THE DEVELOPMENT AND DIFFUSION OF INDUSTRIAL ROBOTS

Two Volumes

Volume II

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ANATOMY OF AN INDUSTRIAL ROBOT SYSTEM

FIGURE A1:1
BASIC HARDWARE ELEMENTS OF A ROBOT SYSTEM

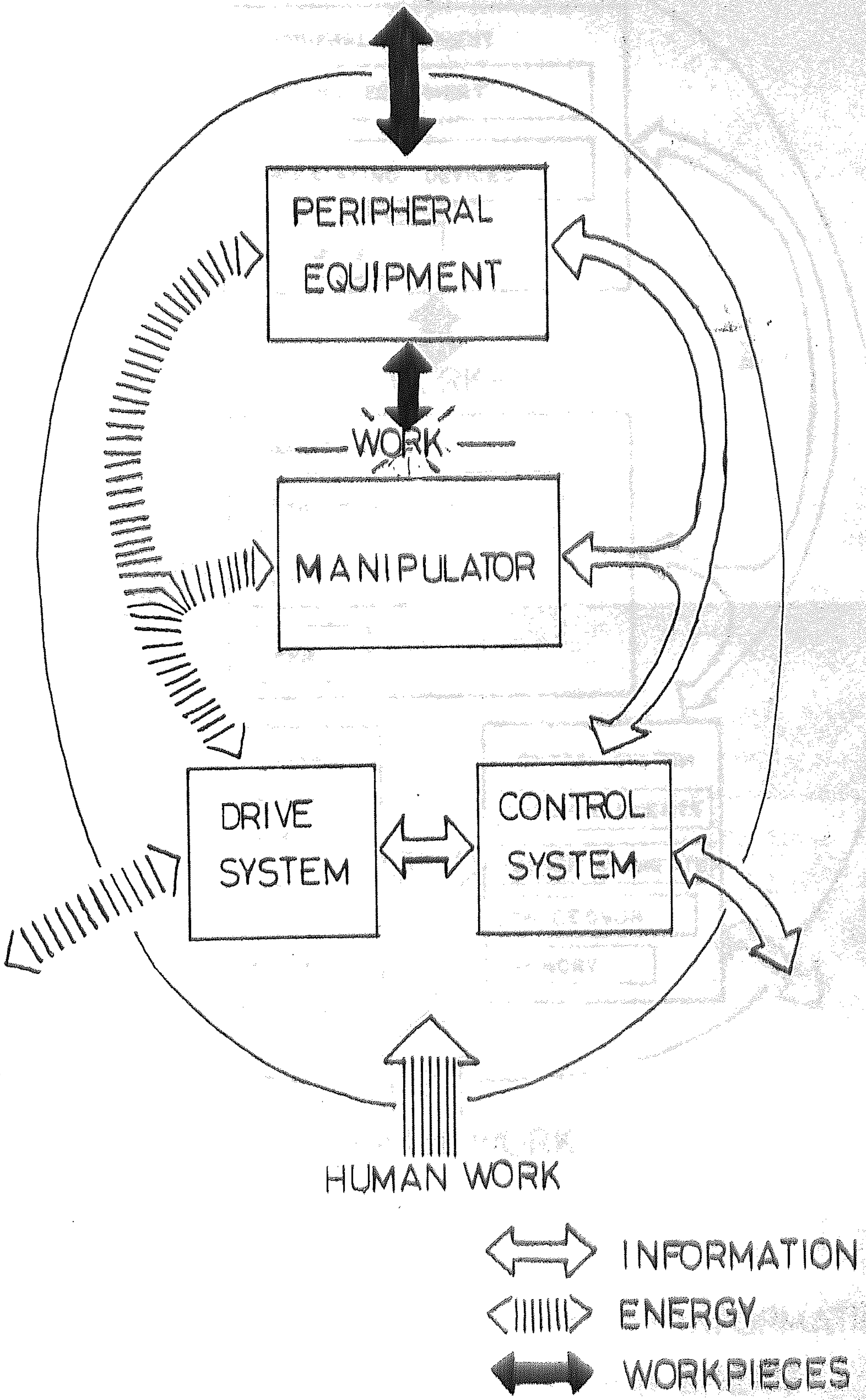


FIGURE A1.2

SUB-ELEMENTS OF A ROBOT SYSTEM (HARDWARE)

