conventional machine tools was that the risk of human error was concentrated at the point of manufacture of the template rather than with each individual workpiece. The potential to virtually eliminate human error sustained tracer control as the champion of modern manufacturing technology until it was overtaken by numerical control after World War II.

Technological advances made during the war provided the capability to create an alternative to tracer systems. Military research programmes had led to the development of advanced servomechanisms, magnetic tape, and standardised components, all of which were central to the further development of control technologies.[5] Furthermore, the wartime research programmes had resulted in a large

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explored in Mary Croarken, *Early Scientific Computing in Britain*, Clarendon, Oxford, 1990.

[5] Servomechanisms were developed for use in gunfire control applications - see Stuart Bennett, *A History of Control Engineering, 1800-1930*, Peter Peregrinus, Exeter, 1979; Stuart Bennett, "The Emergence of a Discipline: Automatic Control 1940-1960", in *Automatica*, Vol. 12, 1976, pp. 113-121; (For an excellent illustration of a gunfire control system see Adam Whyte, *War Diary of the English Electric Company Ltd., March 1938 – August 1945*, English Electric Company, 1946, entry for 31 March 1939). And, for standardised components see Ernest Braun and Stuart MacDonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics*, Cambridge University Press, 1978. For a contemporary text on servomechanisms see Vol. 25 of the MIT Radiation Laboratory Series (an unparalleled series of 28 scientific texts published throughout the late-1940s and early-1950s):

skills base of engineers and scientists who wanted to continue their researches in similar fields after the war. As Mayr writes:

> Practical control engineering made great progress during the Second World War, when each belligerent made efforts to gain superiority in this field. When after the war the secrecy was lifted, there suddenly became available (1) a mature technology of automatic control which had proven itself in dealing with the problems of radar, fire control, autopilots, guided missiles, and so on; (2) a theory that was universal and easy to manipulate; and (3) a staff of scientists and engineers who quickly spread this new knowledge, thus introducing the era of automation and cybernetics.[6]

Furthermore, the potential for the new skills base was clearly recognised. As Braun and MacDonald wrote on the prospects that were envisaged for post-war science, "If science and scientists had the power to make such decisive and spectacular contributions to the deadly serious business of war, surely their powers could be harnessed to the more joyful business of building a new and better peaceful world."[7]

So, in the late 1940s machine tool control technology, which had hardly changed in a decade, suddenly became a focus of interest as engineers in electronics firms with experience in wartime technologies turned their attention to the control problems faced by manufacturing industry. There were two well-recognised problems to be addressed in tracer control systems. First, the tracer control mechanism, particularly the part that manipulated the stylus, was expensive. Second, a great deal of potential machining time was wasted while exchanging templates.

The first problem was solved by separating the tracing process from the machining process because it was realised that often a group of machine tools were producing identical parts, so it was not necessary for each tool to have its own tracer mechanism - a single tracer could be used to generate control information for a whole group of machine tools. The second problem could then be solved by separating the tracing process even further from the machining: if control signals from the tracer stylus were recorded onto some transportable medium, it could then be used to drive the machine tools independently of the tracer. Typically the control data, which could

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Hubert M. James, Nathaniel B. Nichols and Ralph S. Phillips (eds.), *Theory of Servomechanisms*, McGraw-Hill, New York, 1947.

[6] Otto Mayr, *The Origins of Feedback Control*, MIT Press, 1970, p. 132.

[7] See Braun and MacDonald, *Revolution in Miniature*, p. 33.

equally well have been generated by a skilled machinist or a tracer system, was recorded as analogue or digital data onto magnetic tape. It was inevitable that some idle time would be introduced whenever a template was being changed, or the machinist stopped to take measurements, but it was perfectly feasible to edit the tape to remove the idle sections.

The new control technique became known as Record/Playback (R/P). For groups of more than a few machine tools, R/P technology proved less expensive in practice than tracer technology. R/P was invented in the United States, and systems were developed around 1946-47 by a number of companies, including General Electric, Gisholt, and a few other small firms, particularly aiming to fulfil demand from the USAF.[8] For a brief period R/P was marketed - especially by General Electric - as the future of machining, but it was soon displaced by a control technology based on digital electronics.

The Influence of Digital Electronics on Machine Tool Control

The great strength of R/P was that it was a reproduction technology - or a "skill multiplier" as it was described in marketing brochures. It extended the influence of the skilled machinists who had generated the control tape by increasing their productivity manifold. However, its very strength was also its major weakness: multiplying the skill of one machinist also meant multiplying that one machinist's mistakes (see the following section for further analysis of the skills and control issue).

The R/P weakness was particularly evident when it came to the increasingly sophisticated mid-twentieth century machining applications such as turbines and propellers. For such projects it was often necessary to test a long series of prototypes. For example, for a new turbine design, dozens of prototype blades would have to be machined to make a test rig, where a single mistake would have expensive and potentially dangerous consequences. Furthermore, as designs based on mathematical theory rather than empirical observation started to appear, the skills requirement of the machinist increased dramatically, in line with the complexity of individual workpieces,

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[8] See David F. Noble, *Forces of Production*, Oxford University Press, 1984, particularly chapter 5, "By the Numbers I" for the full story of the USAF's involvement in R/P's development during the late 1940s.

and there was a corresponding increase in manufacturing costs. There was clearly an incentive for some means of translating design data directly from the drawing board to the machining systems. Once again, wartime technologies provided a solution. Alongside the developments mentioned in the previous section, military projects such as SONAR and RADAR had spurred research into electronics and pulse manipulation technologies.[9] Two technologies were amalgamated - R/P and pulse manipulation - to create a new method of tool control which became known as numerical control (or N/C). A numerically-controlled system worked by automatically interpolating the movements of a cutting tool between a given series of co-ordinates, so the operator did not need to be a skilled machinist. Assuming that the design data was correct, in theory an N/C system could keep producing identical, perfect parts indefinitely with the minimum of supervision and at the maximum efficiency of the machine tool.

N/C development began in the United States – the concept has been attributed to the late-1940s work of the Parsons Corporation, a manufacturer of helicopter rotor blades.[10] John Parsons had already pioneered the use of (IBM) punched card equipment for calculating the x,y co-ordinates that had to be drilled out in order to generate the required curve of a rotor blade template. It was a logical step to suggest that the machine-generated co-ordinate data be used to directly control a drill, rather than for a human to work from the data on the punched cards. In June 1949 he proposed the concept to the USAF, and was awarded a $200,000, 21-month contract

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[9] Pulse manipulation went on to form the basis of the first digital computer systems, but it was also the key to automatic machining technology. (Although computers soon came to rely on parallel switching technologies, the earliest stored program computers were without exception based on pulse train manipulation because the only available technologies for storage devices were delay circuits of various different types.) See especially Simon H. Lavington, *Early British Computers: The Story of Vintage Computers and the People who Built Them*, Manchester University Press, 1980.

[10] The term "numerical control" was actually coined several years later by William Pease and James McDonough of MIT. See chapter 6, "By the Numbers II" of Noble, *Forces of Production.*

to design and develop the system.[11] However, the focus of developments in N/C technology soon shifted to the Servomechanisms Laboratory of MIT, which appropriated Parson's ideas and oversaw a massively funded research project in the field.[12]

The culmination of the first wave of research came in 1955 when the USAF procured 105 N/C machines for its subcontractors, after which N/C had made the transition from research project to legitimate manufacturing technology. The USAF's action spurred development projects throughout the world's machine tool industry, and coincided with the start of the earliest British N/C research (see the following section). It had proved necessary for the USAF to create an artificial demand for the first N/C systems because the machine tool industry was notoriously conservative and unwilling to invest in the research and development of new technologies.[13] As Rosenberg notes,

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[11] Details from Noble, *Forces of Production*, pp. 96-103.

[12] See Noble, *Forces of Production*, particularly chapters 5 , 6 and 8, in which he describes the early research and development of N/C in the United States, asserting that staff at MIT aggressively appropriated control of the development of N/C technology from Parsons. See also Karl L. Wildes and Nilo A. Lindgren, *A Century of Electrical Engineering and Computer Science at MIT, 1882-1982*, MIT Press, 1985, particularly chapter 14, "Servomechanisms". The work undertaken at MIT was both in the development of control hardware and programming systems. Particularly significant was the development of APT, a programming language for N/C systems - see Douglas T. Ross, "Origins of the APT language for automatically programmed machine tools", in Richard L. Wexelblat (ed.), *History of Programming Languages*, Academic Press, New York, 1981.

[13] See Noble, *Forces of Production*, particularly chapter 8, "Development: A Free Lunch".

> The [US] Air Force offered to fund the entire process of transferring the technology to industry, a risk no other organisation was willing to assume.[14]

In the mid-1950s the structures of the US and UK machine tool industries were similar, each consisting of four or five large companies and a host of smaller companies which either made short production runs of customised machines or long runs of standard general purpose machines such as lathes, milling and boring machines (see Table 4.1 for a breakdown of the British industry by firm size).[15]

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[14] Jack Rosenberg, "A History of Numerical Control, 1949-73: The Technical Development, Transfer to Industry and Assimilation", Information Science Institute Research Report ISI/RR-73-3 (DOD Contract DAHC-15-72-(0308), October 1973.

[15] For the best contemporary source of comparative information on the US and UK machine tool industries see: Anglo-American Council on Productivity, *Metalworking Machine Tools*, British Productivity Council, London, 1953. Representatives from a wide range of UK engineering companies, with positions from fitters to Managing Directors, toured UK factories for 2 weeks then visited US factories for 5 and 1/2 weeks (there was little evidence of trade secrecy - the US companies were eager to demonstrate their technology to British visitors). The team found, as had been anticipated, that productivity was on average higher in the United States (which was attributed mainly to more efficient materials handling), but that technologically there was little to differentiate the two countries.

Table 4.1 Machine Tools Industry 1954 by Establishments (Factories)

Average number employed	Establishments	Total number employed	% of total gross industry output	Gross output £'000
11-24	38	630	1.3	1,001
25-49	54	186	3.5	2,831
50-99	51	3,653	6.6	5,278
100-199	51	7,261	13.7	10,967
200-299	14	3,438	6.4	5,155
300-399	21	7,430	15.0	12,027
400-499	6	2,838	4.0	3,223
500-749	8	4,718	9.0	7,213
750-999	10	8,439	17.0	13,648
1000-1499	4	4,830	10.2	8,172
1500-	3	6,974	13.3	10,528
Totals	260	50,397	100.0	80,043

Source

DSIR, *A Survey of the Research and Development Requirements of the Machine Tool Industry*, HMSO, London, 1959. (The figures are ambiguously attributed to the Board of Trade).

As a rule, mid-20th century manufacturing industry only tended to replace or buy new capital equipment when mid-term forecasts were good, so both the US and UK machine tool industries operated on "boom and bust cycles" – indeed, following the production glut of World War II there was a "hangover" which dogged the industry until about 1950 in both countries.[16] So, the conventional machine tool manufacturers tended to prefer low volume, high profit sales with large mark-ups rather than general purpose standardised equipment, an endemic conservatism which was clearly a direct result of their insecure operating environment.

When British research into N/C systems began in the mid-1950s, manufacturing industry was under pressure to modernise.[17] As Matthews notes, between 1951 and

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[16] Noble, *Forces of Production*, p. 8.

[17] R. C. O. Matthews, C. H. Feinstein and J. C. Odring-Smee, *British Economic Growth, 1856-1973*, Clarendon, Oxford, 1982. Matthews' analysis underpins

1964 capital growth in Britain was five times greater than labour growth. This was due in part to the maturation of "flow production", a manufacturing methodology that combined mass production with sophisticated materials and stock handling. The history of flow production is a parallel theme to that of automation. Frank Woollard's 1954 book, *Principles of Mass and Flow Production* gives the seminal description of flow production.[18] Woollard was heavily influenced by a number of early automated or mechanised systems, but in particular the Morris Motors transfer machine and Sargrove's ECME (both of which were described in chapter 2).[19] The fundamental principles of flow production were to improve stock control, to aim for continuous processing, and to increase the flexibility of the manufacturing system. These were to be achieved by both technical and managerial innovation. It was clear to the early developers of N/C technology that the contemporary theme of flow production would benefit from N/C machining because of the reduced variability in machining time that it would introduce. Consequently, they expected that as manufacturing industry became increasingly oriented towards flow production rapid growth in the demand for their automated tools would occur, at the expense of conventional or special-purpose tools.

One of Woollard's key recommendations was to reduce the layers of management between the company director and the production operatives. As Sir Leonard Lord, Chairman of the British Motor Corporation said, "Flow production involves a marriage of management and mechanism, with management as the dominant partner."[20] The notion was that management, rather than supervisors, should hold control of the manufacturing system on the shop floor. In the next section, the issue of

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Lewchuk's discussion in Wayne Lewchuk, *American Technology and the British Vehicle Industry*, especially pp. 193-5.

[18] Frank G. Woollard, *Principles of Mass and Flow Production*, Iliffe and Sons Ltd., London, 1954.

[19] Woollard had written about the Morris transfer system when it was first introduced: Frank G. Woollard, "Some Notes on British Methods of Continuous Production", in *Proceedings of the Institution of Automobile Engineers*, February 1925.

[20] Quoted in R. H. MacMillan, *Automation: Friend or Foe?*, Cambridge University Press, 1956, p. 21.

control, and its widely debated influence on the development of automation technologies, is considered.

Social and Technical Decisions in the Development of Control Technology

The path of technological development in the control of machine tools has been shaped by both social and technical factors, and its scholarly analysis has been approached from many different angles. At one extreme is the school of Marxist thought, with its managerial control thesis, which suggests that the development of N/C was driven more by management's desire to extend its control over a skilled workforce than in response to economic pressures. In the history of technology, the principal proponent of this theory is Noble, whose writings complement the more sociologically-oriented work of, for example, Harry Braverman, Seymour Melman, and James Beniger. [21] Noble asserts that while the economic advantages of automation were unclear during the 1950s, the keenness of industrial managers to support the development of autonomous control technologies was an inevitable result of management's ongoing attempt to appropriate control from its workforce.[22] Or, as he writes,

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[21] See particularly Noble, *Forces of Production*; Noble, "Social Choice in Machine Design"; David F. Noble, *America by Design: Science, Technology, and the Rise of Corporate Capitalism*, Knopf, New York, 1977; Harry Braverman, *Labor and Monopoly Capital: the Degradation of Work in the Twentieth Century*, Monthly Review Press, New York, 1974; Seymour Melman, *Profits without Production*, Knopf, New York, 1983; James R. Beniger, *The Control Revolution: Technological and Economic Origins of the Information Society*, Harvard University Press, 1986.

[22] See also Melman, *Profits Without Production*, in which he explores the notion that the US industrial culture applauds managerial control more than manufacturing productivity.

> In an earlier work, *America by Design*, I attempted to challenge technological determinism by exploring the history of the institutions, ideas, and social groups which had come to choose technological possibilities in twentieth-century America. Here I am taking this exploration a necessary step further, to show how these institutions, ideas, and social groups, operating in a context of class conflict and informed by the irrational compulsions of an all-embracing ideology of progress, have actually determined the design and use of a particular technology.[23]

However, Noble's analysis is biased towards proving the validity of the control thesis and criticising capitalist management structures. It is based largely on interviews with shopfloor workers, and concentrates exclusively on the positive or negative impact on skilled workers of the development of N/C at the expense of R/P technology. At the other extreme we have economists such as Kaplinskey and Simon, who have argued that automation grew out of an economic crisis in the 1950s which was created by a sharp rise in competitive pressures and a decline in profits for both US and UK companies.[24] Their thesis, that automation was inevitable given the economic circumstances, does not necessarily contradict the Marxists' control thesis. While the Marxists have emphasised the significance of class conflict in order to detract from the economic argument, they have been unable to convincingly eliminate it. On the other hand, the economists have largely ignored the significance of the politics of control on the direction of technological development.

Somewhere between the Marxist and economic analyses come those of the social constructivist school, which is arguably more holistic and less politically-motivated in its analysis of technological development.[25] As MacKenzie notes, when

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[23] Noble, *Forces of Production*, p. xii.

[24] Raphael Kaplinskey, *Automation, the Technology, and Society*, Longman, 1984; and Herbert A. Simon, *The Shape of Automation for Men and Management*, Harper and Row, New York, 1965. See also Erik Christensen, *Automation and the Workers*, Labour Research Department Publications Ltd, London, 1968, for another text based predominantly on statistical analysis.

[25] See for example Donald MacKenzie, *Knowing Machines: Essays on Technical Change*, MIT Press, 1996, especially chapter 2, "Marx and the Machine"; and Wiebe Bijker, Thomas Hughes and Trevor Pinch, *The Social Construction of*

we examine the factors behind the development of a new technology we should ask the question "Best for whom?" and acknowledge that "Workers and their employers may not agree on the desirable features of a production technology."[26] Social constructivism seems best suited to unravel the complex interaction of economic and social factors in the development of automation. It is clear that even before the term "automation" was coined, the popular expectation of automatic control was that it would have both economic and social implications. To attribute the direction of technological development exclusively to just one of the social, economic, or political factors is clearly inappropriate.

Nevertheless, since the principal text on the history of N/C is Noble's *Forces of Production* it is necessary to explore the themes on which he has concentrated, and to illustrate their position within the context of Marxist historiography. Noble describes the development of N/C technology in the United States as the result of an anti-labour culture, epitomised by industrial management's stand against "pacing" which was perceived to be routinely practised by skilled workers in manufacturing operations. [27] While the trades unions would claim that pacing was undertaken in order to avoid exhaustion, Noble's capitalist management believed that it was practised for a variety of unacceptable reasons including: to avoid destroying "gravy" piece-rate jobs by overproducing; to stretch out work for fear of layoffs; and most importantly to express solidarity and hostility to management. Such blatant disregard for managerial demands, according to Noble, was the primary reason for management's encouragement of research programmes into control technologies that would reduce the autonomy of the workforce. Noble compares industrial management with military command, arguing that both tried to broaden their control by developing increasingly sophisticated technologies. He claims that the technical community worked on automation technologies because it had a preference for "formal, abstract and quantitative approaches to the formulation and solution of problems", while management had "a preoccupation with control over both the physical details and the human activities of

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Technological Systems: New Directions in the Sociology and History of Technology, MIT Press, 1987.

[26] MacKenzie, *Knowing Machines*, p. 6.

[27] Noble, *Forces of Production*, p. 33.

production [...] an ongoing class struggle at the point of production."[28] Similarly, Braverman writes,

> [...] in the capitalist mode of production, new methods and new machinery are incorporated within a management effort to dissolve the labor process as a process conducted by the worker and reconstitute it as a process conducted by management.[29]

Noble uses the fact that R/P was displaced by N/C technology, to further the argument that management's desire for control was the driving factor in technological development. He claims that the technology of R/P was adequate for most machining work, so there was no need to develop the more complex and expensive N/C systems. The benefits of R/P over conventional machining were clear: R/P systems offered the advantage of reduced set-up times, because there would be no need to set limit switches or stops, to install or adjust templates. R/P could also be used to record unusual operator skills, which might only be available at a premium from experienced machinists. R/P systems allowed a workpiece to be easily scaled up or down by adjusting gear ratios. On the other hand, Noble argues that the benefits of N/C over R/P were far less obvious. In the conclusion of this chapter I return to the R/P versus N/C debate, but first some early British N/C developments are described, and their impact on the machine tool market of the late 1950s and early 1960s is discussed.

Early Machine Tool Automation Research in Britain

In the mid-1950s four British companies undertook research projects in the automatic control of machine tools. The British systems were developed in response to exuberant reports in trade journals and the popular media of the unprecedented success of experimental US systems (the concept of numerical control was already well established several years before any British companies entered the scene).[30] Two of the

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[28] Noble, *Forces of Production*, p. 191.

[29] Braverman, *Labor and Monopoly Capital*, p. 170.

[30] The principal popular press article was Eric W. Leaver and J. J. Brown, "Machines Without Men", in *Fortune*, Nov. 1946. Even Noble accepts its significance: "The centrepiece of the article was an elaborate proposal [...] which proved to be quite influential among technical people in industry." (quoted from Noble, *Forces of Production*, p. 67. For Noble's paraphrase of the article see pp. 67-71).

British systems, those developed by Ferranti and Electrical and Musical Industries (EMI), used N/C technologies to achieve continuous control of a milling machine. The third system, developed by British Thomson Houston (BTH), was a less sophisticated N/C point-to-point drilling system, in which a drill was successively moved (whilst out of contact with the workpiece) between locations specified by co-ordinates provided as numerical input. The fourth system, which did not continue beyond the research stage, was an ingenious R/P system developed by the Alfred Herbert Company to effect two and one half axis control of a milling machine.[31]

Ferranti

Ferranti, a multidivisional family-owned company with a strong history of electrical engineering and defence contracting, conducted the foremost British research into N/C technology in the 1950s and throughout the 1960s.[32] The work was undertaken as part of its civil products programme, which explains in part why the control system was developed independently of the Argus computer (see chapter 5) which was already being developed by Ferranti for a defence project and which would have been suitable for the task at hand.

The work was conducted under divisional head J. N. (later Sir John) Toothill's supervision, although the head of the project was D. T. N. (Theo) Williamson, Toothill's engineering development chief.[33] The two had travelled to the United States in the early 1950s in order to examine the pioneering work in numerical control being undertaken at MIT. Soon after they returned, Toothill authorised an N/C research project to be based at Ferranti's Crewe Toll (Edinburgh) Laboratory, and work began

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[31] A two and one half axis milling machine is one in which the cutting tool can be moved to any position in two dimensions, but can only be moved to a limited number of fixed positions in the third.