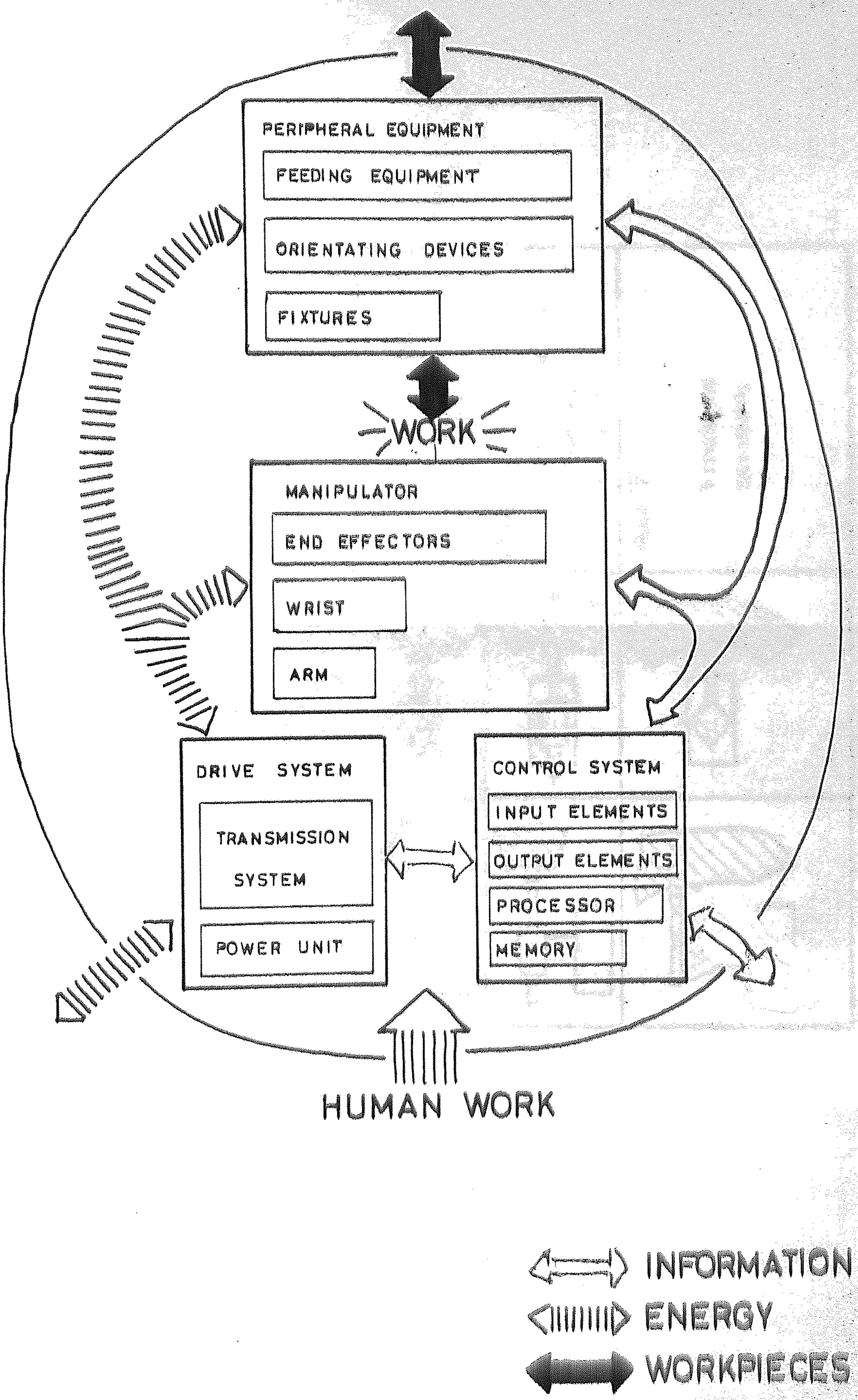


FIGURE A1.3 ROBOT CONFIGURATIONS

FROM: SCHRAFT, R.D., AND SCHMIDT, U. (1976, PA 2-30)

Figure A1.4 - Hierarchy of Sequential Controllers
(Webb 1974, Table 1 and pB454)

Digital Computers

APPENDIX 2

PATTERN OF CHANGE IN THE CHARACTERISTICS OF COMMERCIAL ROBOT TYPES

APPENDIX 2

Pattern of Change in the Characteristics of Commercial Robot Types

Various studies of the characteristics of robots in the market have been conducted since the early 1970's. Some of them reported the characteristics of robot models (JIRA 1973 and 1979, Lundstroem et al 1972, Warnecke and Schraft 1973, Johnson and Hanify 1973, Abraham et al 1977c, and Spur et al 1979); others synthesised the nature of commercial equipment from samples of robots in the market (Hasegawa 1973, Warnecke 1973, Warnecke et al 1974, Schraft 1977, and Warnecke and Schraft 1977a).

A comparison of some of these studies will reveal the pattern of change that has taken place in the characteristics of robots. The main reports chosen with this purpose are: Hasegawa 1973 and Abraham et al 1977c. The first paper gives a clear picture of the state-of-the-art in the early years of robots (before 1973). The second report described the models introduced after 1972 (It is an updated version of a report by Lundstroem et al which described robots introduced before 1972) and can be used to infer the characteristics of robots introduced in the period between 1973 and 1977.

This analysis has several limitations. Robot terminology and procedures for the measurement of characteristics are still non-standardised. Thus, specifications given in technical catalogues vary widely and might not be directly comparable. This is especially true of quantitative characteristics, and particularly those relevant to the performance of the systems. Emphasis will therefore be given to qualitative differences, especially those that indicate the versatility of equipment.

FIGURE A2.1 Pattern of Change in the Characteristics of Commercial Robot Types -(1) Structural Versatility (Estimated from Hasegawa 1973 and Abraham et al. 1977c)

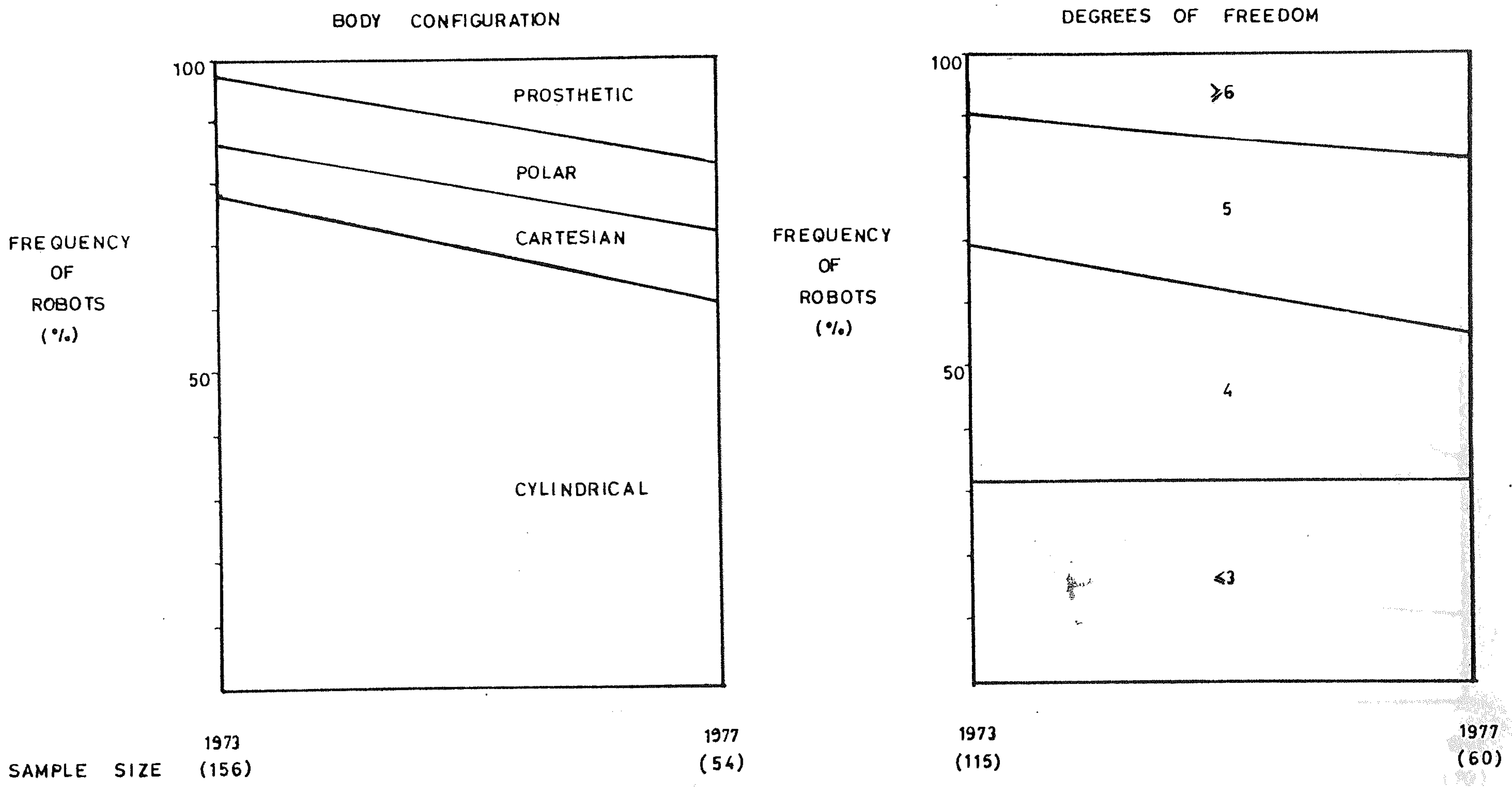


FIGURE A2.2 Pattern of Change in the Characteristics of Commercial Robot Types – (2) Command Versatility (Estimated from Hasegawa 1973 and Abraham et al. 1977c)