[32] I am indebted to John Wilson (University of Leeds) for the loan of a manuscript on the history of Ferranti, which forms the basis of my understanding of the organisational details of the Ferranti project.

[33] For more on J. N. Toothill, and Ferranti's post-war direction see Tom Burns and G. M. Stalker, *The Management of Innovation*, Tavistock Publications Ltd., London, 1961, pp. 53-56.

in July 1952.[34] It was expected that the system would prove useful in-house, producing the large numbers of precision machined parts, particularly waveguides, that were required for Ferranti's AI Mk23 RADAR - a product which had generated a major manufacturing backlog because of a local shortage of skilled machinists.[35] Indeed, it was this skills shortage which had prompted Toothill to authorise the project.

By 1955 a working prototype was ready for public presentation. The system allowed three-axis control of a Du Four Company milling machine, according to control data stored on magnetic tape. The process for generating the control data was innovative, but reasonably straightforward. First the designer would create a "planning sheet", which consisted of a sketch of the workpiece, much like a traditional design drawing, but which also listed certain significant dimensions - the centres of circles, start and end points of lines, and so on (Figure 4.1). From this information a "programme sheet" would be made, which encapsulated the information contained in the design drawing, but in a form which could be more readily processed by a computer (Figure 4.2). The information from the programme sheet would then be punched onto standard five hole paper tape. The paper tape could then be fed as input to a computer, which ran a program that interpolated the design information and wrote out the resulting tool path information onto a magnetic tape. The magnetic tape was formatted as four parallel tracks of binary information - one for each of three axes. The data on the track for each of three axes of movement was recorded as a pulse train - whenever a "one" was read on an axis' track the tool would be moved one unit of displacement in the given direction (each unit corresponding to 1/10,000 inch). The

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[34] See D. T. N. Williamson, "Computer Controlled Machine Tools", in *Process Control and Automation*, Vol. 2, No. 7, (Jul 1955). Further technical details on the Ferranti system are from Anon, *Machine Tool Automation By Electronic Control (Automatic Repetitive Operation and Positioning by Tape, Computer and Other Related Methods)*, Machinery's Yellowback Series No. 38, Machinery Publishing Company Ltd., Brighton, 1964.

[35] Edinburgh was, however, an attractive location for Ferranti to recruit electronics graduates for research programmes. Background details from correspondence with Sir Donald McCallum, 27th June 1996.

fourth track was used to record special control signals, or to provide an error-checking facility.

The control system made use of a significant innovation in metrology which was patented by Ferranti in 1955, a measurement system which made use of the Moiré patterns that could be created by overlapping two fine ruled optical gratings. An opto-electronic detector was used to register discrete steps - equal to one half of the width of the rulings - as the gratings were slid past each other. The result was a suitable system for registering movement in discrete units that would correspond to the digital control signals.[36]

As with any N/C (or R/P) system, it was possible to produce mirror image pieces by reversing the polarity of one of the control signals. Ferranti made impressive use of this in a display of the system's capabilities for machining RADAR waveguides. It was claimed that using conventional machining techniques each waveguide took 300 man hours to produce, but the time was reduced to only a couple of hours using the N/C system. Because each waveguide was constructed from two mirror image pieces, it was possible to use the same control data for both pieces, by simply reversing the polarity of the pulse train on one of the axes, so a perfect fit was assured.

Although each machine tool required the services of a computer to generate the control tape from the drawing data, in practice it was estimated that a single computer could service around fifty machine tools. In the mid-1950s a computer would have been a massive capital expenditure, far out of the reach of even the larger engineering companies. However, Ferranti was not trying to sell a computer with each system - the machine tool user was merely be expected to have access to a computer on which the interpolation program could be executed. The computer could be either in-house or at a large company's computer facility, or even a computer bureau which offered computing facilities at a per-hour charge (Ferranti had already established "Ferranti

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[36] The gratings were provided by the National Physical Laboratory, and were the result of work by Dr. L. Sayce who was experimenting with them for use in infrared spectroscopy. Further details from DSIR, Automation: A report on the technical trends and their impact on management and labour, HMSO, London, 1956, p. 20. The gratings were ruled to 5,000 lines per inch, so each pair of gratings gave 10,000 discrete waveforms per inch of travel.

Computing Centres" in London, Manchester, and Edinburgh). Although the software developed by Ferranti only ran on Ferranti's own computers, it was perfectly feasible to use another manufacturer's computer if similar software were developed, and so the early promotional material provided by Ferranti was deliberately ambiguous when it came to the type of computing facilities that would be required. It was considered important not to discourage potential users by suggesting that they would also be tied to the use of a Ferranti mainframe.

From an early stage Ferranti asserted the economic viability of the N/C tools. Williamson often claimed that over a seven year life span, two N/C systems could replace ten conventional machines at around half the cost. He even claimed that with the Ferranti system the setting-up time was so short that efficient automatic production of small batches and even single components could be achieved.[37]

The prototype certainly proved the technical, if not the economic, viability of the system, and when the first model was demonstrated at the Olympia Machine Tool Exhibition in 1956 representatives from Fairey Aviation Company were impressed enough to propose a collaborative venture to further the development.[38] However, the Fairey collaboration was unique - no other British companies came on board with Ferranti at the time, for reasons to be discussed in the conclusion.

Electrical and Musical Industries

Electrical and Musical Industries (EMI) created a subsidiary firm in 1956, EMI Electronics, which brought together all of its design, manufacture and sale of electronic capital goods into a single organisation.[39] Besides a division working on machine tool controllers, work was being undertaken in a diverse range of fields, from broadcasting equipment to aircraft instrumentation, with a staff of 7,000 spread between 14 locations.

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[37] Williamson, "Computer Controlled Machine Tools", p. 264.

[38] The principal figure at Fairey who promoted the Fairey-Ferranti collaboration was John Gregson (now Lord Gregson). (Further details from McCallum correspondence, 27th June 1996).

[39] The company details are from EMI's annual *Report and Accounts* publications, 1956-64.

While Ferranti's system for the control of machine tools was based on the use of a general purpose digital computer to interpret the drawing data and interpolate the cutting tool motion, researchers at EMI took an entirely different approach. The control unit of the EMI system contained its own interpolator which calculated a continuous curving path according to the control information which consisted of a series of co-ordinates recorded on punched tape.[40]

The prototype EMI system worked on a Research Engineers' Copy-Miller, a two-dimensional cam cutting system with two polar axes of movement, which had originally been designed for tracer control. A separate unit for each tool performed the three-point interpolation between the given co-ordinates.[41] In order to reduce wear on the cutting head the table's rotational speed was automatically linked to the radius of the curve being cut, so that the effective cutting speed remained constant.

The tape used to record (by punched holes) the control information was standard 70mm celluloid film, which was used because it was more robust than paper tape and the input/output equipment was readily available from third party suppliers.[42]

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[40] An early description of the system can be found in Anon, "Electronic Control for Machine Tools by E.M.I.", in *Process Control and Automation*, Vol. 2, No. 12, Dec. 1955, pp. 466-468.

[41] The interpolating unit worked by an ingenious application of electromagnetic induction. In practice an "auto-transformer" was driven with analogue voltages which corresponded to the three points being interpolated. The output from the auto-transformer was then used to drive another transformer which had a number of secondary windings whose ratio of turns corresponded to the series $X^2 - n^2$ (where n takes values from 2 to X-1, and X is the number of turns in the primary transformer). When combined, the outputs from the secondary transformer coils could be used to produce a smoothly varying voltage over the interpolated range. (Technical details on the EMI control system are from Anon, *Machine Tool Automation By Electronic Control*).

[42] Both Ferranti's and EMI's systems used tape readers and punches manufactured by the Creed Company. See F. S. Reade (of Creed and Co., Ltd.,

As an aid to error detection during the tape preparation process EMI used a typical system such that both the celluloid tape and a second paper tape were punched from the original data and compared for mistakes, so the accuracy of transcription could be assured. Just as with Ferranti's system, the accuracy of control was claimed to be 1/10,000 inch, which was seen as the required level of accuracy prevailing in conventional machine tools. In fact, EMI asserted that theoretically the control system was accurate to 1/50,000 inch. A benefit of the technology was that it was robust and small, although it was limited to making parabolic (second order) interpolations - Ferranti's system was more flexible because the interpolating program could be readily changed.

The EMI prototype system was tested in the machine shop of an independent company in Norwich, and the early results were extremely promising. In publicity materials, EMI claimed that a cam which would have taken 5-6 weeks to produce using conventional techniques had been produced in around 2 hours using the system.[43]

In early 1956 EMI began collaborating with the Cincinnati Milling Machine Company. The EMI control system was connected via a system of valve- and relay-based control gear to a Cincinnati No. 3 Vertical (dial-type) Miller (Figure 4.3).[44] Building on the experience gained from developing the prototype system, the new controller now offered 3 axes of control, moving the table longitudinally and transversely and moving the tool up and down.

EMI's stated goal was for the specialist knowledge of the machinist to be built into the system, so that only the programmer needed to know the properties of the

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Croydon), "Automatic Control by Punched Tape", in *Process Control and Automation*, Vol. 4, No. 1, Jan. 1957, pp. 6-8.

[43] It is not clear if the tape preparation time was included in the figures. See Anon, "Electronic Control for Machine Tools by E.M.I.", and Anon, "The Electronic Control of Machine Tools", in *Process Control and Automation*, Vol. 3, No. 3, Mar. 1956, pp. 90-91 (for details of the Norwich testing).

[44] Further details from O. S. Puckle, "Numerical Control of Machine Tools in Aircraft Manufacture", in *Process Control and Automation*, Vol. 4, No. 2, Feb. 1957, pp. 40-46. (Puckle was one of the EMI engineers).

metal, the speeds, feeds, and tool forms. The operator would just need to know how to maintain the machine in good working order. The engineers at EMI were also clearly aware of the competition from Ferranti, and of the capabilities (and limitations) of both theirs and Ferranti's systems. In his overview article, EMI engineer O. S. Puckle highlighted the advantages of an integral interpolator rather than using a digital computer to generate the tool path. In everyday use it allowed for simple changes to be made instantly, but he acknowledged that it also reduced the flexibility to some extent because it was only capable of second order interpolation. However, he asserted that it still allowed more complicated faces to be milled than would be conventionally feasible, which had important implications in the development of turbine blades and propellers - the EMI systems were principally targeted at applications in the aircraft industry.

EMI was notably more successful in finding collaboration to help test and develop its system than Ferranti had been, although the number of partners was still low considering the size of the industry.[45] Following collaboration with Wadkin Ltd., Research Engineers Ltd. and Cincinnati Milling Machine Company, by late 1957 further joint work was undertaken with David Brown Industries Ltd, and with the Rootes company.[46] EMI also persuaded Technics Ltd., a Southampton based machine tool company, to design a new drilling machine specifically for control by the EMI system.[47]

British Thomson-Houston

In contrast to the tape-controlled continuous path systems developed by Ferranti and EMI, British Thomson Houston (BTH) had been working at the same time on a punched-card based point to point control system, which was applied to a Kearns No.

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[45] EMI's industrial collaborations were detailed in a report on the "International Machine Tool Exhibition - 1956.", in *Process Control and Automation*, Vol. 3, No. 7, July 1956, pp. 248-257, which had been held at Olympia from 22nd June to 6th July.

[46] The work with David Brown and Rootes is briefly reported in the 1959 EMI *Report and Accounts*, but no details are given.

[47] Reported in Anon, "New Drilling Machine with EMI Position Control", in *Process Control and Automation*, Vol. 4, No. 10, Oct. 1957, p. 379.

0 Horizontal Boring Machine (essentially a fixed position drill mounted above a two-axis controlled table bed which would hold the workpiece).[48] BTH was already an established manufacturer of advanced tracer control systems that measured the air-gap inductance between the tracer head and the template so as to follow the contours of the template without making any physical contact. However, numerical control was an entirely new research area for the company.

The prototype system consisted of a servomechanism connected to the controls of the boring machine, and it was put under factory trials at the British United Shoe Manufacturing Company, in Leicester (Figure 4.4).[49] In use, the operator would insert a series of punched cards into a control panel that would specify the co-ordinates to which the drill bit should be automatically moved. The cards were of a standard size, but specially made to be oil-resistant because it was anticipated that the life span of a paper card would be too short in a factory environment.

BTH's developments had been dominated by concerns over the accuracy of tool positioning. To this end, the system's most interesting innovation was the method employed to check the position of the machining head - a feedback control system with an electromagnetic "sensing" device was claimed to enable it to obtain greater accuracy than the nominal accuracy of the standard version of the same machine tool.[50] BTH's measuring system made use of the varying magnetic field that could be registered by a detector head as it moved along a steel rod containing a series of 1-inch brass inserts along its length. The brass inserts made a magnetic field that varied in regular 1-inch cycles. Furthermore, the rod was constructed such that it had the same coefficient of expansion as the cast iron bed of the table, so that if the tool dimensions varied according to temperature the measuring would remain in proportion. Finally, the control system was devised such that the detector head always approached its

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[48] Details from M. Monk, "Automatic Coordinate Setting", in *Automation in Industry*, Vol. 3, No. 25, June 1956, pp. 129-132 and Dennis Player and W. K. Temple, "Machine Tools of the Future", in *Instrument Practice*, Vol. 11, No. 8, Aug. 1957, pp. 832-845.

[49] See also J. A. Stokes, "Electronic Control of Machine Tools", in *Process Control*, Vol. 2, No. 4, Apr. 1955, pp. 141-144.

[50] Details from Anon, *Machine Tool Automation By Electronic Control.*

destination from the same direction, moving rapidly to within 1/4 inch of the desired position, then closing slowly on the precise point. Once the head was in the correct position the table and tool were clamped in position, so that the cutting action could not be displaced.

Another error-reducing feature was that when the operator inserted a punched card indicator dials on the control panel would rotate to show the position recorded on the card, so that mistakes would hopefully be noticed by the operator. As with both the EMI and Ferranti systems, the accuracy attained was 1/10,000 inch.

A conventional user of the Kearns machine would set the co-ordinates by hand, using dials on its control panel. The use of punched cards had a number of benefits: it was faster; there was a lower margin for error; and the operator required less skill. BTH's claims for the performance of the system were far less extravagant than Ferranti's or EMI's. An example time was quoted for milling a frame piece with 6 drilled and counterpoised holes, 9 drilled and tapped holes, and 11 drilled holes. By conventional methods it was claimed that the machining would take 4 hours 34 minutes. Using the BTH system it was completed in 2 hours 17 minutes.[51]

Alfred Herbert Ltd.

Alfred Herbert Ltd. developed the fourth system. While Ferranti, EMI, and BTH were all predominantly electrical/electronic engineering companies, Alfred Herbert was a long-established machine tool manufacturer. Capitalised at £11M in 1959, it was the largest in Britain, and had been publicly listed since 1944. An indication of its conservatism can be found in the disclosure that by the end of the 1950s the company held cash and quoted investments to the value of £8.5M.[52] Accordingly, it is little surprise to find that while the electronics firms were working on numerical control of

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[51] Once again, it is unclear if the quoted time included the time to prepare the cards - if so then the time for subsequent pieces would be further reduced. Figures from Anon, "A Horizontal Boring Machine With Automatic Co-Ordinate Setting", in *Process Control and Automation*, Vol. 3, No. 4, Apr. 1956.

[52] For a comparative analysis of the principal UK machine tool manufacturers see Anon, *The United Kingdom Machine Tool Industry*, Pidgeon and Stebbing, London, 1959, (the statistics for Alfred Herbert are from pp. 54-5).

machine tools, in the mid 1950s Alfred Herbert researchers were still investigating R/P technology, which was by then considered outdated. Nevertheless, the work was interesting because it was based on an entirely different type of technology than the other companies were using.[53]

The work was conducted at the "Factored Division" of Alfred Herbert, in Coventry, where a system was built to give R/P control of a Heald Borematic machine tool, a flat-bed milling machine, not unlike the Du Four machine that Ferranti had started working with. The Alfred Herbert method called for the actions of a skilled machinist to be recorded as analogue signals on a standard magnetic tape. The control signals were encoded using sonically tuned relays (relays activated by tuned frequency circuits) which were connected to the controllers. The resulting audio signals were mixed together and recorded on the tape using a domestic-type twin reel tape recorder (Figure 4.5). The same tuned circuits could then be used during playback to separate the signals and operate solenoid valves connected to the machine controls. In use, the machine tool first needed to be laboriously configured, or programmed, by setting a series of stops - the control signals would cause the tool to move until it hit a stop. It was claimed that the method of control had been forced on the designers by choice of machine tool, although why they chose such a primitive system given the high profile of the Ferranti, EMI, and BTH work being carried out at the same time is unknown. But, as Young recalls, the Alfred Herbert research department did not have an "ear to the ground" in the 1950s - it was not in regular contact with Alfred Herbert's manufacturing operations, and consequently was not necessarily investigating recognised problem areas.[54]

Alfred Herbert never developed a product model using the tuned circuit control technology. Given the state of the art of machine tool control in the late 1950s it is almost certain that the R/P technology was considered outdated and abandoned for that reason. The Alfred Herbert story is probably the best example of the influence of

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[53] Information on the Alfred Herbert system is scarce because it never became a production model. Most of the details are from DSIR, *Automation*, p. 18, and Anon, *Machine Tool Automation by Electronic Control.*

[54] Details from interview with Sir Richard Young (Chairman of Alfred Herbert Ltd. during the 1960s), 28th May 1996.

the technological evangelism during the automation hysteria. Because of the wild claims made in the 1950s, expectations for automation technology had been raised so high that the Alfred Herbert system appeared outdated before it had even got beyond the prototype stage.

From Prototype to Product - Addressing the Market

The "British problem", or the failure to translate technological innovation into a marketable product, was clearly not experienced by the electronics companies which developed the earliest N/C machine tools in Britain. By the late-1950s all three companies had successfully developed commercial systems from their prototypes. Automation and industrial modernisation were being widely discussed, and a rosy future seemed assured for the first companies to enter the market. However, the anticipated market and the actual market proved to be markedly different.

The Anticipated Market

The innovators of N/C anticipated that their new technology would be widely adopted within just a few years, but their speculation was fuelled by unrealistic extrapolation from the sales figures of the preceding years. By the late 1950s, following several years of above average growth in sales (Table 4.2), there was an anticipation that demand would once again rise to its wartime levels. However, this ignored the fact that World War II had caused a major dislocation in the statistics of machine tool production. Machine tool sales had boomed during the war, so the fall in sales in the late 1940s and early 1950s had been perceived as a slump, while in fact it was merely a return towards the pre-war levels. [55]

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[55] The US figures follow a similar trend to those of Britain during the period. In the twenty years preceding World War II the US industry had enjoyed consistent sales of around $200M per year. However, wartime demands had caused sales to leap to $1,300M in 1942, with a yearly average for 1940-3 of $900M. (Figures from S. Lilley, *Men, Machines, and History: The Story of Tools and Machines in Relation to Social Progress*, Lawrence and Wishart, London, 1965 (second edition), p. 199.)

Table 4.2 United Kingdom Machine Tools Industry, 1948-57

	1948	1951	1952	1953	1954	1955	1956	1957
Gross output (£M)	72.1	116.1	148.8	146.6	137.5	152.9	179.9	183.4
Employment ('000s)	79.0	89.4	81.4	98.2	92.6	95.2	100.2	103.6

Source

From a draft copy of 1959 DSIR report (in PRO BT 258/809). The figures are ambiguously attributed to the Board of Trade.

But the overestimation of the growth prospects was only part of the problem. Inaccurate predictions were frequently made because of a lack, or misrepresentation, of information appearing in the trade press and official statistics. Tables 2 and 3 show one such example of contradictory data – there is a disparity between the gross output of the machine tool industry according to the Board of Trade (Table 4.2) and according to the Pidgeon and Stebbing report (Table 4.3). The problem lies in the way that machine tools were categorised – sometimes the production figures for hand tools and woodturning tools were added to those of mechanised metal-cutting tools. Many of the automation hysteria texts repeated statistics without giving the full context of the reports from which they were extracted, so misleading figures were widely disseminated, and had a profound influence.

Table 4.3 United Kingdom Machine Tools Industry - Imports and Exports, 1954-57

Year	UK Production (£m)	Exports from UK (£m)	Imports into UK (£m)
1954	65.6	20.2	16.1
1955	75.4	20.8	16.9
1956	85.5	23.9	25.7
1957	95.3	28.1	21.8

Source

Anon, *The United Kingdom Machine Tool Industry*, Pidgeon and Stebbing, London, 1959, p. 76.

For example, a widely circulated memo presented by the Confederation of Shipbuilding and Engineering Unions (CSEU) claimed that Britain was a net importer of machine tools, but only quoted figures for 1956.[56] Later that year the Board of Trade, in a memo to the NPACI, countered the claim, insisting that Britain "is a *net* exporter of machine tools except in periods of exceptionally heavy demand in the home market."[57] It noted that 1956 had been an exceptional year, unrepresentative of the general trend, and showed that the data in the CSEU memo had been taken out of context.

Nevertheless, sales of conventional machine tools were booming. By 1956 the British machine tool industry's order book, at the prevailing levels of manufacture, would take 15 months' work to fulfil.[58] Anticipating the imminent emergence of a

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[56] From MSS.292/615.61/2 (Engineering Industry - Melman Report) Memo from the Confederation of Shipbuilding and Engineering Unions, March 1959.

[57] MSS.292/615.61/2, memo from the President of the Board of Trade to the NPACI, 1959 [their underline].