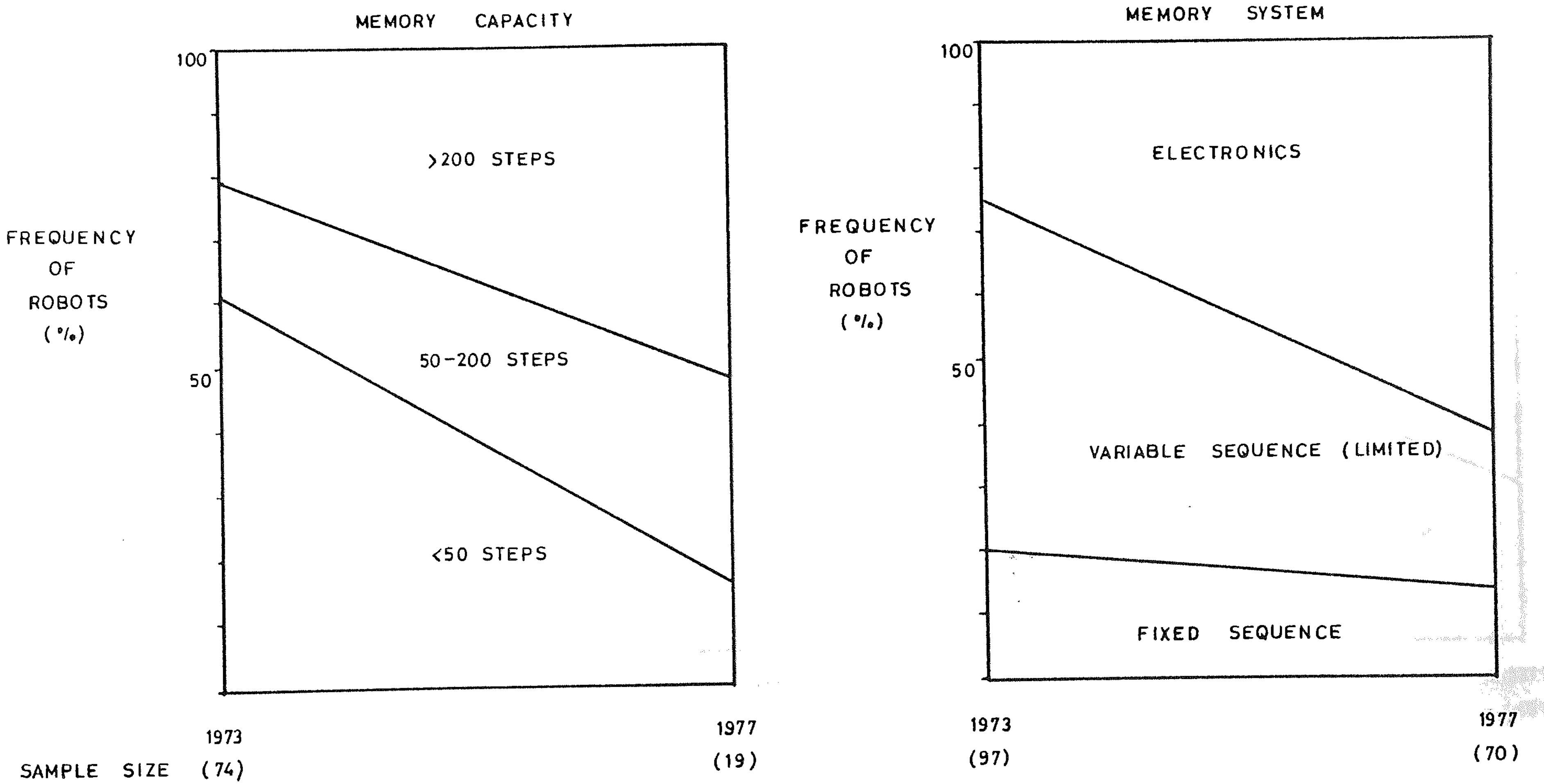


FIGURE A2.3 Pattern of Change in the Characteristics of Commercial Robot Types – (3) Command Versatility (Estimated from Warnecke et al. 1974, Warnecke 1975, and Abraham et al. 1977c)

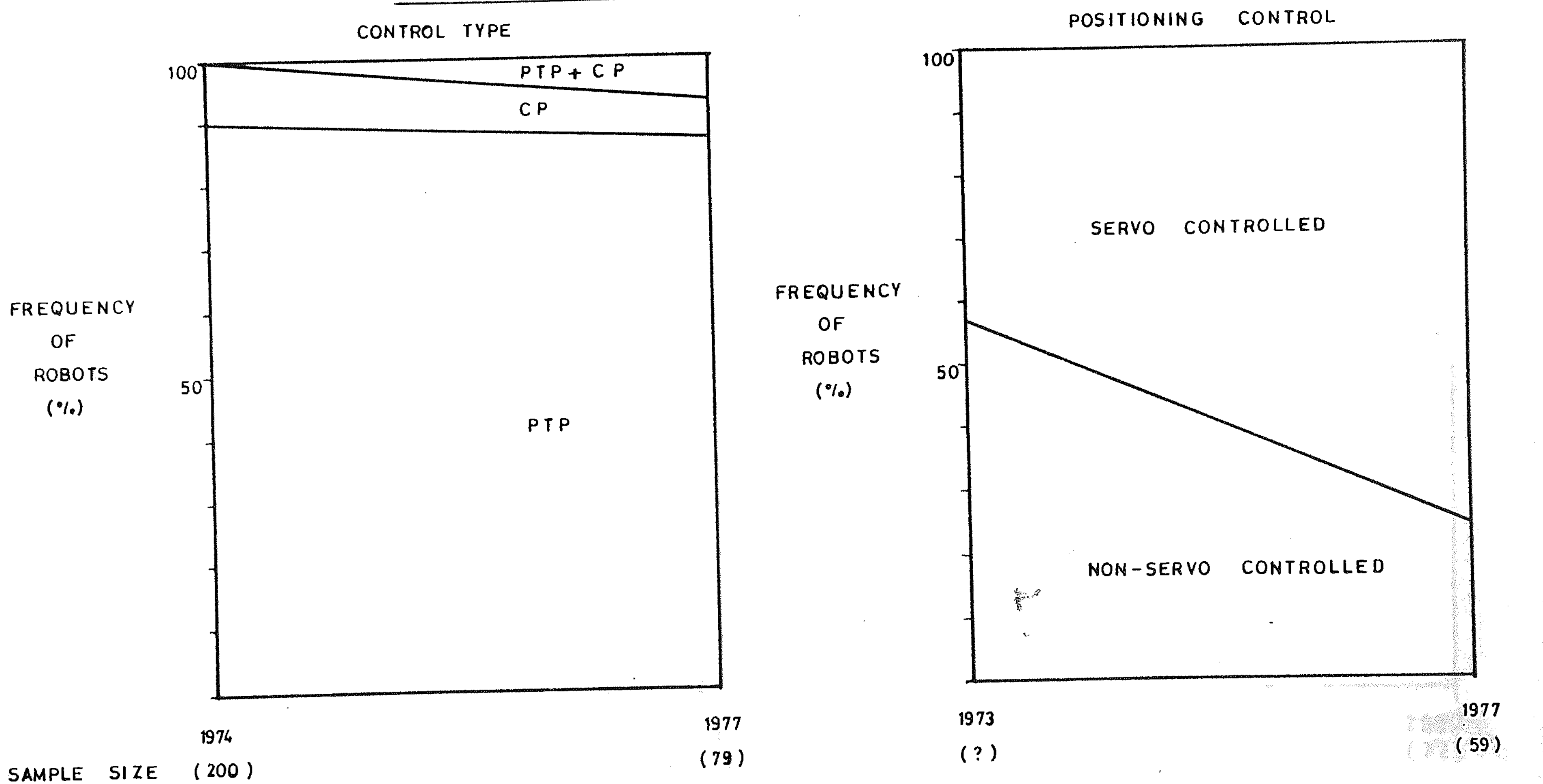


Figure A2.4 - Pattern of Change in the Characteristics of Commerical Robot Types - (4) Other Characteristics (Estimated from Hasegawa 1973 and Abraham et al 1977c)