[58] Data from a brokers' company report, quoted in *Process Control and Automation*, editorial, Vol. 3, No. 10, Oct. 1956, p. 349. Similarly, in the United States sales had soared from $560M to over $1,000M during the same period. Sciberras and Payne have noted that the US firms neglected the overseas markets when demand the domestic market boomed. (Sciberras and Payne, *Machine Tool Industry*, p. 30.)

massive market for N/C systems, both EMI and Ferranti rushed to develop products from their prototypes. In both cases it required that the companies addressed criticisms of the overall system cost. EMI produced a cut-down version of their control system, which they called the EMICON. It was a 2-axis controller that could be connected to a wide range of machine tools by placing servomotors on the normal hand controls of the tool, and relied on dead reckoning measurement. EMI also believed that for some users the exclusively tape-based control system had been discouraging, so a hand-input mechanism was added to the control system so the co-ordinates could be manually entered.[59]

Ferranti developed two commercial systems aimed at different sectors of the anticipated market. The collaboration with Fairey Aviation had been instrumental in persuading Ferranti to address cost criticisms by changing from electrical to hydraulic servomotors and transistorising the circuitry. Originally the control system had been over-engineered to military-style rugged specifications, and was operated at positive pressure in order to reduce the ingress of dust. The mainly analogue circuitry had been designed to tolerate a 30% failure before errors would occur.[60] The first new development was a cut-down system, which only provided point-to-point control, while the second was a 3-axis continuous path system, called the Mark IV. Both systems had been re-engineered so that they would now work from a standard mains power supply rather than a frequency converted supply, and the electronics had been redesigned with an emphasis on replaceable modular construction so that the system unit could be more easily kept operational. Ferranti also began to explicitly offer the services of their Computing Centres in London or Edinburgh for magnetic tape production in their advertisements, where new software had been developed that could

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[59] Anon, "E.M.I. Electronics Exhibition", in *Process Control and Automation*, Vol. 6, No. 1, Jan. 1959, pp. 22-24.

[60] Further details on the Mark IV from Anon, "Ferranti Introduce New Machine Tool Control Systems", in *Process Control and Automation*, Vol. 6, No. 8, Aug. 1959, pp. 336-341.

plot a drawing of the workpiece using the control data so that it could be compared with the original drawing for mistakes before a control tape was made.[61]

The British firms, particularly EMI and Ferranti, frequently stressed that their systems were economically viable, even for use in small machine shops, and provided convincing figures to support their claims. The three key elements required by any users of an N/C system were reliability, economy, and accuracy.[62] Clearly by 1960 the companies were confident that they had addressed all three issues, so it was a surprise when the orders still failed to flood in.

The Actual Market

The pioneer British N/C developers had accelerated their development programmes to meet the anticipated market. But meanwhile, trade associations and political institutions were beginning to publish the results of their own investigations into automation, and the reports shared one common theme: that the automation of British industry would be a much slower process than had been predicted.

If we step forward to 1964 we see that the official statistics for sales of automation equipment remained unsatisfactory. For example, the Board of Trade's import/export statistics divided machine tools into many categories by type, but still had no separate categories for "electronic control", or "numerical control". It is not clear whether the BoT had decided that the figures were not sufficiently significant to merit disaggregation, or whether it was simply unaware of the importance of the statistics. Either way, the upshot was that the statistics for N/C machine tool systems were enumerated within a catch-all "automation and ancillary" category which

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[61] Details from Anon, "Ferranti Introduce New Machine Tool Control Systems".

[62] Wilhelm Simon identifies these three requirements his book, *The Numerical Control of Machine Tools: Basic Principles, Systems Analysis and Industrial Applications*, Edward Arnold, London, 1973 [translated from the German 1970 original], p. 3.

accounted in 1964 for just under 1% of the total machine tool sales. Furthermore, the BoT's import figures did not even feature the "automation and ancillary" category.[63]

The inadequacies in the official statistics were widely acknowledged. For example, in early 1964 the NEDC's Economic Development Committee for the Machine Tool Industry criticised the BoT's data, commenting that "Methods for covering output of auto[matic] control machines, and for distinguishing between standard and non-standard production require consideration."[64] In fact, it was not the BoT, but rather a trade journal, which first made an in-depth survey of the market for N/C technology. In June 1964, *Metalworking Production* published the first comprehensive survey of N/C systems in Britain, based on the results of a poll of all the known manufacturers, conducted early that year.[65] The results were as much as ten times lower than had been predicted a decade earlier (Table 4.4).[66]

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[63] Incidentally, the three principal importers remained in the same order as they had been throughout the 1950s - West Germany (£2,230,600), the United States (£1,645,000), and Switzerland (£937,500) from a total imports value of £6,718,300.

[64] BT/258/1923, Draft note by the Working Party on Current Trends and Statistics, "Trends in the Machine Tool Industry", Appendix 1, "Inadequacies in the existing statistical coverage for the machine tool industry."

[65] Harold Burton (the journal editor), "Breakthrough for numerical control", in *Metalworking Production*, 17th June, 1964, pp. 15-20.

[66] In the late 1950s it had been predicted that within twenty years 75% of machine tools in the United States would be numerically controlled - in fact it proved to be less than 2%. (Statistics from Noble, "Social Choice in Machine Design", p. 39.)

Table 4.4 Deliveries and Orders for N/C Machine Tools Classified by Type of Control

Type of control	To Dec. 1962	From Jan 1963	On order	Totals
Continuous Path	53	30	20	103
Straight Line	16	11	10	37
Co-ordinate Positioning	163	122	122	407
Totals	232	163	152	547

Notes

Numbers "on order" are to end March 1964.

Source

Metalworking Production, June 17, 1964.

The "gradualists" assertion that the uptake of automation would be much slower than was originally predicted had proved to be largely correct. Although market growth was rapid, it was nowhere near what had been predicted during the automation hysteria. Diebold's analyst company, Diebold Group, had claimed in the early 1960s that by the end of the decade 50% of machine tools in use in the United States would be N/C systems.[67] *Metalworking Production* had predicted more conservatively that 800 systems would be in use by December 1964, with a market growth of around 50% per year for the next 2-3 years.[68] In fact, even this estimate was optimistic - according to a later Board of Trade survey it was not until 1966 that the figure of 800 N/C systems had been reached, and growth had averaged just 20% per year (Table 4.5).

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[67] John Diebold, *Beyond Automation: Managerial Problems of and Exploding Technology*, McGraw-Hill, New York, 1964, pp.114-5.

[68] Quoted in Christensen, *Automation and the Workers*, p. 19.

Table 4.5 Numerically Controlled Machine Tools, UK Manufactured

	1956-1965	*Year 1966*		*Year 1966 (New Orders Received)*	
Category of Machine	No.	No.	Value (£'000)	No.	Value (£'000)
1. Machining centre and multipurpose	76	140	1,736	225	3,069
2. Drilling	193	116	1,034	111	989
3. Milling	127	14	234	35	1,176
4. Other	157	31	530	48	979
Total	553	301	3,561	419	6,214

Source

Board of Trade Journal, May 19th, 1967.

By the mid 1960s the conventional machine tool manufacturers had finally decided to market N/C systems, and a number of electronics firms had been subcontracted to provide controllers. Besides Ferranti, EMI and BTH (which had now become a part of AEI), controllers were on offer from a number of electronics companies including Mullard, Plessey, ECKO, and Airmec (Table 4.6). At the 1964 International Machine Tool Exhibition, which was held at Olympia in June 1964 and had over 2,000 exhibits there were more than twenty N/C systems on display.[69] The N/C systems on display were now being marketed directly by the conventional machine tool manufacturers themselves, including key British companies such as Wadkin, Alfred Herbert (although not using the R/P technology described earlier), BSA Tools, High Precision Equipment, Staveley-Richards, Archdale, and Kearns.[70]

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[69] A report in *Metalworking Production* listed 150 of the most important ones, of which 21 had some form of automatic control mechanism (a number of other "automatic" systems may also have been N/C, but the descriptions in the article are too short to be certain).

[70] Anon, "The 1964 International Machine Tool Exhibition", in *Metalworking Production*, 24th June 1964, pp. 143-215.

Table 4.6 British Numerical Control Systems Available circa 1963

Name	Example system	Cost
Contour Machining Systems:		
AEI Numeritrol	Newall jig borer.	£11,500
EMI Emicon	Various	£12,000 to £20,000
Ferranti Mark IV	Hayes "Tapemaster" vertical milling machine.	£7,000 to £10,000
Staveley Type E2448	Various.	£4,500+
Co-ordinate Positioning Systems:		
AEI Co-ordinate System	Kearns horizontal boring machine.	£2,250 to £9,000
Airmec Autoset	Wadkin portal frame drilling machine.	£1,750
ECKO 117A	Asquith radial arm drilling machine.	£1,500
EMI Type B100	David Brown turret drilling machine.	£2,500 to £3,500
EMI C1010	Meddings Drilling Machine.	£2,100 to £2,600
Mullard Autoplot	Mullard co-ordinate positioning machine.	£2,500
Plessey Mark II	Herbert - De Vlieg "Jigmil".	£2,500 to £3,500
Staveley E2570	Richards horizontal boring machine.	£2,500
Warner and Swasey Tele-Probomat	Moore jig boring machine.	£3,800

Notes

Most systems were applied to a range of machine tools. The "example system" lists the tool as described in the PERA survey.

Source

Production Engineering Research Association, "Numerical Control – An Economic Survey", PERA Report No. 119, 1963.

What Caused the Slow Uptake of N/C Technology?

The British firms developing early N/C systems had been taken in by misleading statistics and the optimists' and alarmists' hyperbole, and had based their development programmes accordingly. In this section I will consider the underlying reasons for the uptake of automation to have been much slower than anticipated, looking in particular at the issues of the appropriateness of the technology and of managerial conservatism.

The Economics of Automation

Although N/C developers had expected the technology to be compelling to all sectors of manufacturing industry, early 1960s sales of N/C machine tools were almost exclusively limited to new installations in high-technology industries (particularly aircraft engine manufacture) or large factories that were undergoing major modernisation programmes. By the mid-1960s examples of productivity gains could be quoted with authority due to the growing experience of using existing systems, but demand for N/C still did not increased significantly. Surveys showed that industrial automation had proved itself economically viable, with anything from 10% to 900% gains in productivity per machine reported. Probably the most authoritative of the surveys was one commissioned by the Production Engineering Research Association (PERA) in 1963.[71] PERA surveyed seventeen N/C installations, and asked the users to provide cost breakdowns for typical production runs using the new equipment and using their previous systems. The example workpieces are detailed in the report – in some cases they were single items, and in others they were batch-produced in large volumes. My calculations, working from the PERA data, show that for a workpiece made in batches of less than 50 the cost benefit for users of N/C systems was approximately 58% and the time benefit was 49%. Larger batches yielded even better cost and time benefits of 45% and 40% respectively (Table 4.7).

Reports also showed that N/C systems were more efficient in their ratio of metal-cutting time to idle time, a traditional indicator of efficiency, which increased from an average of around 15-18% using conventional machine tools to 50% using N/C systems.[72] Furthermore, automation technologies had provided the means for companies to manage with reduced inventories, giving increased productivity per square foot of factory space.

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[71] Production Engineering Research Association, "Numerical Control – An Economic Survey", PERA Report No. 119, 1963. The average figures are calculated from the chart on p. 6.

[72] Figures from Christensen, *Automation and the Workers*, pp. 23, 26, and 28.

Table 4.7 N/C Compared with Conventional Manufacturing Methods

Batch size	N/C Time (machine hours)	N/C Cost (l/s)	Conv. Time (machine hours)	Conv. Cost (l/s)	Time Benefit (%)	Cost Benefit (%)
720	19648:00	20829/-	31000:00	31210/-	63.3	66.7
72	30:15	45/12	128:00	142/13	23.6	31.9
3500	43:00	48/13	106:00	120/-	40.5	40.5
60	2238	4461/-	4800:00	7980/-	46.6	55.9
6	1:45	2/8	4:18	4/1	40.5	59.2
2	1:24	1/12	1:39	2/9	84.3	65.3
12	62:00	97/5	100:00	206/11	62.0	47.0
12	32:00	51/14	48:30	65/11	65.9	78.8
46	1380:30	2961/-	2995:00	4165/-	46.0	71.1
1	42:00	35/10	178:00	140/10	23.6	25.3
2	204:00	298/-	437:00	619/-	46.7	48.3
1	11:30	23/9	60:15	70/5	19.1	33.4
1	9:00	102/10	452:00	552/-	0.02	18.6
1	5:15	9/18	21:30	26/-	24.4	38.0
500	773:00	1123/4	1961:00	2144/-	39.4	52.3
100	109:00	183/10	178:30	211/12	61.1	86.7
10	57:30	67/-	85:00	93/-	67.6	72.0
Average benefits for batches larger than 50					48.9	58.0
Average benefits for batches smaller than 50					39.7	45.5

Notes

"Conv." denotes Conventional.

Source

PERA, *Numerical Control - An Economic Survey*, Report No. 199, November 1963, p. 6.

Inappropriate Technology? Comparing Britain with the United States

Until the mid-1960s the British N/C developers managed to persuade observers that their work was technologically more advanced than the systems being developed in the

United States - the DSIR, for example, reported in 1959 that "In general the findings of this enquiry confirm the impression that Britain still has the lead in this field and ought to exploit it."[73] British N/C systems appeared to be bucking the national trend in terms of international technology lag, just as early computer technology had done in the preceding decade. As Braun notes, the British technology lag - the average time before catching up with a new technology - averaged 2.6 years in the 1950s, and actually improved to 1.6 years during the 1960s. Besides the United States, which enjoyed a technology lag of around 0-0.1 years, Japan was the only country with a shorter lag than Britain in the 1960s.[74]

So why did the N/C industry fail to grow as rapidly as had been predicted? In the United States the delay in growth of the N/C machine tool industry has been considered a result of the USAF's early sponsorship of development work, and in particular its promotion of the APT programming language for tool control.[75] This was because when APT was first introduced in 1959 the USAF declared that all military aircraft manufacture which made use of N/C technology would have to be standardised, using APT. Consequently, any machine tool manufacturer whose market was the military aircraft production industry was forced to adapt its existing N/C research programmes to accommodate APT. The demands of APT were high - its standard four axis control notation required considerable computing technology that was not economically viable for use in small machine shops - at least until the establishment of the minicomputer industry in the late 1960s (see chapter 5). Because of the intensive computing demands of APT, the US systems were too costly to be used in any but the largest of machining operations. So, for several years the N/C systems developed by US machine tool manufacturers failed to meet one of the three

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[73] DSIR, *A Survey of the Research and Development Requirements of the Machine Tool Industry*, HMSO, 1959, p. 50. See also Christensen, *Automation and the Workers*, p. 10.

[74] Braun and MacDonald, *Revolution in Miniature*, p. 146.

[75] For background on the development of APT see Noble, *Forces of Production*, chapter 6; and Ross, "Origins of the APT language for Automatically Programmed Tools".

essential features identified earlier (reliability, economy, and accuracy) that were required for the widespread acceptance of the new technology.

Noble has argued strongly that the only reason for APT systems to have enjoyed the limited success that they did was because of the USAF support. He writes,

> It is only in the reductionist fantasies that decisions about new technologies are made strictly on the basis of hardboiled, no-nonsense evaluations and refined analytical procedures for estimating their cost-effectiveness. [...] Whatever the motivation for introducing the equipment, the purchase must routinely be justified in economic terms. But justifications are most often made by people who want to make the purchase, and if the item is desired enough by the right people, the justification will, in the end, reflect their interest.[76]

However, the control thesis goes deeper – Noble goes on to explain R/P's displacement by N/C in terms of a process that he describes as a "triple of filters", namely: an "objective" assessment of the technical/scientific merit of the project; an assessment of its economic rationality; and the influence of self-correcting market forces.[77] Because these are predominantly political and cultural categories, Noble argues, the success of any technology says more about the power of those who promote it than about the suitability of the technology itself. But clearly N/C promised all of the benefits associated with R/P, with the added bonus of further reduced operating costs because there would be no need to employ a skilled machinist to make the initial recording. In place of several machinists there could be a single "part programmer", whose job would be to develop the control program from the design drawings. And, as Braverman and Bright have argued, the skill requirement of a part programmer is significantly lower than that of a machinist.[78]

It appears that the one of the principal reasons that R/P lost support was because it was less flexible than N/C – an N/C system could offer a potentially unlimited number of axes of simultaneous control, as opposed to the maximum of 3

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[76] See Noble, "Social Choice in Machine Design", p. 27 and Noble, *Forces of Production*, pp. 213-217.

[77] Noble, *Forces of Production*, p. 145.

[78] See chapter 9, "Machinery", of Braverman, *Labor and Monopoly Capital*; and James R. Bright, "The Development of Automation", in Melvin Kranzberg and Carroll W. Pursell Jr. (eds.), *Technology in Western Civilization, Vol. II*, Oxford University Press, 1967, pp. 635-655.

that a skilled human machinist, and hence an R/P system, could manage. Furthermore, the labour costs of skilled machinists had been inexorably climbing for thirty years, and increasingly complex machined parts were being demanded, so it appeared likely that R/P would soon become inadequate. There was clearly a strong economic incentive to explore N/C's proposed ability to reduce manufacturing cost.[79]

However, perhaps the most influential factor in the abandonment of R/P technology was the fact that the media presented it as an anachronism, whereas N/C was portrayed as elegant and modern, and depicted as a Zeitgeist to a market of predominantly expanding companies in exciting new industry sectors. Even Noble acknowledges that N/C was marketed as the technology being researched by companies at the cutting edge of the development of automation. There can be no doubt that N/C was technologically superior to R/P - this had been conclusively demonstrated by the mid-1960s. Furthermore, the perceived extension of managerial control that N/C offered merely added appeal to an already compelling technology. So, clearly the reticence to adopt N/C was unrelated to the technical capabilities of the technology. And, because the British developments were never inhibited by the requirement to support APT, the influence of the USAF on technological direction seems to have been negligible - the British companies had a free hand to develop reliable, efficient, and most importantly economical systems. Finally, there can be little doubt that by the mid-1960s their offerings (with perhaps the exception of Ferranti's, which required the services of a large computer) were cost effective for use in many areas of automated manufacture in small and large industries. Given all of the above, was the delayed uptake of N/C technology a result of managerial conservatism?

Managerial Conservatism in British Manufacturing Industry?

If British N/C technology was capable of meeting its claims to reduce manufacturing costs and increase productivity, it must be asked whether endemic conservatism throughout manufacturing industry was the reason for its delayed uptake? Why, when the economic arguments for the introduction of N/C systems seemed so strong, did the

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[79] For a more detailed analysis see Chapter I, "The Long-Range Economic Effects of Automation" of Simon, *Shape of Automation for Men and Management*, 1965.

market fail to grow as rapidly as had been expected? Perhaps, as General Electric vice president Harold Strickland intimated, it was due to managerial conservatism: "Automation is inevitable [but] it takes a lot of hard work and sacrifice by a lot of people to bring about the inevitable."[80] Or, as Woollard, the proponent of flow production, noted, "Selling automation to existing supervisory staff is often more difficult than convincing the shop-floor worker that it is desirable."[81]

Conservatism within the management of British manufacturing industry has been long recognised. Rolt, whose *Tools for the Job* is the definitive history of the pre-electronics machine tool, writes on the state of British manufacturing up to the late 1930s, "The tendency in Britain up to this date was to introduce new machine tools only as a solution to some new and novel production problem and not because they could carry out more rapidly and efficiently operations which existing tools could do."[82] It would seem that, if we exclude the period of the war, British industrial management has remained fairly consistent in its gradualist approach to making changes in working practices, tending on the whole to be reactive rather than proactive. For example, referring to the *Manchester Guardian* "Survey of Industry, Trade and Finance for 1953" Woollard noted that while US companies spent on average 20% of their capital expenditure for fixed plant and machinery on electrical control equipment, British companies averaged only 3-4%.

Moreover, the automation hysteria was a period of uncertainty during massive media activity, one of indecision rather than action. At its height, the Earl of Halsbury, Managing Director of the NRDC, had appealed to the managers of manufacturing industry not to be cautious. He was convinced that fear of the unknown would be the limiting factor in the automation of British manufacturing industry. But it seems that Halsbury's calls had been ignored - a decade later, after the automation hysteria had subsided, the problem of managerial conservatism still regularly attracted attention. Technology pundits, such as Rex Malik, who were concerned that British industry

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[80] Quoted in Noble, *Forces of Production*, p. 230, from a 1960 article by Strickland.

[81]. Quoted in MacMillan, *Automation: Friend or Foe?*, p. 50.

[82] Rolt, *Tools for the Job*, p. 225.

should aim for greater modernisation or risk being left behind by the United States and Western European countries, continued to blame non-technical, conservative management for the lack of progress.[83]

Perhaps industrial managers were arguing that automation was too expensive to adopt? In British industry purchasing policies for new capital equipment were tied, for historical reasons, to the notion of 10 years (or more) amortisation – it was unthinkable to write off existing equipment in order to install new systems until the old equipment had come to the end of its useful lifetime.[84] Nevertheless, the DSIR had shown as early as 1956 that there was plenty of risk capital available for firms wishing to increase automation, so companies that wanted to automate would, in theory, have little difficulty raising funds to cover the capital equipment outlay.[85] Given that the economic benefits of automation had been unequivocally proven, and that the capital was available for companies to introduce it, it seems clear that managerial conservatism was indeed the most likely cause of the delay in automation's uptake.

However, even if we acknowledge that conservatism was widespread in British industrial management, surely there were some companies that were keen to try out the new technologies? Given that early N/C technology was technologically appropriate and affordable, perhaps the case was that N/C systems were not actually readily available from conventional sources? Was it the case that British industry was simply not being given enough opportunities to buy N/C equipment because there were so few systems available in the machine tool market?

Conclusion

Of the four pioneering British firms in machine tool automation only one - Alfred Herbert - was a machine tool manufacturer, and its prototype was deemed too primitive to be developed into a product. Electrical/electronic engineering companies,

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[83] See Rex Malik's 1964 polemic criticising the British managers, *What's Wrong with British Industry?*, Penguin Books, London, 1964.

[84] For further analysis of the theme of bureaucratic rigidity and its role in the changing industrial environment in twentieth century Britain see Hirst and Zeitlin, *Reversing Industrial Decline?*

[85] DSIR, *Automation*, pp. 50-52.

who lacked credibility in the machine tool market, or access to its traditional sales conduits, conducted the other three N/C research projects. Their marketing efforts seem to have been directed at the machine tool users, rather than convincing the conventional machine tool manufacturers to integrate N/C systems into their existing product lines. Obviously if a manufacturing company wanted to modernise its plant the first port of call would be its traditional machine tool suppliers, but until the mid-1960s most of them were only capable of providing conventional machine tools. The conclusion must be that the British electronics firms were wasting their resources marketing the technology towards end-users when they should have been pushing the conventional machine tool manufacturers to integrate the controllers into their systems.

However, it is likely that the conventional machine tool manufacturers were not open to the advances of the electronics firms anyway. It is significant to note that the machine tool market grew at an average annual rate of 6.2% between 1954 and 1963. Given a strong sellers market there was little incentive to branch out into new technological developments.[86] For example, when Richard Young (now Sir Richard) became Deputy Chairman of Alfred Herbert in 1965 he criticised the R&D budget, noting a ratio of dividends to research spending of 7:1. The company directors told him that while Alfred Herbert was still making good money there was no need to fund any major research programmes.[87]

With the exception of the aborted developments at Alfred Herbert, none of the conventional machine tool manufacturers had tried to develop N/C technology in the 1950s. Furthermore, even though the potential of numerical control was widely publicised in the automation literature throughout the decade, the machine tool manufacturers seem to have ignored the new market entirely, even though they could have worked together with the electronics firms. A draft of the 1959 DSIR report includes the following passage:

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[86] Figures from Zeitlin, *Between Flexibility and Mass Production*, (forthcoming) chapter 9. (He notes that because of the extremely cyclic nature of the industry the choice of base year can have a significant effect on the actual figure.)

[87] Interview with Sir Richard Young, 28th May 1996. See also Sciberras and Payne, *Machine Tool Industry*, pp. 45-46.

> The response by the machine tool industry to the overtures of electronic equipment manufacturers in the first instance was uncooperative, and it is only recently that the continuous pressure from both users and electronic [sic] firms has forced a few manufacturers of machine tools to incorporate certain design features in their products for the better utilisation of the control equipment.[88]

The DSIR had concluded that the pressure on the machine tool manufacturers to introduce N/C systems was coming predominantly from the users, rather than the electronics firms, but that the demand was being largely ignored. However, a memo from the BoT to the DSIR warned against publishing the paragraph quoted above, claiming that "There has been considerable co-operation between *appropriate* British machine tool makers and electronic equipment manufacturers over many years and the criticism in the second paragraph is quite unjustified."[89] Clearly the BoT wanted to deflect any further criticism of the industry – the Melman report was still a hot topic. The DSIR acquiesced, and the paragraph was dropped from the published report, so the machine tool industry was spared a home truth that might have had a profound effect. However, the reprieve was short-lived - the conservative machine tool manufacturers were soon to find themselves in a shrinking minority of backward-facing industries as the mid-1960s saw the election of a Labour government. Under the leadership of Harold Wilson, Labour won the election with its rhetoric of industrial modernisation, and the new "Britain that is going to be forged in the white heat of this [scientific] revolution." And, as the new minicomputer industry emerged, it looked as if once again Britain had the chance to lead in technological development.

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[88] Draft (PRO/BT/258/809 document 18) of DSIR, "A Survey of the Research and Development Requirements of the Machine Tool Industry", 1959, p. 46.

[89] PRO/BT/258/809 document 14 [my italics].

Chapter 5 - The Minicomputer Industry

Introduction

In November 1964 Harold Wilson appointed Frank Cousins as Britain's first Minister of Technology and warned him that he had about one month to save the British computer industry. For the next three years the Ministry of Technology (MinTech) wrestled with the problem, eventually presiding over the formation, through merger, of ICL in 1968.[1] The promotion of a single national champion mainframe manufacturer was seen as the only way for the British industry to compete with IBM, the US manufacturer and world market leader.

While popular and political attention was fixed on the mainframe sector of the computer industry, a similar situation was developing in the minicomputer sector. A handful of British manufacturers found themselves elbowed aside by their US competitors, most notably Digital Equipment Corporation (DEC). By the late 1980s DEC was the second largest computer company in the world (behind IBM), but in the early 1960s it was widely believed that the British manufacturers would be able to compete effectively in the world minicomputer market, or at least hold their own within the British market.

This chapter describes the development of the British minicomputer industry, explaining how it grew out of the field of process-control technology, how MinTech tried (and failed) to alter the structure of the industry, and how it was ultimately relegated to serving a number of contracting niche markets. The principal question to be addressed is: Was the British minicomputer industry a failure, and if so, why?

The Computer Industry, circa 1962

In the early 1960s the words "computer" and "mainframe" were essentially synonymous. A mainframe was a massive, power hungry device, attended by a group of operators who kept the system in operation twenty-four hours a day, and acted as an interface between the computer and its users. Mainframes were generally bought by

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[1] Chapter 12, "Government relations and the formation of ICL" of Martin Campbell-Kelly, *ICL: A Business and Technical History*, Clarendon, Oxford, 1989.

large corporations and major public sector departments for use in electronic data processing (EDP), usually automating routine clerical and accountancy work. A decade later, at the beginning of the 1970s, it was possible to buy computers a fraction of the size and cost of a mainframe. These new "minicomputers" were used in small businesses to perform stock control, in laboratories for data capture and analysis, and in factories for controlling automated machinery. They drew power from the standard single-phase electricity supply and could be used "hands-on", without any intermediary operators. Because of their low cost, they could be turned on and off as needed and be left idle when they were not required.

During the late 1950s the semiconductor transistor had started to become commonplace in commercially manufactured electronic goods, replacing electromechanical relays and vacuum tubes. In the computer industry, the mainframe manufacturers rushed to develop transistorised "second generation" systems.[2] This change in hardware technology coincided with the so-called "software crisis", which was fuelled by the recognition that each new computer system had a limited useful life before its users' requirements would outgrow its capabilities. Users and manufacturers alike became concerned that software development costs were beginning to overtake hardware costs as software was periodically rewritten to work on new computers. It became apparent that the manufacturers' practice of developing new computers without regard to software compatibility had to stop, and that they would have to provide homogeneous system ranges so that users could upgrade hardware without having to replace their software. This was an opportunity that IBM addressed in 1964

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[2] Electronic computers are often classed in generations. The first generation (1940s and early 1950s) is characterised by the use of vacuum tube technology in the central processor. Second generation computers (c.1955 until c.1965) replaced vacuum tubes with transistor technology. After 1965 the third generation of computers introduced integrated circuits (ICs). For an overview of the development of the mainframe industry see Kenneth Flamm, *Creating the Computer: Government, Industry and High Technology*, The Brookings Institution, Washington, DC, 1987. An excellent description of the generations of computer hardware can be found in John P. Hayes, *Computer Architecture and Organisation*, McGraw-Hill, London, 1988, pp. 1-80.

with the introduction of its System/360, the first upwardly compatible range of mainframes.[3] In such a range, every model could run the same software, with the more expensive models having a faster processing speed and larger storage devices. System/360 was a phenomenal success, and it propelled IBM to the forefront of the mainframe industry. IBM's initiative in response to the software crisis forced the pace in the rest of the industry. This was reflected by a merger wave in Britain as companies either responded to the new competitive environment, or tried to retreat gracefully from the industry. By 1968 there was only a single surviving British mainframe manufacturer, ICL.[4]

Meanwhile, transistor technology was having a profound effect in the field of automation, which can be loosely defined as the use of automatic equipment to replace mental and physical labour.[5] Industrial automation grew out of the systems developed for automobile factories during the 1930s, and was a process that could be applied in areas whose operating characteristics could be precisely specified.[6] These were areas that previously would have required skilled or semi-skilled human operators. Some typical examples were: traffic control systems; railway signalling equipment; and centralised controllers for chemical processing plants. Process controllers, systems for industrial automation, were constructed in the 1950s using electromechanical technologies by companies such as General Automation and Foxboro in the United States, and Ferranti and EMI in Britain. It was typical for a special-purpose process controller to be developed for each particular application or for a limited group of

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[3] See E. W. Pugh, *IBM's 360 and Early 370 Systems*, MIT Press, 1991.

[4] Campbell-Kelly, *ICL*, pp. 206-64.

[5] "Automation" was a very emotive term during the period, with many different connotations. For a long contemporary discussion on the definition of terms, see L. Landon Goodman, *Man and Automation*, Penguin, London, 1957. See also Raphael Kaplinskey, *Automation, the Technology, and Society*, Longman, Harlow, 1984; and James R. Beniger, *The Control Revolution: Technological and Economic Origins of the Information Society*, Harvard University Press, 1986.

[6] The history of the US industry is detailed in David F. Noble, *Forces of Production: a Social History of Industrial Automation*, Oxford University Press, 1984.

similar applications. Controllers of this type were dedicated, or "hardwired" devices, and were intrinsically difficult to modify for use in tasks for which they were not designed.

By the late 1950s and early 1960s, just as mainframe computer users were facing the software crisis, process controller manufacturers faced an analogous hardware crisis. As the adoption of automation became widespread, they found that they could not keep pace with demand, especially because customers demanded increasingly complex controllers. The industry's response was to develop general purpose control systems that could be relatively inexpensively tailored to each individual application.[7] These systems would perform a series of simple operations according to a list of instructions, which could be considered a rudimentary computer program. By changing the list of instructions, they could be adapted to a wide range of different tasks. This mode of operation meant that they had many similarities to mainframes, but the differences were significant: their limited programming capabilities were specifically designed with control applications in mind, rather than general purpose business and scientific use; they used only inexpensive read-only memory, as opposed to the random access memory used in mainframes, because it was not anticipated that it would be changed very often; and their input/output facilities were for use with low speed measuring devices and actuators rather than high speed magnetic tape or discs. Nevertheless, it was a relatively small step from these general purpose control systems to fully-fledged electronic computers. Ferranti took this step, for example, in 1960, when engineers took the process control system from Ferranti's Bloodhound missile and used it as the basis of development for the Argus computer.[8]

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[7] The transition from special-purpose to general-purpose systems is discussed in C. Freeman, C. J. E. Harlow, J. K. Fuller, and R. C. Curnow, "Research and Development in Electronic Capital Goods", in *National Institute of Economics Review*, Vol. 34, Nov. 1965, pp. 40-91.

[8] John Wilson, *The History of Ferranti*, (draft manuscript, University of Leeds, previously Manchester). This book will cover the company's history in the period after 1930, and I am indebted to Wilson for the loan of a draft manuscript. See also Anthony Gandy, "The Entry of Established Electronics Companies into the Early Computer

Other companies in Britain and the United States were independently working on other such projects at the same time. When the similarities between these new systems and mainframes were seen, the same terminology began to be used, and the new systems were then called process control computers.

Beyond industrial automation, research scientists became aware in the early 1960s of the potential in using computers. This was a latent market which required small, low cost computer systems that could be used in areas in which it would be uneconomic to use, or rather, under-use, a mainframe computer. The process control computers fitted the bill; because they cost much less than a mainframe they could be paid for from a departmental equipment budget - it was not necessary to convince a company's supervisory board to authorise funding. A small, inexpensive, computer could be economically justified even if it was not in use all of the time. Minicomputers were never portable, but they could be installed virtually anywhere, whereas a mainframe system required a specially appointed room with air conditioning, a raised floor for cabling, and often a three-phase power supply. In the late 1960s, as the new process control computers began to be used in new fields outside of industrial automation, they started being called small computers, or more fashionably "minicomputers".[9]

Because minicomputers had to be sold at low cost, and therefore low profit margins, high volume sales were necessary. In order to keep unit costs down further, minicomputer manufacturers could not afford to develop major support services, so after-sales contact with customers had to be kept to a minimum. (Customer support represented a considerable part of the cost of a mainframe computer system.) Fortunately, many of the customers in the new markets were technically sophisticated. It was feasible to supply them with a naked system, that is, one without an applications software package, sometimes without even operating system software. These users could develop their own software, or commission it from a third party, and they understood the technical issues that this would entail. Many of these new customers

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Industry in the UK and USA", (PhD Thesis), London School of Economics, 1992, pp. 90-91.

[9] Computing folklore holds that the term "minicomputer" was a reference to the "miniskirt" fashion.

were keen to try out small computer systems, so while mainframe manufacturers had to approach individual customers and persuade them to buy their systems, minicomputer manufacturers were able, to some extent, to adopt a passive approach, and wait for the customers to approach them.[10] Sales could be achieved merely by developing products suitable for the technically sophisticated markets. Consequently, during the early 1960s, minicomputers were used almost exclusively in laboratories, as data-logging devices, where the software was developed by the customers, or in factories, as process controllers, using customised versions of generalised software packages.

The Players, their Origins and Strategies

Within a political and industrial climate that was favourable to industrial automation, a handful of British companies were encouraged to enter the market during the 1960s. The economic climate and low entry costs also encouraged new enterprises: it was estimated that the cost of developing a minicomputer system was less than $5 million in the late 1960s. By contrast, Brock estimates that the barriers to entry to the mainframe industry were in excess of $1 billion at the same time.[11]

In Britain, minicomputer manufacture attracted a number of electronic capital goods manufacturers in the early 1960s, while a number of entrepreneurial start-ups entered the field later, during the mid-1960s. There was even one office machinery company that developed a minicomputer system. The principal British players are shown in Table 5.1.[12]

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[10] See Glen Rifkin and George Harrar, *The Ultimate Entrepreneur: The Story of Ken Olsen and Digital Equipment Corporation*, Contemporary Books, London, 1988, p. 68; and Rex Malik, *And Tomorrow ... The World? Inside IBM*, London, 1975.

[11] Gerald W. Brock, *The US Computer Industry: A Study of Market Power*, Ballinger, Cambridge, MA, 1975, p. 57.

[12] Some other companies such as Arcturus Electronics and Plessey tried to enter the minicomputer market but were largely unsuccessful, while others such as English Electric, EMI, and Marconi developed more application-specific process controllers.

Established Electronics Firms

The diversified electronics companies, Ferranti, GEC, Plessey, and Elliott Automation (EA), were the first to enter the small computer market, through the technological evolution of their existing products. EA built on its industrial automation equipment, while the other three companies derived technology from their defence systems: Ferranti from missile control systems; GEC and Plessey from communications equipment. Later, all three companies separated their military and civilian minicomputer operations, under pressure from the Ministry of Defence.[13] Developments in the minicomputer industry were not significantly driven by changes in electronics technology (see Section IV), so the levels of technology transfer between the military and civilian operations were minimal in all cases.

Ferranti was a multidivisional family-owned company, and had been one of the first British companies to become involved in mainframe manufacture.[14] In 1959, work began in the Guided Weapons department to develop process control computers for the civilian market, derived from its Bloodhound missile technology, although it was not until 1961 that the first system was sold. In 1963 the minicomputer work was separated wholly from its military roots, with the formation of Ferranti's Automation Systems Division. The director of the new division was given relative independence from the Ferranti board provided he could maintain an economically viable operation. This was not difficult to achieve because the Bloodhound developers had already solved many of the technical problems. It is interesting to note that when it was first introduced the computer was called the Ferranti Process Control Computer, but it was soon changed to Argus. This was in line with the tradition of Ferranti's Digital Systems Division, which named all of its mainframe computers after constellations. The

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[13] Ferranti built separate sites near Manchester to the house military and civilian work on Argus computers. GEC also housed military and commercial operations in different sites.

[14] For the early history of Ferranti, see John Wilson, *Ferranti and the British Electrical Industry, 1864-1930*, Manchester, 1988. See also Geoffrey Tweedale, "Marketing in the Second Industrial Revolution: A Case Study of the Ferranti Group, 1949-63", in *Business History*, Vol. 34, Jan. 1992, No. 1, pp. 96-127.

inference was obvious: this was a fully-fledged Ferranti computer, albeit aimed at a different market.

Elliott Automation was a company that had been established - originally named Elliott Brothers - in the late nineteenth century to develop scientific instrumentation. By the early 1960s it had diversified into the manufacture of mainframe systems, but its main business had become process control equipment. EA's managing director was Leon Bagrit, who delivered the Reith Lectures in 1964 on The Age of Automation,[15] and was well known for his technological enthusiasm which bordered on evangelism.[16] Perhaps fired by his slogan, "Never re-invent", EA began minicomputer developments in the late 1950s in an attempt to reduce the cost of automation equipment.[17] The resulting commercial product, the Elliott Automation 802, was first demonstrated in 1962 during a trade fair at Olympia. The product sold successfully for about five years, in part due to a marketing arrangement with the US firm, National Cash Register. EA was broken up during the merger wave of 1967-68. Its mainframe concerns went to the newly formed ICL, while its minicomputer concerns were taken over by GEC. Although GEC already had a minicomputer operation, the EA department retained an independent identity after the take-over. The head of the subsumed EA minicomputer department had a relatively free hand, provided he retained the approval of the GEC board.[18]

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[15] Sir Leon Bagrit, *The Age of Automation: The BBC Reith Lectures 1964*, London, 1965.

[16] Blackett cites Bagrit as a model manager of high-technology industry, P. M. S. Blackett, *Technology, Industry, and Economic Growth*, Southampton, 1966, p. 6.

[17] Further details from interview with Laurie Bental, (Senior Manager at Elliott Automation and later GEC), 18th May 1994.

[18] The GEC/AEI merger in 1967 is the principal topic of Robert Jones and Oliver Marriott, *Anatomy of a Merger: A History of GEC, AEI, and English Electric*, Cape, London, 1970 and Sir Joseph Latham, *Take-Over: The Facts and the Myths of the GEC/AEI Battle*, Iliffe, London, 1969. For the managerial structure of GEC, see Derek F. Channon, *The Strategy and Structure of British Enterprise*, MacMillan,

Entrepreneurial Start-Ups

The most important of the start-ups was Computer Technology Limited (CTL), which was formed by a group of minicomputer engineers who had left EA to form their own company in 1965. A consortium including American Research and Development (ARD) and Robert Maxwell's Pergamon Press funded CTL. ARD was a venture capital source that was strongly associated with high-technology industries, and which became famous for its phenomenally successful backing of DEC.[19] On the other hand, Maxwell was one of the many businessmen caught up in the euphoria surrounding industrial modernisation. Iann Barron, who acquired a reputation as the enfant terrible of the British minicomputer industry, founded CTL. As Chairman he exercised control over the company's direction for five years until he was ousted by the company's board, and relegated to a technical advisory role.[20] He remained with the company for ten years. As a start-up, CTL had strong obligations to make a quick financial return during its early years, and to some extent this interfered with Barron's original mission to develop and advance the state of the art in small computer technology. Subsequent chairmen of the company paid more heed to the shareholders than Barron had been inclined to. CTL was formed with good intentions and many bright engineers, but it was 1968, two years after the company had been formed, before they had developed a

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London, 1973, pp. 133-36. Further details from interview with Laurie Bental, 18th May 1994.

[19] See Paul. A. Gompers, "The Rise and Fall of Venture Capital", in *Business and Economic History*, Vol. 23, No. 2, Winter 1994, pp. 1-26. Gompers writes, "The concept of the 'home run' in venture capital was synonymous with DEC and the term would become pervasive in the industry during the 1980s and 1990s. Everyone wanted to finance the next DEC." (p. 6).

[20] CTL suffered in 1971, following the crash of Autonomics, a computer services company, and one of CTL's principal customers. Barron was replaced as Chairman by Tom Margerison, of London Weekend Television, and ex-deputy editor of *The Sunday Times*.

marketable product, the Modular One, and this delay was a concern to its investors in the interim.[21]

The second important start-up was Digico, formed in 1965 by Keith Trickett and Avo Hiiemae, two ex-ICL electronics engineers who had developed a prototype system, DIGIAC,[22] in a garage. Digico raised venture capital from the Technical Development Council (a branch of ICFC).[23] The DIGIAC was developed for a specific laboratory data-logging application, in connection with spectrum analyser hardware. The two founders jointly controlled Digico, with thinly drawn boundaries between their areas of authority. As a consequence the company lacked strategic direction.[24] However, unlike CTL, Digico already had a prototype system before the company was founded, so there was no product development delay between the company's creation and its first sales. Digico quickly went on to develop a more general purpose minicomputer, the Micro 16, which it began selling in 1966, two years before CTL's Modular One.

The remaining major player was Business Computers Limited (BCL). BCL was formed through the merger of Business Mechanisation Limited (Bismec), an office machinery company founded in the 1930s, and Systemation Limited, an electronics design company. In the early 1960s the companies collaborated on special purpose accounting and stock control systems, called SADIE and SUSIE.[25] In recognition of each others' assets, namely a well-developed sales and support network on the one hand, and an experienced hardware design team on the other, the two companies

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[21] According to Barron, Maxwell was reluctant to contribute funds to the company until it had a marketable product. Interview with Iann Barron, (CTL founder and Managing Director, 1966-1971), 23rd Feb. 1994.

[22] A contraction of DIGItal Automatic Computer.

[23] See Geoffrey Foster, "Britain's Electronic Davids", in *Management Today*, Sept. 1973, pp. 91-93, 174, 180, and 186.