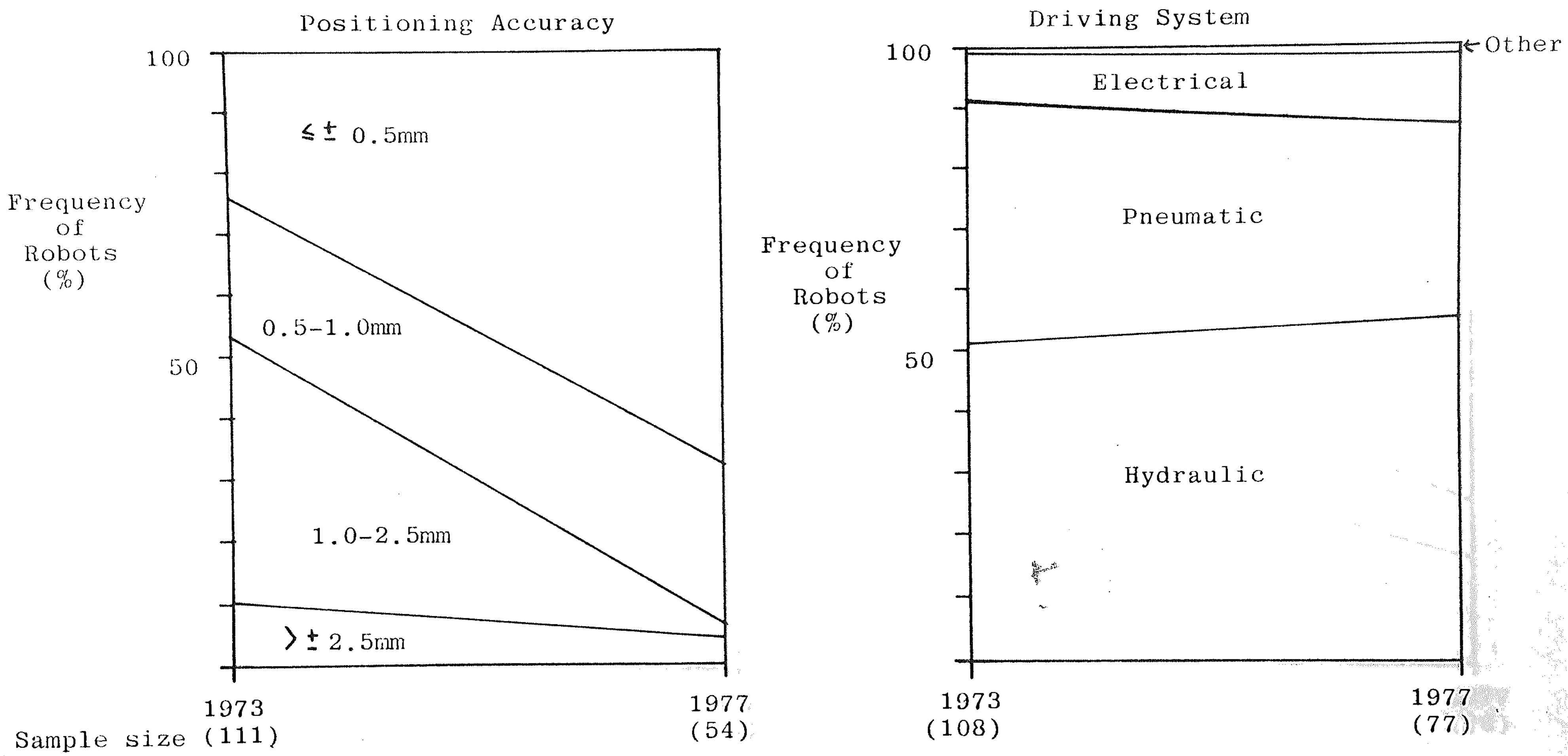


Figure A2.5 - Pattern of Change in the Characteristics of Commerical Robot Types - (5) Main Groups (Estimated from Warnecke 1973 and Abraham et al 1977c)