[24] Eventually the Chairman (Eric Lubbock MP, Chairman of Digico, 1969-1983) had to dismiss one of the founders: letter from Avebury to R. Hamilton, 26th Jan. 1994.

[25] Acronyms for Sterling Accounting and Decimal Invoicing Electronically, and Stock Updating Sales Invoicing Electronically.

merged in 1968 to form BCL. The managing director of Bismec headed the new company, although technical direction remained in the hands of Systemation's managing director. Later that year, BCL introduced its Molecular 18, a general purpose minicomputer system.

Table 5.1 British Minicomputer Manufacturers, 1960-1980

Company	Product Name	Date Delivered	Notes
Diversified electronic goods/components manufacturers:			
Ferranti Limited (Automation Systems Division)	Argus	1961	Developed from Bloodhound missile control computer.
Elliott Automation Limited	802	1961	The first British commercial minicomputer.
General Electric Company (GEC)	4080	1967	Took over EA small computer interests in 1967.
Plessey	XL-12	Cancelled	Proposed system, never delivered.
Entrepreneurial start-ups:			
Computer Technology Limited (CTL)	Modular One	1968	The CTL founders defected from EA in 1965.
Digico Limited	Micro 16	1966	Developed from a garage built "DIGIAC" prototype.
Arcturus Computers Limited	A18-D	1969	Arcturus was also started by ex-EA engineers. The A18-D was a commercial failure.
Office equipment company:			
Business Computers Limited (BCL)	Molecular 18	1966	Merger between Bismec and Systemation.

The Changing Operating Environment

During the second half of the 1960s, as new markets opened outside of process control, one principal government agency tried to influence the minicomputer industry.

This was the Ministry of Technology, which was formed in 1964 when Harold Wilson's Labour government entered office.[26] Promotion of industrial automation had been at the heart of the Labour Party's election manifesto during the 1964 election campaign.[27] Harold Wilson spoke of "the Britain that is going to be forged in the white heat of this [scientific] revolution".[28] Industrial modernisation was seen as one way to address Britain's relative economic decline, which was attributed in part to inefficiency in British industry.[29] Labour believed that adoption of new automation technology, combined with radical changes in British management structures, might help to bridge the economic gap and improve Britain's position within the global economy, or at least allow it to catch up with its European neighbours.

The Ministry of Technology

As mentioned in the introduction, Frank Cousins was appointed the first Minister of Technology, and told by Wilson that he had "about a month to save the British

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[26] The original plans for a Ministry of Technology had been outlined by Patrick Blackett in the early 1960s. See David Horner, "The Road to Scarborough: Wilson, Labour, and the Scientific Revolution", in R. Coopey, S. Fielding, and N. Tiratsoo, *The Wilson Governments, 1964-1970*, Pinter, London, 1993, p. 67.

[27] See Andrew Graham, "Industrial Policy", in Wilfred Beckerman (ed.), *The Labour Government's Economic Record: 1964-1970*, Duckworth, London, 1972, and P. Mottershead, "Industrial Policy", in F. T. Blackaby (ed.), *British Economic Policy, 1960-74*, Cambridge University Press, 1978.

[28] Harold Wilson, *Labour's Plan For Science*, Labour Party Annual Conference, Scarborough, 1st Oct. 1963.

[29] See Michael Shanks, *The Stagnant Society*, Penguin, London, 1961, pp. 198-; Rex Malik, *What's Wrong with British Industry?*, Penguin, London, 1964, p. 26, p. 124; and more recently, Michael Dintenfass, *The Decline of Industrial Britain, 1870-1980*, Routledge, London, 1982; B. Collins and K. Robbins, *British Culture and Economic Decline*, Weidenfeld and Nicolson, London, 1990; B. Elbaum and W. Lazonick (eds.), *The Decline of the British Economy*, Clarendon, Oxford, 1987; M. Wiener, *English Culture and the Decline of the Industrial Spirit, 1850-1980*, Cambridge University Press, 1981.

computer industry", by which Wilson meant the mainframe industry. [30] Cousins initiated the dialogue that led to the formation of ICL in 1968, although he resigned from the Cabinet in 1966, and was replaced by the zealous Anthony Wedgwood Benn.[31] Benn had previously served as Postmaster General at a time when the Post Office was beginning to use computers to automate sorting processes. Once the mainframe industry reorganisation was under way, MinTech turned its attention to the minicomputer industry, and came to the conclusion that DEC - the leading US company - would soon displace the British manufacturers unless something was done to prevent it.

The ministry sought technical advice from the National Research and Development Corporation (NRDC), an agency that had been formed in 1949 to foster technological innovation.[32] The NRDC was in favour of rationalisation of the computer industry, both in the mainframe and minicomputer sectors, and its advice reflected this, consisting of a checklist of three classes of minicomputer, designated Types A, B, and C, with target prices for each type.[33] The NRDC proposed that three separate British manufacturers could collaborate to develop a single range of computers, one for each of the categories, and thus avoid destructive competition. In the long term this would hopefully allow the British companies to compete

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[30] Harold Wilson, *The Labour Government 1964-1970*, Weidenfeld and Nicolson, London, 1971, p. 9.

[31] Benn often mentions his involvement with the (almost exclusively mainframe) computer industry in his diaries. See Anthony Wedgwood Benn, *Out of the Wilderness: Diaries 1963-67*, Hutchinson, London, 1987, pp. 164, 179, 254, 261, and 501; and Anthony Wedgwood Benn, *Office without Power: Diaries 1968-72*, Hutchinson, London, 1988, pp. 25, 100, 173, and 275.

[32] The story of the NRDC, from its creation until 1965, is told in Hendry, *Innovating for Failure*.

[33] These corresponded to central processor architectures based on 8, 16, and 32 bit word-lengths respectively, the size of a unit of data that the processor could handle in one operation. See National Research and Development Corporation file NAHC/NRDC/C/5/708. (Held in the National Archive for the History of Computing (NAHC), at Manchester University.)

internationally. A series of talks were held with representatives from the manufacturers during 1966-67, in an effort to persuade them to co-operate. However, by that time most of the manufacturers had their own well-advanced designs, with GEC and Ferranti already marketing products. Moreover, all of the British computers, except the ones proposed by Digico and Arcturus, fell into the Type B category. There were no Type C proposals.

MinTech recognised that it would not be possible to persuade the companies that already had products to co-operate in developing new (Type C) systems, so attempts were made to persuade some of the start-ups to co-operate, by trying to marry those with proven design skills with experienced manufacturers. For example, MinTech suggested to a number of electronics companies that they should consider manufacturing CTL's design, with the ministry offering to underwrite production of the first systems. MinTech returned to Barron at CTL to suggest a number of liaisons, first with Plessey, then Associated Electrical Industries, and finally English Electric, but Barron always refused through fear that he would lose authority over the technical direction of the product. MinTech became piqued with Barron's lack of co-operation, and eventually offered its support, in the form of development grants or assured sales, exclusively to Digico's Micro 16 and Plessey's XL-12 projects. Only Digico and Plessey had been forthcoming with information about their proposed systems and receptive to suggestions from MinTech. All of the other companies had either refused to co-operate with each other, or had not considered it worthwhile to attend the discussions with MinTech.

The MinTech support for Digico and Plessey proved commercially damaging for several of the other companies, because it implied that the government only had confidence in Digico and Plessey: in particular, CTL suffered during the summer of 1968, on the eve of introducing its Modular One system, and had to pretend to already have an established customer base in order to sell its first system.[34] Moreover, support from MinTech did not guarantee success - Plessey never managed to finish developing

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[34] Interview with Iann Barron, 23rd Feb 1994.

its XL-12 project,[35] while Digico's computer was considerably more expensive than had been anticipated (although it did prove commercially successful).[36] Both CTL and Arcturus criticised MinTech's policies in memoranda presented to the 1969-70 Select Committee on Science and Technology.[37] When asked about government support for the industry, Barron replied, "We believe that naturally there should be support which is not necessarily just to one computer manufacturer [...] and that support by constraint is not to the benefit of the industry as a whole."[38]

Once the attempts to make mergers or alliances were abandoned, further Government support was made in the form of development grants for complete systems in specialist application areas. These grants were not very successful because they were often divided between several companies in order to prevent accusations of favouritism. For example, a grant to develop a pathology laboratory data logging system was divided evenly between CTL and GEC.[39] This resulted in both companies selling a small number of systems, sharing a niche market that might have sustained a single company, but not two. Similarly, Ferranti complained to the Board of Trade that an NRDC development grant had been split between Ferranti and EMI, to the benefit of neither company.[40] Nevertheless, supporting novel application areas was a rational

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[35] Martin Campbell-Kelly, "Data Communications at the National Physical Laboratory (1965-1975)", in *Annals of the History of Computing*, Vol. 9, 1988, pp. 221-47.

[36] The NRDC had offered to buy some initial systems if Digico managed to develop them to price and performance specifications. The required performance was achieved, but at the cost of failing to meet the price (NAHC/NRDC/C/5/708).

[37] Select Committee on Science and Technology (Sub-Committee D), Session 1969-70, Vol. 1: Minutes of Evidence, (London, 1970), esp. Memorandum from Arcturus Electronics Ltd., and Memorandum from Computer Technology Ltd.

[38] Select Committee on Science and Technology, Session 1969-70, Vol. 1 paras. 1042-46. (Interview with Barron, Margerison, and Woods of CTL) See also para. 1071.

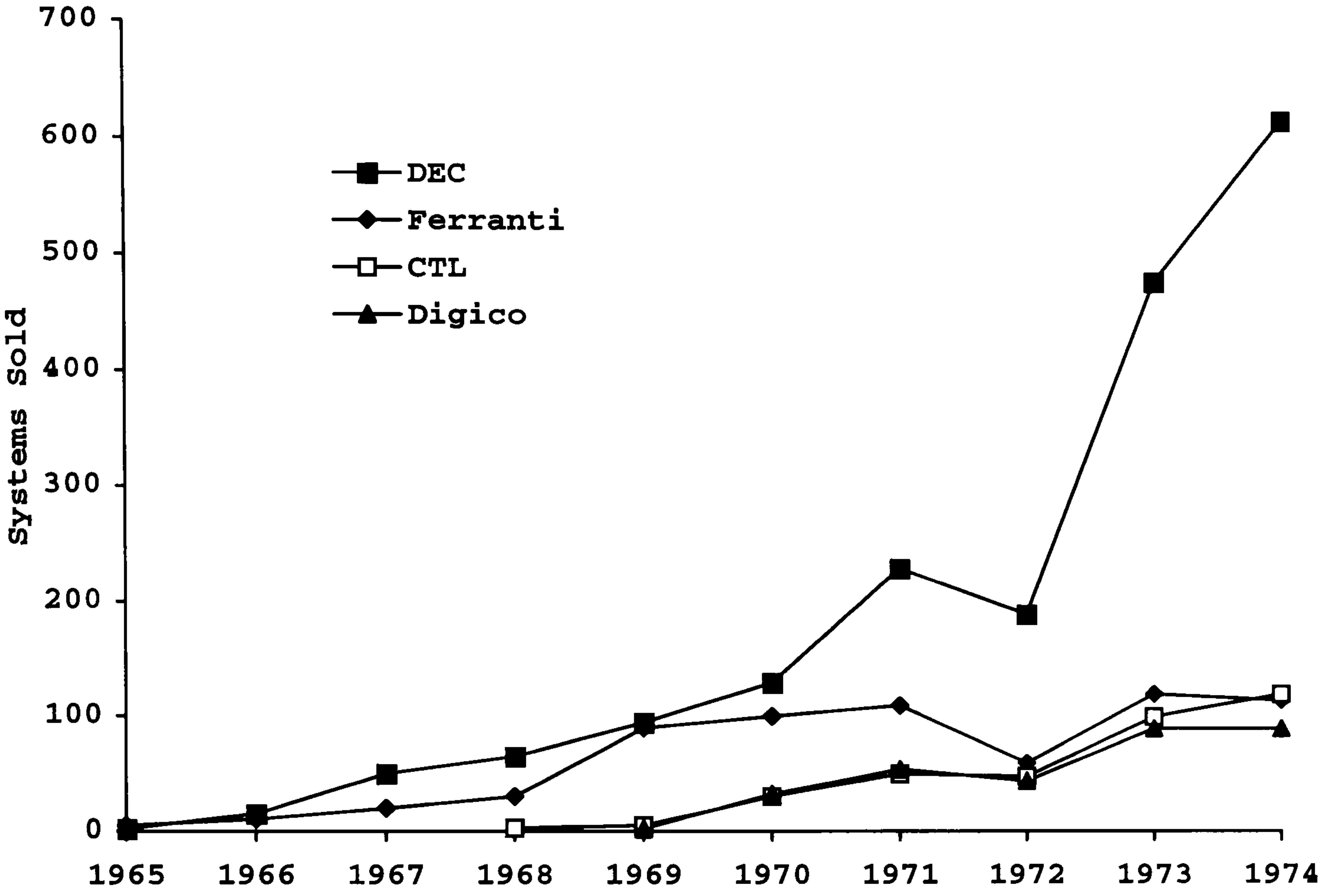
[39] Reported in *Computer Weekly*, 6th July 1972, p. 3.

[40] Letter from the Ferranti board to the Board of Trade, dated March 1965, in PRO/BT/258/1421.

way to help the industry to develop, because for a small-scale minicomputer manufacturer to increase its market share, it was necessary to address new applications rather than simply improve the system hardware. In fact, advances being made in electronics technology during the 1960s had a relatively minor influence on the development of the industry. For example, when small-scale integrated circuits (ICs) came into use during the mid-1960s, they had an impact on the size and performance of the systems, but the underlying hardware designs generally remained unchanged.

Changing Technologies

For both the minicomputer and mainframe industries, one changing area of hardware technology that had a profound knock-on effect on business strategies was the technology of peripheral devices. When minicomputers were first introduced, their users would generally communicate with the computer using a "teletype", which was a single unit consisting of a printer and a keyboard. These were cheap and widely available, having originated in the telegraphy field, and were already used by the mainframe industry. The major change came in the early 1970s, when teletypes were displaced by visual display units (VDUs), which consisted of a keyboard and a cathode ray tube screen. Introduction of VDUs changed patterns of use in the minicomputer market, as described later, but also changed the users' perceptions of the manufacturers. Most minicomputer manufacturers did not make peripherals, but re-badged ones from peripheral manufacturers, so it was common for different minicomputer manufacturers to use the same peripherals. Because the most noticeable feature of a computer system - to the inexperienced user - was the VDU, and because many manufacturers were using the same, or similar, VDUs, it was difficult for potential customers to differentiate between minicomputer systems. This meant that product differentiation became less important than brand recognition. Advertisements in the trade press played on the name of a company rather than the merits of its product. For example, CTL appealed to a perception of typical "English" qualities: reliable and confidence inspiring. On the other hand, DEC produced advertisements highlighting the fact that its systems were the de facto standard, and the yardstick by which all others were measured.[41]



Notes

Figures show annual sales. Data was not recorded for Elliott Automation or GEC because their products were (wrongly) considered to be process control systems by *Computer Surveys* at this time.

Source

Computer Surveys, July 1975.

Figure 5.1 Minicomputers Supplied in the UK 1965-1974 (per annum)

Figure 5.1 and Table 5.2 show how the British market grew between the mid-1960s and the mid-1970s. DEC's increasing dominance in the industry came as little surprise to MinTech. Although the ministry had clearly made some tactical mistakes in

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[41] This is evidenced by the MinTech/NRDC proposals, which explicitly corresponded with DEC systems. Because DEC's range was so widely known, the industry press automatically compared other manufacturer's systems with their DEC counterparts. Accordingly, product differentiation became a major issue for the British manufacturers: Interview with Bob Finch, (CTL Managing Director, 1981-1985), 23rd Mar. 1994.

its handling of policies, it proved well informed on the state of the market. MinTech projections for the industry were based on the same data sources that were available to the manufacturers, so their lack of perspective, highlighted by their negative response to the MinTech proposals for co-operation, was a matter for concern within the ministry.[42] The manufacturers believed that they knew best, or at least better than MinTech. This tunnel-vision was a major factor in the British industry's concentration in niche markets and its demise during the early 1980s.

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[42] MinTech, along with the industry, relied upon *Computer Surveys*, a quarterly periodical which carried reports on the British computer market, and included minicomputer surveys from the mid-1960s. The issue is discussed at length throughout PRO/BT/258/1422. Also, letter from Murray Laver, (Head of Computing Section, Ministry of Technology, 1966 to 1969), to R. Hamilton, 3rd Nov. 1994; and interview with Jeremy Bray, 25th Oct. 1994.

Table 5.2 Minicomputer System Prices, 1974 (Principal Manufacturers)

Company	Product	Cost for basic processor
Arcturus Electronics	A18-D	£3,350
Computer Technology Ltd	Modular One	£8,150 (8K words)
Data General	Nova 820J	£3,725
Digico	Micro 16V	£1,700
Digital Equipment	PDP-8/E	£2,370
	PDP-11/20	£5,300
Ferranti	Argus 700E	£3,450 (8K words)
	Argus 500E	£8,700
GEC Computers	2050	£3,530 (16K bytes)
	4080	£21,000 (64K bytes)
Intertechnique	Multi 8/M301	£2,200
Philips Electrologica	P855	£1,590

Notes

In most cases the costs shown are for a basic processor with 4K bytes RAM, unless otherwise indicated ("word" does not necessarily denote 16 bits – some minicomputers operated on 12 bit words). The data has been extracted from a list of over fifty systems, including those from US and European suppliers, published annually in *Computer Weekly.*

Source

Computer Weekly, 24 January 1974, p.11.

The Decline of the British Industry

While the British manufacturers continued to operate within market sectors in which they had previous experience, towards the end of the 1960s there was an increasing awareness of the potential for using minicomputer systems in new sectors. The British manufacturers were preoccupied with a direct sales approach, persuading individual customers to try out a minicomputer system. For example, CTL developed a system for monitoring and controlling gas flow volumes for British Gas, while Ferranti developed a printing control system to replace linotyping for the Scottish Daily Record. Such systems were usually sold to customers in markets in which the minicomputer manufacturers already had other customers, to exploit the manufacturers' existing capabilities. Meanwhile, new markets emerged spontaneously, so while most British manufacturers focused on scientific and industrial markets, new customers in fields such as office data-processing had to approach the manufacturers. For example, in 1969 Digico was still predominantly selling laboratory data-logging systems, when it was persuaded by a Preston book wholesaler to develop a computerised stock control system.[43]

In the early 1970s, when the British minicomputer manufacturers began to recognise and embrace the new markets, they found that many of these customers demanded high levels of service, as would have been provided by the mainframe industry. They required complete business solutions rather than merely hardware, but also demanded low operating costs and small initial capital outlay. A mainframe would be too expensive, and provide far more processing power than was required. Such requirements were, to some extent, incompatible with the minicomputer manufacturers' aims of high-volume, low-profit per unit sales, because they incurred considerable software development costs. A new type of company addressed this market by developing general-purpose software packages to be used with hardware bought from third parties. These software-oriented companies, staffed by computer programmers and systems analysts rather than hardware engineers, became known as OEMs.[44] Each business system they delivered was one more unit sale for their preferred manufacturer, and often in a niche market. Unfortunately for the British industry, most of the OEMs developed software for US-built hardware, principally from DEC and Data General (DG).[45] The most successful British OEM was Systime

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[43] This was described in an article on Digico in *Computer Weekly*, 23rd Aug. 1973, p. 10.

[44] An Other Equipment Manufacturer develops systems based on computers built by an Original Equipment Manufacturer. The acronym OEM is shared in the literature, and can sometimes be confusing.

[45] DG was the second largest US manufacturer, a spin-off from DEC, just as CTL was a spin-off from Elliott Automation. For an insight into Data General, Tracy Kidder's Pulitzer Prize winner, *The Soul of a New Machine*, Little, Brown, Boston, 1981, is the journalistic inside story of a DG project development team.

Ltd., formed in 1972 to deliver systems based on DEC PDP-11 hardware.[46] For the OEMs this was simply the most effective choice: DEC and DG minicomputers were cheaper than their British-built equivalents, and excellent software development aids were available from both manufacturers by the early 1970s.

Around the same time, a major new market developed for minicomputers equipped with VDUs, as front-end processors (FEPs) in mainframe electronic data processing environments. FEPs were used to off-load some of the communications activities that a mainframe computer would otherwise have to maintain in order to support users' terminals. Several of the British minicomputer manufacturers developed FEP systems for use in conjunction with ICL 1900 series mainframes. Each company hoped that by developing a FEP package it would be able to sell several hundred units to existing ICL users. However, because all of the British manufacturers concentrated on designing ICL compatible systems, they soon found that the market was not large enough. In fact, it could only comfortably support a single player, who proved to be CTL - ICL bought minicomputers from CTL for use as FEPs, re-badging them to be sold as ICL systems. (This was a major market that sustained CTL until the early 1980s.) Converting FEP systems to work with different mainframes was the next task for the British companies. They hoped to exploit the market for IBM compatible front-end processors, but by the time they had developed their systems the US minicomputer manufacturers already dominated the market. It proved to be impossible for the British manufacturers to catch up, and these products had to be abandoned.

Within mainstream minicomputer markets the story was similar. Because a manufacturer's resources for software support tended to improve in direct proportion to the size of its installed user base, major players were the only ones able to continually expand the scope of their operations. British manufacturers did not have the resources to develop and maintain software for more than a few of the necessary application areas. The problem was exacerbated by the growth of mutual-support

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[46] See chapter 7, "The UK industry: 'Who the hell are CTL?'" of John Kavanagh, *Alien's Guide to the Computer Industry*, Reed Business Publishing, London, 1988. Systime was still conducting business until the early 1980s. See Tom Lester, "Systime's Big-Time Target", in *Management Today*, May 1981, pp. 55-59 and 146.

organisations such as DECUS, the DEC Users Group, which was a forum for the free exchange of software and advice. Not only could DEC provide software for most application areas, but in more esoteric fields DECUS could help new users to find or develop software.

The British manufacturers were inevitably concentrated in the niche markets on the one hand, and inexorably driven out of the major markets on the other. Arcturus went bankrupt in 1971, and shortly afterwards, in 1974, BCL went into receivership in the face of escalating software development costs. The company was rescued by an eleventh hour bid, and re-named Business Computers (Systems) Limited.[47] The new management transferred all outstanding software contracts to an OEM company, and restricted the new company to providing hardware without applications software, at least until the company was back on its feet.

Besides the changing market environment, the 1970s saw considerable changes in the political environment facing the minicomputer manufacturers. When Edward Heath's Conservative government had come into office in 1970, one of its first acts was to merge MinTech into the Department of Trade and Industry.[48] Conservative anti-interventionist policies, combined with the lack of a visible hand in the high-technology industries, left the British manufacturers experiencing a policy vacuum.[49] MinTech's aim to prevent DEC taking the lead in the minicomputer market had failed. Meanwhile other European countries had established their own champions: Intertechnique (France), Siemens (Germany), and Philips (Netherlands).[50] Government

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[47] The demise of BCL and rise of BC(S)L was widely reported in the trade press during 1974-75.

[48] By the end of the 1960s MinTech had itself absorbed a large part of the NRDC's responsibilities. See Great Britain Ministry of Technology, *The Ministry of Technology*, HMSO, London, 1967.

[49] The unstable economic environment in the 1970s compounded the problems faced by the British manufacturers. See George A. Luffman and Richard Reed, *The Strategy and Performance of British Industry, 1970-1980*, MacMillan, London, 1984.

[50] For a brief overview of the major European manufacturers see C. J. Fielden and D. P. Turtle, "New Challenge in Europe", in *Data Processing*, July-Aug. 1972, pp. 305-17.

attention was drawn back to the mainframe industry, or rather ICL, which was in financial trouble, while Rolls Royce faced similar problems. This was a politically damaging situation, and the decision was reluctantly made to support both "lame ducks". Set against this background, it is easy to assume that the government swept the minicomputer industry under the rug. In fact, most parliamentarians believed that the minicomputer industry was part and parcel of the mainframe computer industry. It was often said that Government computer policy began and ended with ICL. When the reports of the Select Committees in Science and Technology, 1969-70 and 1974, were published, they failed to differentiate the minicomputer industry, even though minicomputer manufacturers had presented memoranda. BCL tried to bring this issue to the attention of the government in 1972, when the company held a demonstration of their computers in a restaurant near the Palace of Westminster. It was attended by around fifty MPs, many of whom admitted that they had not realised that there were "other" (than ICL) British computer manufacturers.[51]

By 1974, when the Wilson government came back into office, the British minicomputer industry was in decline. Subsequently, Callaghan, who was uninterested in the computer industry, replaced Wilson. As far as the British computer manufacturers were concerned, the policy vacuum effectively continued. The lack of significant government involvement in the computer industry continued until 1978, when a Horizon programme, *Now the Chips are Down*, sparked interest in the formation of a British microprocessor manufacturer.[52] Any remaining concerns with the declining minicomputer industry became completely eclipsed by the ensuing debate which led to the creation of Inmos.[53]

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[51] Reported in *Computer Weekly*, (2nd March 1972), p. 11. See also Philip Siekman, "Europe's Love Affair with Bigness", in *Fortune*, Mar. 1970.

[52] See Tessa Blackstone and William Plowden, *Inside the Think Tank - Advising the Cabinet, 1971-1983*, Heinemann, London, 1988, and Peter Henessey *et. al.*, *Routine Punctuated by Orgies: The Central Policy Review Staff, 1970-1983*, University of Strathclyde, 1985. The impact of the Horizon programme was the subject of *Images and Innovation*, an Open University broadcast in 1986.

[53] Iann Barron returned to prominence in the British computer industry as one of the three founders of Inmos. See McLean and Rowland, *The Inmos Saga: A*

Discussion

The relative failure of the British minicomputer industry can be best explained by comparing the operating environments in Britain and the United States. There were two significant differences: the size of the potential market in the United States was many times larger than in Britain; and the British manufacturers had a tendency toward niche specialisation that was absent in the larger US companies. Market size, combined with a high level of government sponsorship is generally cited as the reason for the United States' dominance of the world mainframe market.[54] However, government support can be discounted as a major factor in the minicomputer industry, in which the market was larger, development times were shorter, and unit costs were lower. For example, DEC took the lead in the industry without receiving any direct US government development grants.[55]

The disparity between the British and US market sizes was clearly a very important factor that allowed the US manufacturers to consolidate their head start. There was also a technology lag between Britain and the United States, believed to be about three years in the late 1960s, with most other European countries a further year

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Triumph of National Enterprise?; Kelly, *The British Computer Industry: Crisis and Development*, p.107; Paul Stoneman, *Technical Diffusion and the Computer Revolution: The UK Experience*, Cambridge University Press, 1976; John Redwood, *Going for Broke - Gambling with Taxpayers' Money*, Blackwell, Oxford, 1984; and E. Sciberras, "The UK Semiconductor Industry", in Keith Pavitt (ed.), *Technical Innovation and British Economic Performance*, MacMillan, London, 1981.

[54] Flamm, *Creating the Computer*; and Kenneth Flamm, *Targeting the Computer: Government Support and International Competition*, The Brookings Institution, Washington, DC, 1987; and Steven W. Usselman, "IBM and Its Imitators: Organisational Capabilities and the Emergence of the International Computer Industry", in *Business and Economic History*, Vol. 22, No. 2,Winter 1993.

[55] Rifkin and Harrar, *The Ultimate Entrepreneur*. See also: Flamm, *Targeting the Computer*. US government defence project funding, essentially to IBM's R&D, was more than the entire British computer industry's turnover during the 1960s.

behind Britain.[56] With a larger market the US companies were able to achieve economies of scale that were simply not possible in Europe, and their advantages continued to grow as the result of a "learning effect", by which companies with significant market share in high-technology industries are able to benefit from a combination of economies of scale and scope. The prominence of user groups and their product evangelism was a further factor, which amounted to valuable free advertising. By the late 1960s this combination of factors was enough to discourage most new entrants to the industry.

Like many high-technology industries with a few dominant companies, a crucial issue to the computer industry is "lock-in". This is a positive feedback mechanism that arises because existing users of a particular system are economically disadvantaged to change to a competitor's system.[57] Through this mechanism, any company that gains some small competitive advantage early in the development of a market can rapidly become the market leader. Furthermore, the dominant company will set the industry's standards, forcing the smaller companies into niche markets. This pattern was clearly evident as DEC overtook its competitors.

British manufacturers certainly had a tendency towards niche specialisation. They had very strong perceptions of the market when they began selling minicomputers in the 1960s. The start-ups, CTL, Digico, and Arcturus, saw them as tools for use in laboratories, and to a lesser extent as process controllers. The diversified electronics corporations, Ferranti, GEC, and Plessey, on the whole saw minicomputers as controllers for factory automation. BCL, the office equipment company, saw them as business data processing machines. In other words, each of the companies saw the use of minicomputers in a frame of reference that was coloured by its own organisational perspective. Consequently, when they first began to market their systems, they targeted companies with similar organisational cultures to themselves,

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[56] For a discussion of the technology lag see Ernest Braun and Stuart MacDonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics*, Cambridge University Press, 1978, p. 146.

[57] See W. Brian Arthur, "Self-Reinforcing Mechanisms in Economics", in Philip W. Anderson, Kenneth J. Arrow, and David Pines (eds.), *The Economy as an Evolving Complex System*, Addison-Wesley, Reading, MA, 1988.

although not necessarily in the same field. For example, CTL sold to university laboratories, Ferranti sold to companies such as ICI, while BCL sold to small businesses. As Geoffrey Foster wrote in 1973,

> It is difficult to escape the impression that, through its brief history so far, the company [CTL] has been overly fascinated by the technical brilliance of its achievements and insufficiently precise about their practical application.[58]

Or perhaps even more tellingly, as Bob Finch (Managing Director of CTL in the early 1980s) said,

> Out of 20 academic institutions, I'd be surprised if one hadn't heard of us. Out of 20 businesses, I'd be surprised if more than one had.[59]

For the British companies, similar organisations were simply within the easiest markets to approach at first. But meanwhile, US companies such as DEC were not restricting their focus on particular user groups. Or, as Olsen later said, "I believe technology is everything – if you design a good enough product you don't even need a salesman."[60] Furthermore, the concentration of the British companies into niche markets could be attributed in part to tension between the companies' technological mission and its investors, who tended to be economically cautious. This led to a lack of investment at a crucial time during the first few years of the industry, when the British companies should have been trying to broaden their markets. They never achieved sufficiently large volumes of sales to engage in price competition with the rival US companies, so were forced in the late 1970s to compete by providing greater levels of service.

With the exception of the shared development grants, it is difficult to criticise government involvement with the minicomputer industry. Although the Wilson and Heath governments had completely different ideologies in terms of intervention, their goals for the computer industry had much in common. In both cases the main concern was to modernise British industry, and secondly, to help British computer companies to defend against US competition. Each of these aims was evaluated in a wider

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[58] Geoffrey Foster, "Britain's Electronic Davids".

[59] Sandy Porter, "CTL's Second Coming", in *Management Today*, July 1980, pp. 70-75.

[60] Stratford P. Sherman, "Digital's Daring Comeback Plan", in *Fortune*, Vol. 123, Iss. 1, 14th Jan. 1991, pp. 62-65. (The quote is from p. 65).

economic context, which called for a satisfactory balance of payments in high-technology industries. Improving industrial efficiency through adoption of automation techniques took precedence over protecting the emerging minicomputer manufacturers. This meant that efforts to restrict foreign competition, such as the imposition of import tariffs, were out of the question even if British governments had not been afraid that the US government would retaliate by restricting technology transfer.

While a national champion policy was never promoted within the minicomputer industry, as it had been in the mainframe industry, MinTech did attempt to promote product champions - companies that would, between them, cover the entire field of minicomputers without competing directly with one another. However, the British companies ignored the government overtures because they believed that the government was ill informed, and that their directors were better placed to make commercial judgements than civil servants. This belief was clearly unfounded because even if it is granted that the average parliamentarian did not recognise the distinction between the minicomputer and mainframe industries, it was not the average parliamentarian that tended to have contact with the industrialists. Rather, it was the well-informed civil servants within MinTech and the NRDC.[61] The proposals made to the manufacturers were strategically justifiable, but the leverage applied by MinTech was minimal. Nevertheless, it could be argued that MinTech's policy failure occurred principally because the proposals were advanced too late, and that it might have been considerably more successful if they had been revealed earlier. It is interesting to note that the role of MinTech, originally intended to be the government's arm in high-technology industry, was often reversed so that rather than operating as a tool for industrial intervention it was a conduit of information to keep the ministers up to date with technology.[62]

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[61] Coopey notes that fully 50 per cent of the top 100 MinTech staffs were from a science background. R. Coopey, "Industrial Policy in the White Heat of the Scientific Revolution", in Coopey, *Wilson Governments*, p. 119.

[62] This perspective is often ignored in analyses of MinTech's involvement in the computer industry. Interview with Jeremy Bray, 25 Oct. 1994; Laver, personal correspondence.

One might ask why customers bought British minicomputers at all. Within the public sector, procurement policies favoured British mainframe manufacturers throughout most of the period, but they were less prescriptive regarding minicomputers.[63] In the private sector, the main attraction was that British companies could offer support services far more easily than the US companies; even those that had set up subsidiaries within Britain. Private companies tended to buy British equipment and pay extra for extended service contracts, even though the systems themselves were often more expensive than the US ones. Was this an optimal strategy for the users, or would they have been better served by buying the less expensive US built equipment? Unfortunately, in most cases it would have been less expensive for British companies to have bought the systems that were becoming recognised standards, and to have risked problems with service, than to stick with systems that would eventually become unsupported, then later be forced to change to an alternative system.

In conclusion, while many political and industrial pundits would assert that the British minicomputer industry was a failure, this claim is based on a somewhat simplistic criterion of success: that Britain should have a national champion that is also a significant global player. This was certainly never the case for any of the British minicomputer manufacturers. However, if we consider the broader aims of governments during the 1960s and early 1970s, we see that there were two principal objectives of technology policy: to promote the use of new technologies in industry, in order to improve Britain's industrial competitiveness; and to reduce the balance of payments in high-technology products by supporting indigenous manufacturers. To achieve the first goal, it was simply necessary for British industry to be investing in minicomputers, regardless of their country of origin. Clearly this was the case: while fewer British-built than US-built minicomputers were sold in Britain, British industry did invest in a large number of systems (Figure 5.1). Furthermore, the second goal - to reduce the balance of payments in high-technology products - was never relevant to the British minicomputer industry because it relied on electronic components imported from the United States. In fact, for each British minicomputer system sold, the largest

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[63] See Jill Hills, *Information Technology and Industrial Policy*, Croom Helm, London, 1984, pp. 156-8.

value-added part was in service and support, rather than in manufacturing. Accordingly, the service emphasis of the British manufacturers was particularly apt. It was only possible to reduce support costs by achieving high volume sales, so while their US counterparts concentrated on volume sales with minimum after-sales service, the British firms were rational to adopt a strategy of providing complete business solutions by offering individually customised software packages. Seen from this perspective, it is apparent that the British firms never intended to compete on the same terms as DEC, Data General, and the other major US players. Rather, they were quite content to develop locked-in niche markets, which would provide a regular income sufficient for modest growth in the long term.

Chapter 6 - Conclusion

Analysis of the Principal Themes

In the preceding chapters the history of the development of process control technology in Britain has been traced from the origins of the automation concept, through the automation hysteria of the 1950s and the early development of numerical control technology, up to the evolution of the minicomputer. In each case the analysis has been driven by two key themes: the notion of failure, with the implicit assumption that any industry which is not a world leader should be considered a failure; and the role of control technology with respect to Britain's industrial decline. In this concluding chapter I will present some final remarks on each of the themes, then explore some of the further research questions that are raised by this thesis.

Another Failure Study?

It is important to note that in both the early British N/C machine tools industry and the minicomputer industry, the failure has not been at the level of the firm, but rather at a national level. That is, some of the firms have been modestly successful, but in each case the market leaders have been non-UK firms. For minicomputers, the leaders were the US start-ups that had access to larger markets and earlier access to new technologies. For N/C-machining technology, which took longer to become established, the eventual market leaders were the Japanese companies responding to a local demand for flexible manufacturing systems, as described in more detail later. Nevertheless, in each example area the flagship British companies - Ferranti with its N/C business, and CTL with its minicomputers - were moderately successful even though the industry itself would be considered a national failure.

As described in Chapter 4, Ferranti first developed its N/C technology in response to internal demands - the company had a shortage of skilled machinists, required for the manufacture of RADAR wave-guides. Ferranti's N/C system was more sophisticated than any of its contemporaries, requiring access to a (Ferranti) mainframe computer in order to generate the control tapes, and this was probably one of the major reasons for its disappointing take-up when it was first offered as a commercial system in the late 1950s. However, over the seven years from 1961 sales of Ferranti's N/C systems improved, increasing at an average rate of 24% per annum. Nevertheless, the operating costs and capital employed continued to rise at levels exceeding this.[1] In part the rising costs were due to an idiosyncrasy of Ferranti's organisational culture: the company typically aimed to integrate its systems with a customer's existing equipment. In the case of N/C systems, the result was that rather than develop self-contained packaged solutions, Ferranti found itself having to customise each system in order for the control unit to be connected to a company's existing machine tools. As we saw in Chapter 5, the same problem was simultaneously dogging the progress of Ferranti's minicomputer development. Throughout the entire lifetime of Ferranti's N/C development programme the issue of customisation was never satisfactorily resolved.

Ferranti's work in N/C technology was the last of the British systems developed in the mid-1950s to be abandoned, finally ending when the Wilson government's Industrial Reorganisation Corporation (IRC) turned its focus to the N/C machine tools industry. The IRC wanted to concentrate British N/C development in the hands of a single manufacturer, but it did not consider Ferranti a viable choice to champion the British industry because Ferranti was a private company with a relatively weak financial base.[2] Instead, the IRC arranged for Ferranti's N/C interests to be acquired by Plessey, which had recently become interested in N/C-machining technology. By the late-1960s the N/C market was finally becoming significant (see Figure 6.1), and Plessey had become actively engaged in acquisitions which would enable the company to exploit the new market. The Ferranti board's approval of the sale to Plessey aroused consternation amongst many of the Ferranti staff because they did not yet see Plessey as technologically competent in the field of numerical control. However, given the financial performance of the N/C product line, Ferranti's management had clearly been offered a rational opportunity to divest itself of an unprofitable business, and there was the added assurance that Plessey would continue

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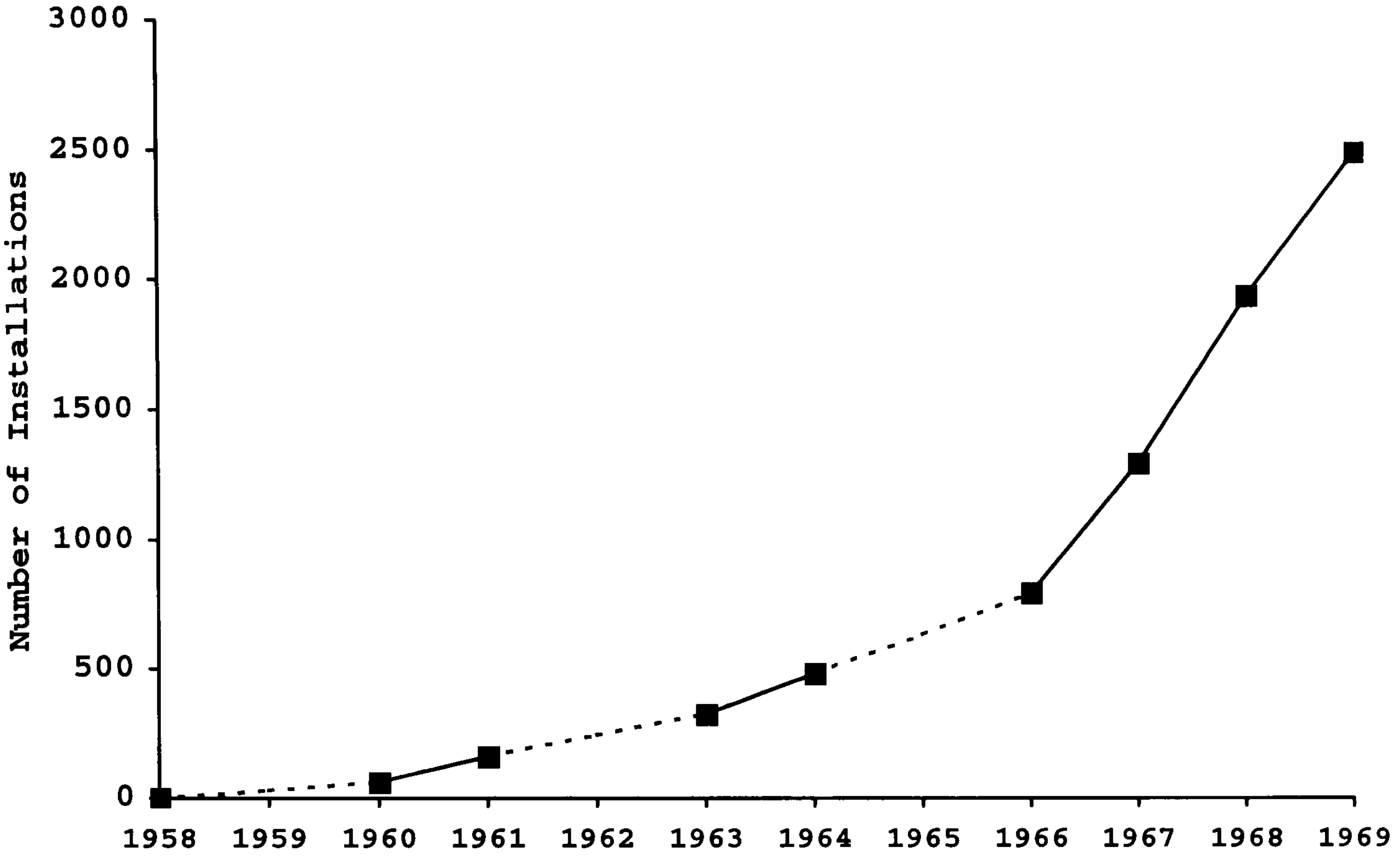
[1] The figures are taken from John Wilson's manuscript, Chapter 11, "The Ferranti Dilemma". It should be noted that these figures do not take into account the internal benefits that Ferranti enjoyed from the use of the equipment in RADAR production at its Crewe Toll manufacturing centre.

[2] Wilson manuscript, Chapter 11, "The Ferranti Dilemma".

to develop the technology. So, in 1969, about fifteen years after the work had started, Ferranti's N/C developments came to a profitable, if not universally satisfactory conclusion.



Notes

Installations = manufacturers' output, less exports, plus imports. 1958 has been chosen as a base year at which there were no installations. The source does not give figures for 1959, 1962, and 1965.

Source

The figures are attributed to Ministry of Technology Statistics by Bell, *Changing Technology and Manpower Requirements in the Engineering Industry*, SPRU Research Report No. 3, Sussex University Press, 1972, p. 35.

Figure 6.1 United Kingdom Annual N/C installations (cumulative)

Looking again at the minicomputer industry, the flagship manufacturer was undoubtedly CTL, the mid-1960s entrepreneurial start-up that was based on a strong technical team with experience in the automation industry. Throughout the 1970s the company operated with modest success within a number of small niche markets, while its American competitors continued to grow and to encroach on the mainframe market.

In 1980, two new sibling companies for CTL were created, Office Technology Limited (OTL) and Network Technology Limited (NTL), and all three companies were placed under the control of a holding company, Information Technology Limited (ITL). A year later ITL appointed the entrepreneur Tony Davies as its Managing

Director. Davies had already successfully built a computer company, MemBrain, which he had created in the early 1970s, and he was a prominent and respected figure in the computer industry - later that year he became an advisor to the Information Technology Minister, Kenneth Baker. Davies sold his interests in MemBrain in order to raise £2,000,000, which he then used to buy in to ITL and secure his position as MD.

Davies' influence on the technical direction of CTL was profound. Under his control the company changed tack entirely and began operating as an OEM house - that is, buying in hardware from other companies, to be re-badged as CTL systems.[3] Davies had acknowledged that CTL was not able to develop a wide enough range of its own hardware to compete at every level in the minicomputer market. By selling OEM systems, Davies argued that it was possible to broaden the scope of CTL's operations by offering a wider range of bespoke solutions. It was a major change in emphasis for the company, which had always relied on its own technical capabilities to develop new products. The first OEM deal was struck with Convergent Technologies of Santa Clara, to sell a small workstation (itself based on an outsourcing arrangement with Intel, which supplied 8086 microprocessors). For the first time, CTL had a product which could compete on price as well as technology with a system from

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[3] In Chapter 5, there was a brief reference to the OEM companies, such as Systime, who provided bespoke system solutions using off-the-shelf hardware, typically from DEC and Data General. In many respects, OEM companies were more successful than the British minicomputer manufacturers. They also provided competition for the British manufacturers on two fronts, as both a local supplier of software services, and as an importer of hardware built by the American competitors. The importance of OEM companies is extremely difficult to quantify because their sales figures are closely tied to the imports of DEC and Data General systems. Furthermore, analysis of their technical contribution involves the investigation of software rather than hardware technology, a notoriously difficult task because of the transient nature of the subject.

DEC – the CTL/Convergent workstations were marketed at around 60% of the cost of their counterparts in the DEC range.[4]

The new strategy was successful, and CTL's fortunes improved, but Davies still claimed to be dissatisfied with the company's functional organisation, and in 1984 he initiated a restructuring of ITL. Under Davies' direction the three companies, OTL, CTL, and NTL, came together as a single organisation based on a functional structure. He rationalised the decision in terms of a need to improve efficiency and centralise manufacturing facilities. However, Bob Finch - who headed CTL at the time - says that with hindsight it is obvious that the changes were Davies' attempts to position the company in preparation for his private plan to make a public share offering.[5] Nevertheless, the result was five more years of profitable trading, although predominantly in supporting CTL's existing locked-in customer base. A share issue was made in 1987, followed by an acquisition, in 1989, by ACT (the parent of the Apricot Computer company). CTL ceased operating as a systems vendor - ACT's acquisition had been simply to gain access to CTL's extensive customer support network, rather than to extend its existing user base. The purchase by ACT marked the end of CTL's involvement in the minicomputer industry, almost exactly twenty-five years after the company had been formed.

Control Technology and Industrial Decline

It is easy to fit both the British minicomputer and N/C industries within the narrow definition of failure. However, while it can be argued that the local market was never quite large enough to sustain a viable British minicomputer industry in the face of competition from US companies, the failure of British N/C technology is harder to justify. The root of the failure was managerial conservatism, which was particularly manifested when the conventional machine tool manufacturers declined to support the electronics firms until the N/C market had become sufficiently mature.

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[4] In fact this particular deal was not particularly lucrative because a year later NCR bought Convergent Technologies, and began marketing the systems directly in the UK.

[5] Interview with Bob Finch, (CTL Managing Director, 1981-1985), 23rd Mar. 1994.

N/C controllers had to be integrated with conventional machine tools, which were necessarily built by mechanical engineering rather than electronics firms. Accordingly, for an electronics firm to successfully promote N/C technology it had to gain the co-operation of both the end-user and a conventional machine tool manufacturer. But, in the 1950s, as described in Chapter 4, the conventional machine tool manufacturers were not receptive to the concept of N/C technology, not least because they were operating in a comfortable seller's market. As Table 6.1 shows, the value of the machine tool industry's order book in the mid-1950s was increasing faster than its output.

Table 6.1 United Kingdom Machine Tool Industry - Orders Placed, Deliveries, and Order Book at Year End, 1953-55

Year	Orders Placed (£m)	Output (£m)	Order Book (£m)
1953	52.7	66.2	72.3
1954	78.9	65.6	81.0
1955	98.2	75.4	100.2

Source

Anon, *The United Kingdom Machine Tool Industry*, Pidgeon and Stebbing, London, 1959, p. 76.

It is crucial to note that contemporary critics were aware of the conservatism of the machine tool manufacturers. The report of a TUC meeting, held in Coventry in 1958, and attended by representatives of local machine tool manufacturers - including Alfred Herbert – further illustrates the significance of the seller's market:

> The general picture which emerged from the discussion was that up to recent months machine tool firms had large order books and were quite happy to plod along on low levels of output, dictating the terms under which customers could have machines. Profit margins were wide and the bulk of Management complaisant.[6]

The most direct implication of the conventional machine tool manufacturers' failure to adopt a forward-looking strategy was that the electronics firms developing new control technologies were completely unable to gain access to the mainstream

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[6] See MSS.292/571.81/5B, (Trade Union Policies on Automation, 1956-60). Summary report of CSEU meeting held in Coventry on 16th Jan. 1958.

machine tools sales conduits. As a result, by the early 1970s there were no remaining indigenous manufacturers of N/C technology in the UK.[7] Meanwhile, Japan had risen from a position of obscurity in the production of machine tools, to become the world's second largest exporter (after West Germany). The key to the success of the Japanese N/C industry had been the sudden growth of domestic demand for flexible manufacturing systems. By the late 1970s, over one third of Japanese machine tool exports were numerically-controlled systems, which had been re-christened Computer Numerical Controlled, or CNC systems. By 1982, Japan's production of CNC systems alone was greater than the total output of all types of tool made by the British machine tool manufacturers.[8] Table 6.2 shows the impressive growth rate achieved by the Japanese industry during the 1970s.

Table 6.2 World Market Shares of the Main Exporting Countries (percentages)

	1966	1976	1978	1980	1982
Germany, East	9.0	10.9	6.8	6.3	6.7
Germany, West	27.2	31.0	30.8	26.3	24.2
Italy	5.5	6.5	7.4	7.5	7.9
Japan	3.3	6.5	12.6	13.1	13.4
Switzerland	7.5	8.0	8.1	8.1	7.1
UK	7.5	5.3	5.3	6.1	5.1
USA	14.1	9.6	6.9	6.7	6.7
Total (%)	74.1	77.8	77.9	74.1	71.1

Source

OECD, 1984 and NMTBA, 1982. Taken from Sciberras and Payne, *Machine Tool Industry*, 1985, p. 32.

In other words, by the mid-1980s there was a major global market for N/C, or CNC, systems. This was a technology in which several British firms could have had, at the very least, a head start, given a proven ability to innovate and develop. As

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[7] See also E. Sciberras and B. D. Payne, *Machine Tool Industry: Technical Change and International Competitiveness*, Longman, Harlow, 1985, p. 38.

[8] Sciberras and Payne, *Machine Tool Industry*, pp. 34-35.

Sciberras and Payne have noted, there had been neither technical nor economic barriers to prevent companies outside of Japan from developing competitive systems in the early 1970s. Nevertheless, in Britain the opportunity had been lost through a combination of the technological development peaking too early and the conservatism of the conventional machine tool manufacturers. Or, as Sciberras and Payne similarly concluded:

> The most significant factors appear to have been the attitudes or strategies of the NC suppliers and the relationships between the suppliers and the machine tool industry in the different countries. [9]

Further Research Questions

Automation is a catch-all term that encompasses a broad range of sociological and technological phenomena. In this thesis just two themes, industrial failure and relative economic decline, have been explored. The result is that throughout each of the three main chapters (3 to 5) there are a number of briefly considered issues which could open into broader subject areas and raise questions that deserve further exploration. Four of these are discussed here: the significance of rhetoric in the course of the automation hysteria; the role of British military procurement in the development of control technologies; a wider analysis of the world machine tool and minicomputer markets; and the role of users' demands in the direction of technological development, particularly with respect to the machine tool industry.

First, there is the significance of rhetoric in the automation hysteria discourse. Early in Chapter 3, while discussing the automation hysteria, there were references to widely used notions of a "second industrial revolution" and an "age of automation". The examination of the automation hysteria would benefit from a more in-depth analysis of the cultural significance of themes such as the technology crisis, the information revolution, and the automation age, all of which featured prominently in automation literature. The central question to be answered is: Was the widespread use of these themes merely rhetorical, and a deliberate attempt to grab headlines, or did they have some greater significance, and represent new ways in which technologies were being assimilated into society?

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[9] Sciberras and Payne, *Machine Tool Industry*, p. 40.

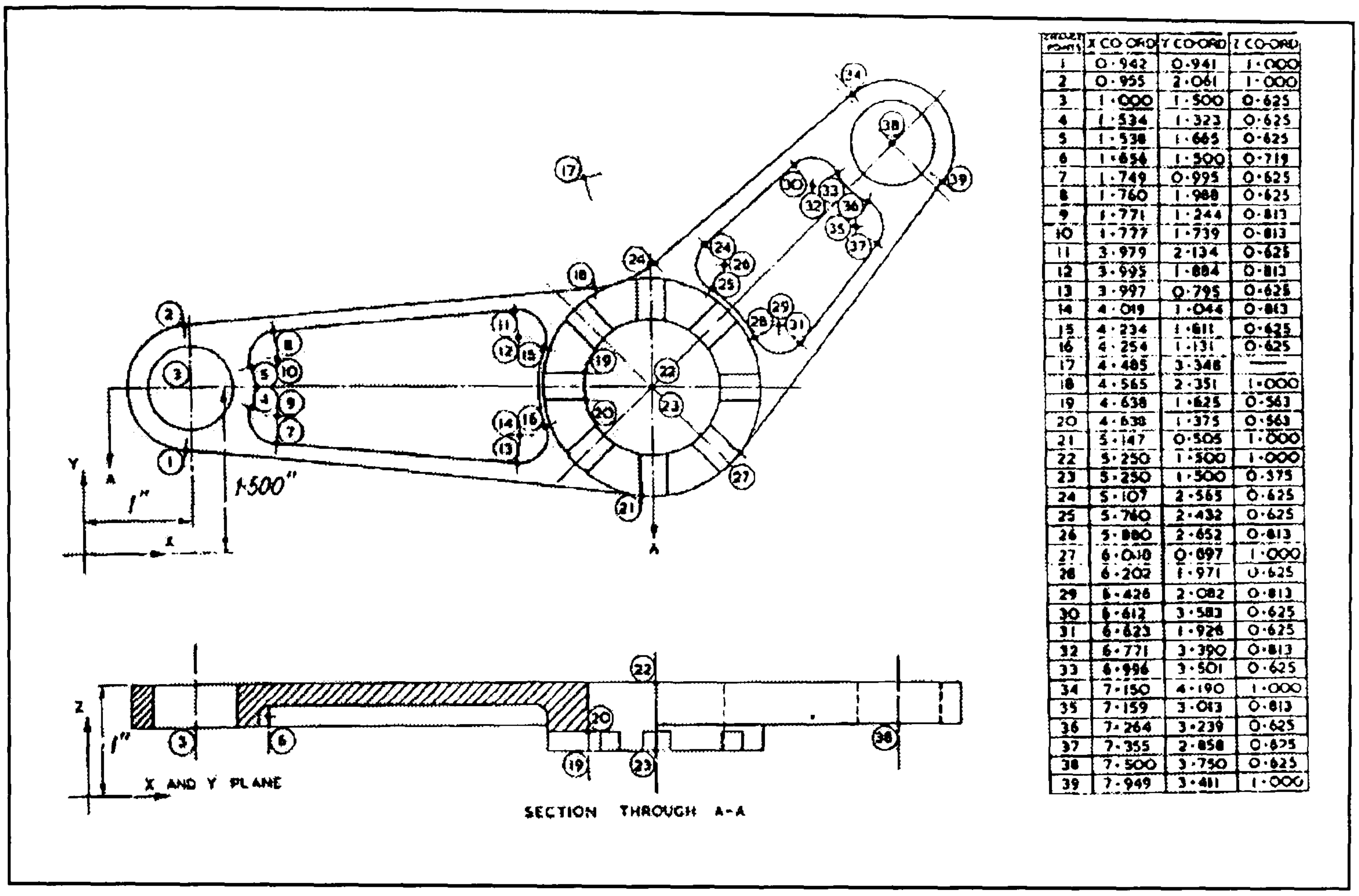
Next, there is the role of military procurement on British technological developments. In Chapter 3, and again in Chapter 5, the significance of the Cold War was considered within a context of competitiveness fears. However, I discounted the role of military procurement in the direction of technological development on the basis that military sales during the formative years of N/C and minicomputer technologies were relatively small. Nevertheless, because the subject of the military influence dominates American scholarship on control technology, in order to integrate this thesis more strongly with existing literature in the history of automation it would be appropriate to look more closely at the role of British military procurement, particularly in the early Post-War period.

The third further research question concerns the wider international scope of N/C and minicomputer developments. The bulk of the thesis focuses on the British and to a lesser extent the US industries. It is appropriate for the analysis of the minicomputer industry to concentrate on developments in Britain and the United States because there were no significant European imports or exports in the early 1970s. However, much of the analysis of the development of N/C machine tools in Chapters 3 and 4 would benefit from a broader international perspective. In particular, the developments in the Japanese and German (both East and West) machine tool industries were undoubtedly more significant than their omission suggests. Some brief investigation reveals that the earliest Japanese developments in N/C technology were contemporary with the first British and American research programmes. Given the eventual domination of the world market by Japanese manufacturers it is clear that a detailed analysis of the early work in Japan would be valuable.

Finally, and most significantly, there is the role of users' demands in the development of control technologies. Throughout Chapters 3 and 4 the automation hysteria is considered in terms of its inputs, which are divided into two groups - alarmists and positivists - both of which published prolifically, and hence dominate the historical record. However, a third group, which was equally important, but which exerted its influence by its market behaviour rather than by publishing commentaries, was that of the users and purchasers of automation equipment. The most rewarding further research area must surely be the investigation of the influence of major purchasers of automation equipment, such as automobile or aircraft manufacturers, on the marketing strategies and technical direction of the electronics firms that created these new control technologies.

PAGE
NUMBERING
AS ORIGINAL

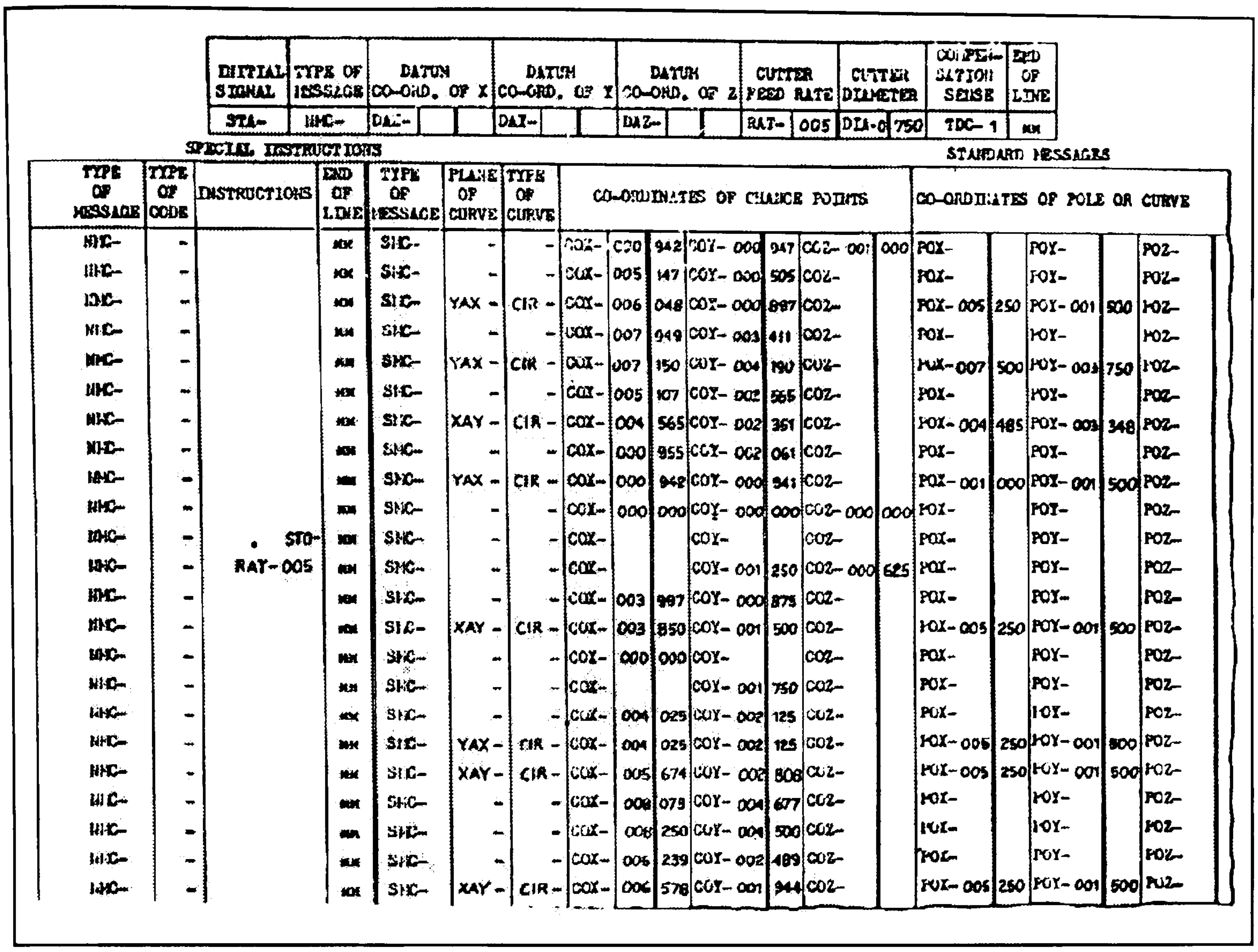
Appendix A – Illustrations



[illegible]	X CO-ORD	Y CO-ORD	Z CO-ORD
1	0·942	0·941	1·000
2	0·955	2·061	1·000
3	1·000	1·500	0·625
4	1·534	1·323	0·625
5	1·538	1·665	0·625
6	1·656	1·500	0·719
7	1·749	0·995	0·625
8	1·760	1·988	0·625
9	1·771	1·244	0·813
10	1·777	1·739	0·813
11	3·979	2·134	0·625
12	3·995	1·884	0·813
13	3·997	0·795	0·625
14	4·019	1·044	0·813
15	4·234	1·611	0·625
16	4·254	1·131	0·625
17	4·485	3·348	—
18	4·565	2·351	1·000
19	4·638	1·625	0·563
20	4·638	1·375	0·563
21	5·147	0·505	1·000
22	5·250	1·500	1·000
23	5·250	1·500	0·375
24	5·107	2·565	0·625
25	5·760	2·432	0·625
26	5·880	2·652	0·813
27	6·010	0·097	1·000
28	6·202	1·971	0·625
29	6·426	2·082	0·813
30	6·612	3·583	0·625
31	6·623	1·928	0·625
32	6·771	3·390	0·813
33	6·996	3·501	0·625
34	7·150	4·190	1·000
35	7·159	3·013	0·813
36	7·264	3·239	0·625
37	7·355	2·858	0·625
38	7·500	3·750	0·625
39	7·949	3·411	1·000

The Planning Sheet for a lever workpiece to be machined using the Ferranti N/C system.

Figure 4.1 A Typical Ferranti "Planning Sheet"



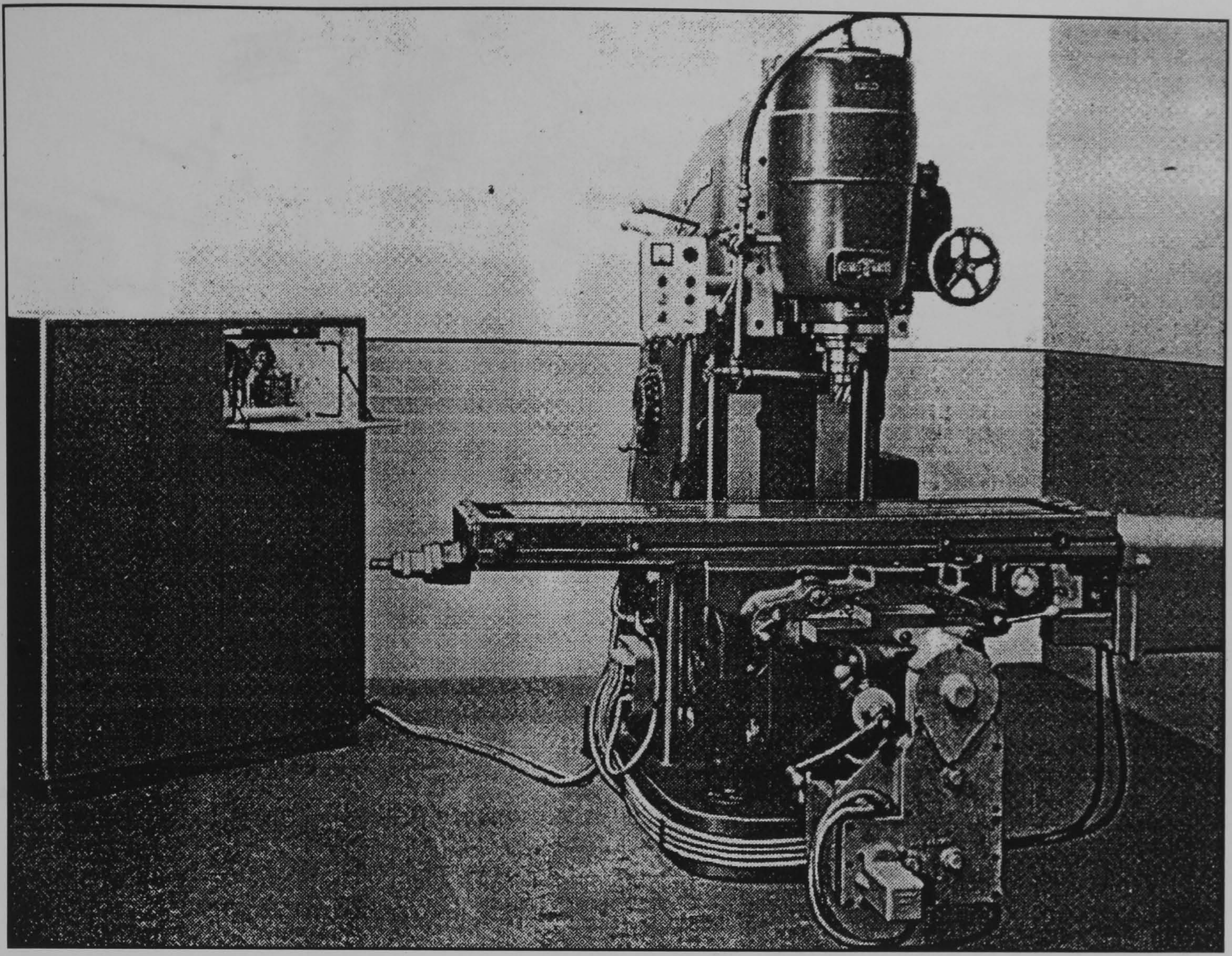
INITIAL SIGNAL	TYPE OF MESSAGE	DATUM CO-ORD. OF X			DATUM CO-ORD. OF Y			DATUM CO-ORD. OF Z			CUTTER FEED RATE		CUTTER DIAMETER		COMPENSATION SENSE	END OF LINE
STA-	NMC-	DAX-			DAY-			DAZ-			RAT-	005	DIA-0	750	TDC- 1	**

SPECIAL INSTRUCTIONS

STANDARD MESSAGES

TYPE OF MESSAGE	TYPE OF CODE	INSTRUCTIONS	END OF LINE	TYPE OF MESSAGE	PLANE OF CURVE	TYPE OF CURVE	CO-ORDINATES OF CHANCE POINTS							CO-ORDINATES OF POLE OR CURVE				
NMC-	-		**	SMC-	-	-	COX-	000	942	COY- 000	947	COZ- 001	000	POX-		POY-		POZ-
NMC-	-		**	SMC-	-	-	COX-	005	147	COY- 000	505	COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	YAX -	CIR -	COX-	006	048	COY- 000	897	COZ-		POX- 005	250	POY- 001	500	POZ-
NMC-	-		**	SMC-	-	-	COX-	007	949	COY- 003	411	COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	YAX -	CIR -	COX-	007	150	COY- 004	190	COZ-		POX- 007	500	POY- 003	750	POZ-
NMC-	-		**	SMC-	-	-	COX-	005	107	COY- 002	565	COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	XAY -	CIR -	COX-	004	565	COY- 002	351	COZ-		POX- 004	485	POY- 003	348	POZ-
NMC-	-		**	SMC-	-	-	COX-	000	955	COY- 002	061	COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	YAX -	CIR -	COX-	000	942	COY- 000	941	COZ-		POX- 001	000	POY- 001	500	POZ-
NMC-	-		**	SMC-	-	-	COX-	000	000	COY- 000	000	COZ- 000	000	POX-		POY-		POZ-
NMC-	-	• STO-	**	SMC-	-	-	COX-			COY-		COZ-		POX-		POY-		POZ-
NMC-	-	RAT- 005	**	SMC-	-	-	COX-			COY- 001	250	COZ- 000	625	POX-		POY-		POZ-
NMC-	-		**	SMC-	-	-	COX-	003	987	COY- 000	875	COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	XAY -	CIR -	COX-	003	850	COY- 001	500	COZ-		POX- 005	250	POY- 001	500	POZ-
NMC-	-		**	SMC-	-	-	COX-	000	000	COY-		COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	-	-	COX-			COY- 001	750	COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	-	-	COX-	004	025	COY- 002	125	COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	YAX -	CIR -	COX-	004	025	COY- 002	125	COZ-		POX- 005	250	POY- 001	800	POZ-
NMC-	-		**	SMC-	XAY -	CIR -	COX-	005	674	COY- 002	808	COZ-		POX- 005	250	POY- 001	500	POZ-
NMC-	-		**	SMC-	-	-	COX-	008	075	COY- 004	677	COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	-	-	COX-	008	250	COY- 004	500	COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	-	-	COX-	006	239	COY- 002	489	COZ-		POX-		POY-		POZ-
NMC-	-		**	SMC-	XAY -	CIR -	COX-	006	578	COY- 001	944	COZ-		POX- 005	250	POY- 001	500	POZ-

Figure 4.2 The "Programme Sheet" for the Part Shown in Figure 4.1



The EMI control system connected to a Cincinnati No. 3 Vertical Miller.

Figure 4.3 An EMI N/C Machining System

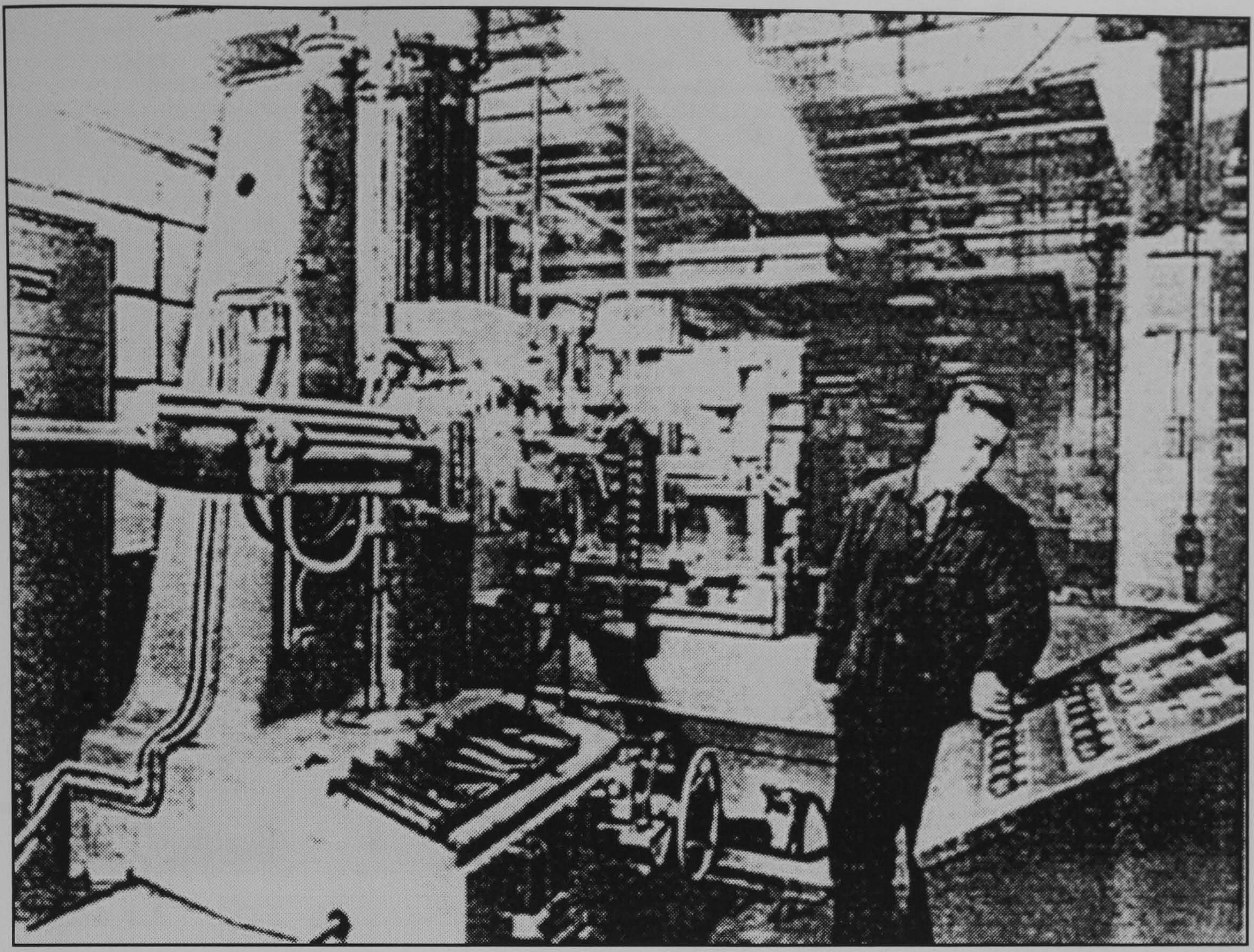


Figure 4.4 The BTH Punched Card Controlled Machining System on Trial at the British United Shoe Manufacturing Company

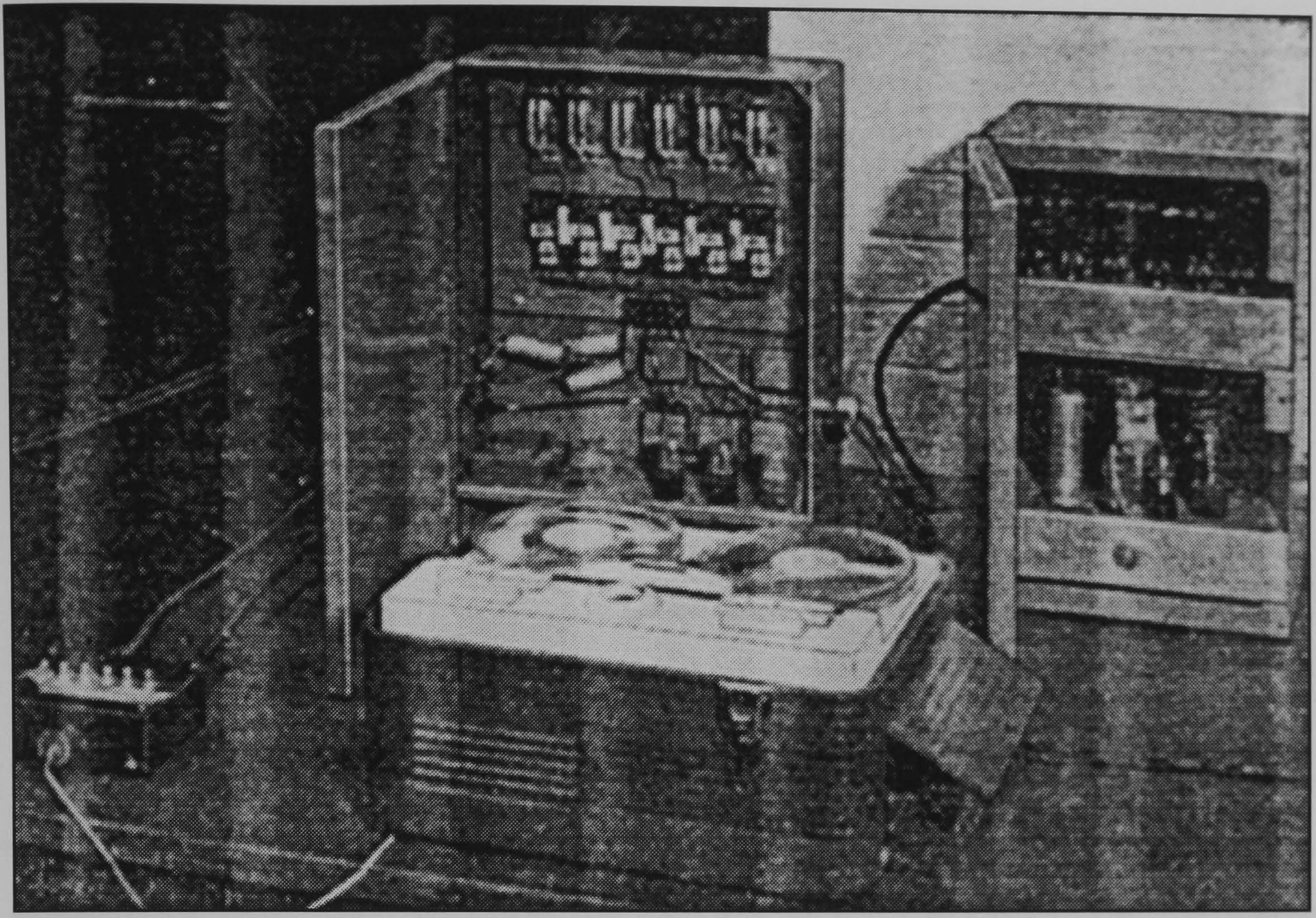
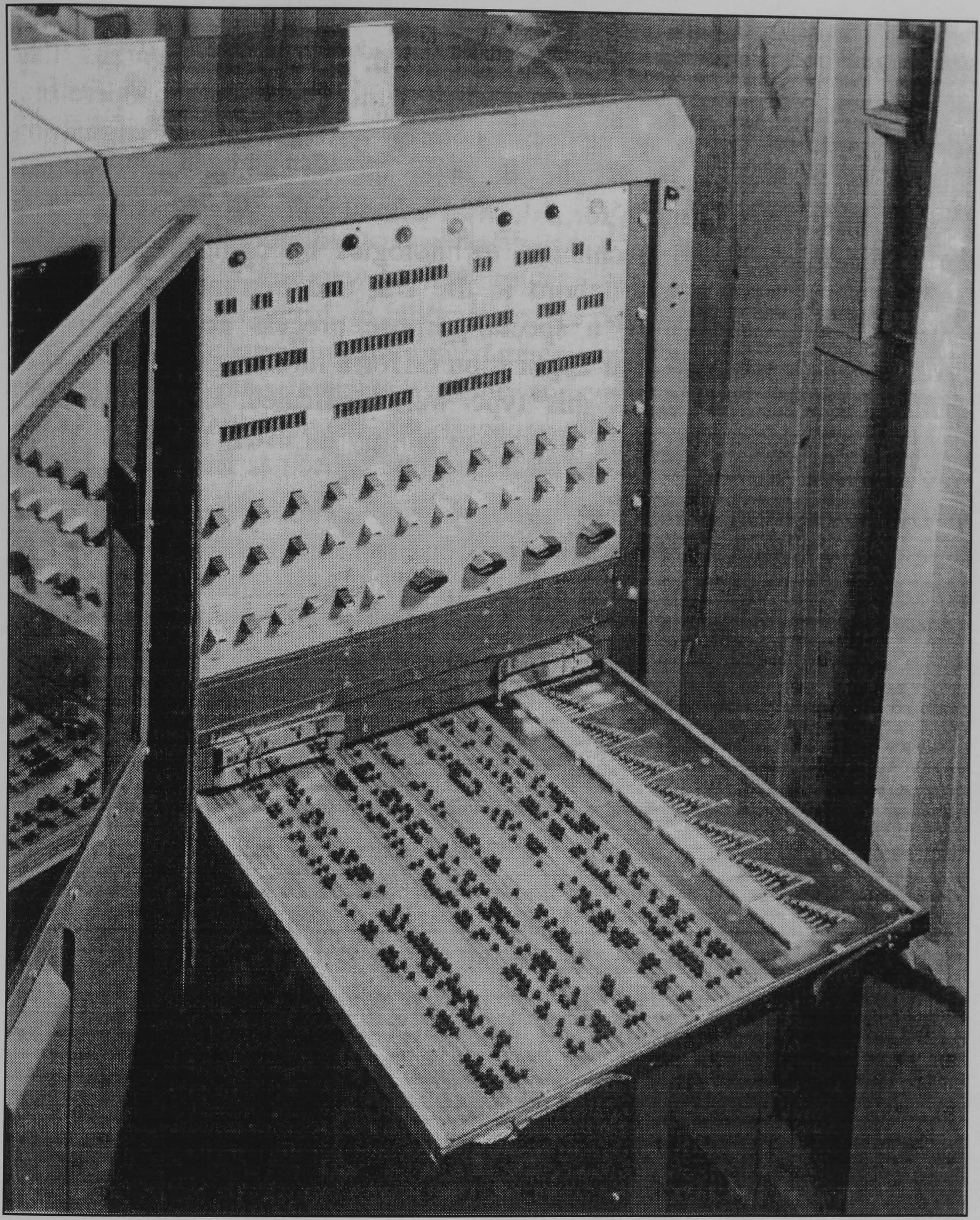
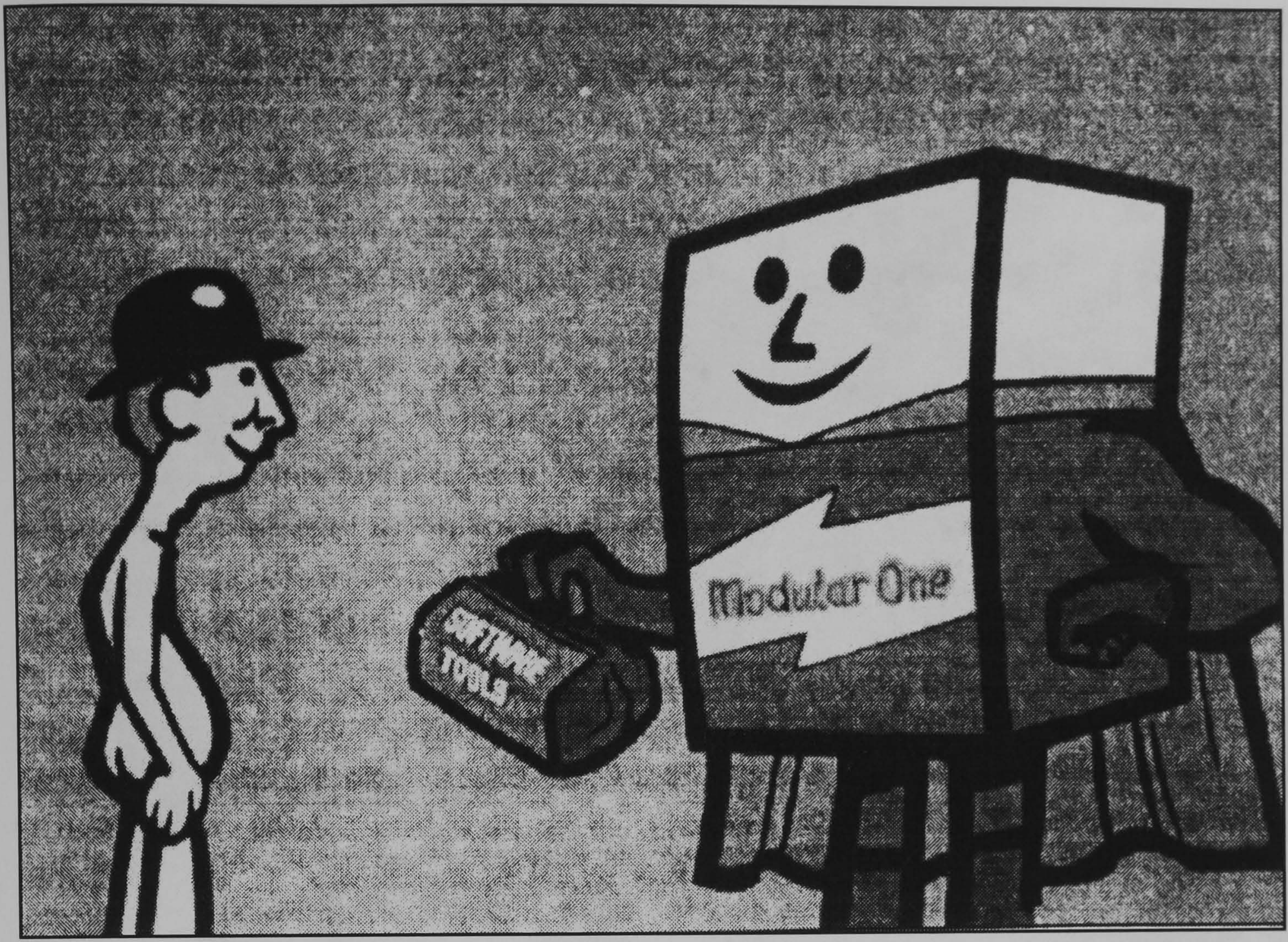


Figure 4.5 The Alfred Herbert Prototype N/C System



Special-purpose process control technology was still clearly evident in this 1961 Ferranti Argus 200 system. Programs were laboriously recorded in the read-only memory by placing thousands of pegs in instruction trays.

Figure 5.1 A Ferranti Argus 200 System



The British firms tried to expand into business markets by developing software tools and standard application packages. This c. 1971 cartoon appeared in a CTL trade brochure aimed at small/medium sized businesses

Figure 5.2 CTL Advertisement (circa 1971)

By the mid-1970s the minicomputer had displaced the mainframe in many commercial application areas, but the British firms were slow to address the new market. This artists impression, from a 1977 Digico trade brochure, shows a typical 'Electronic Office' based around a minicomputer system.

Figure 5.3 Digico Trade Brochure (1977)

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