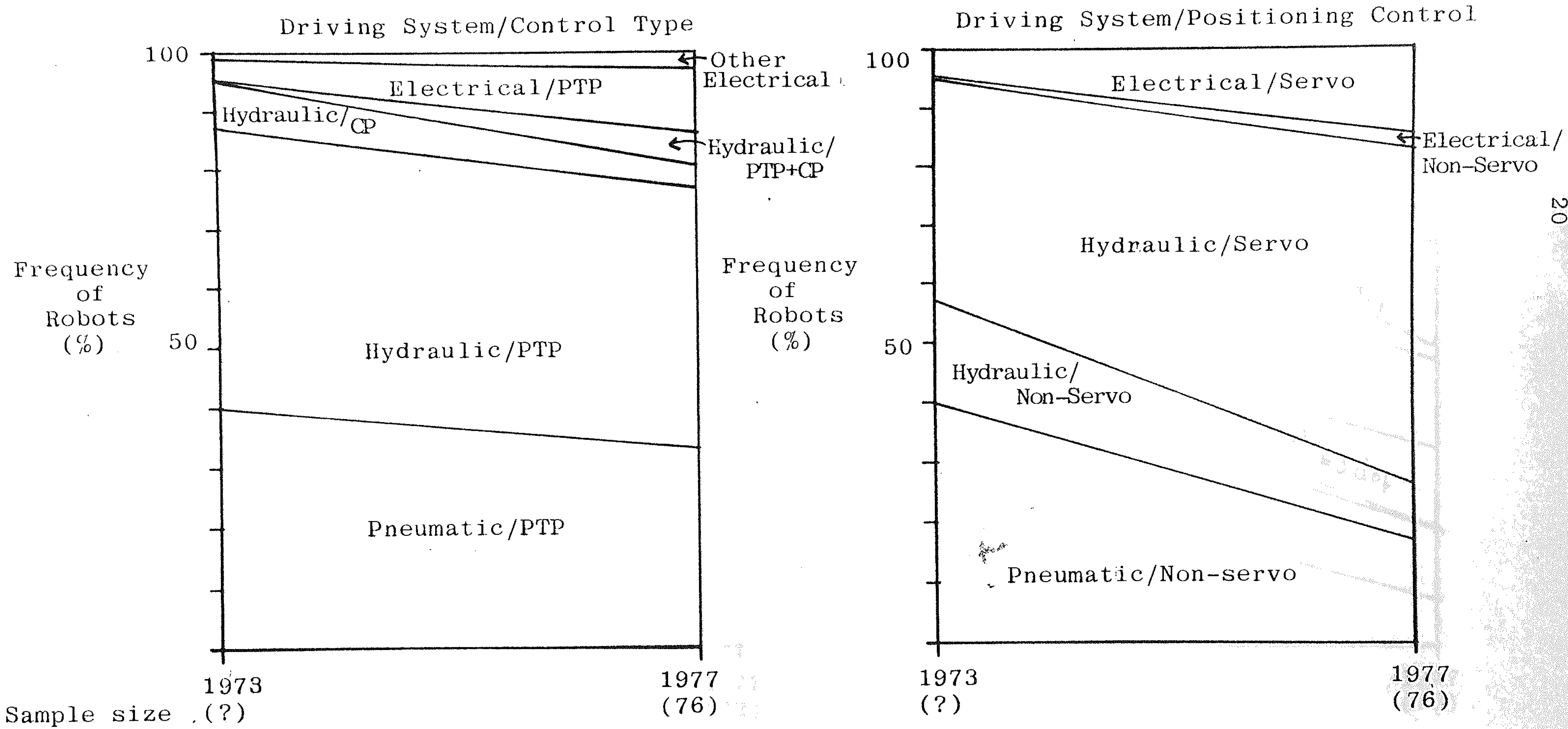
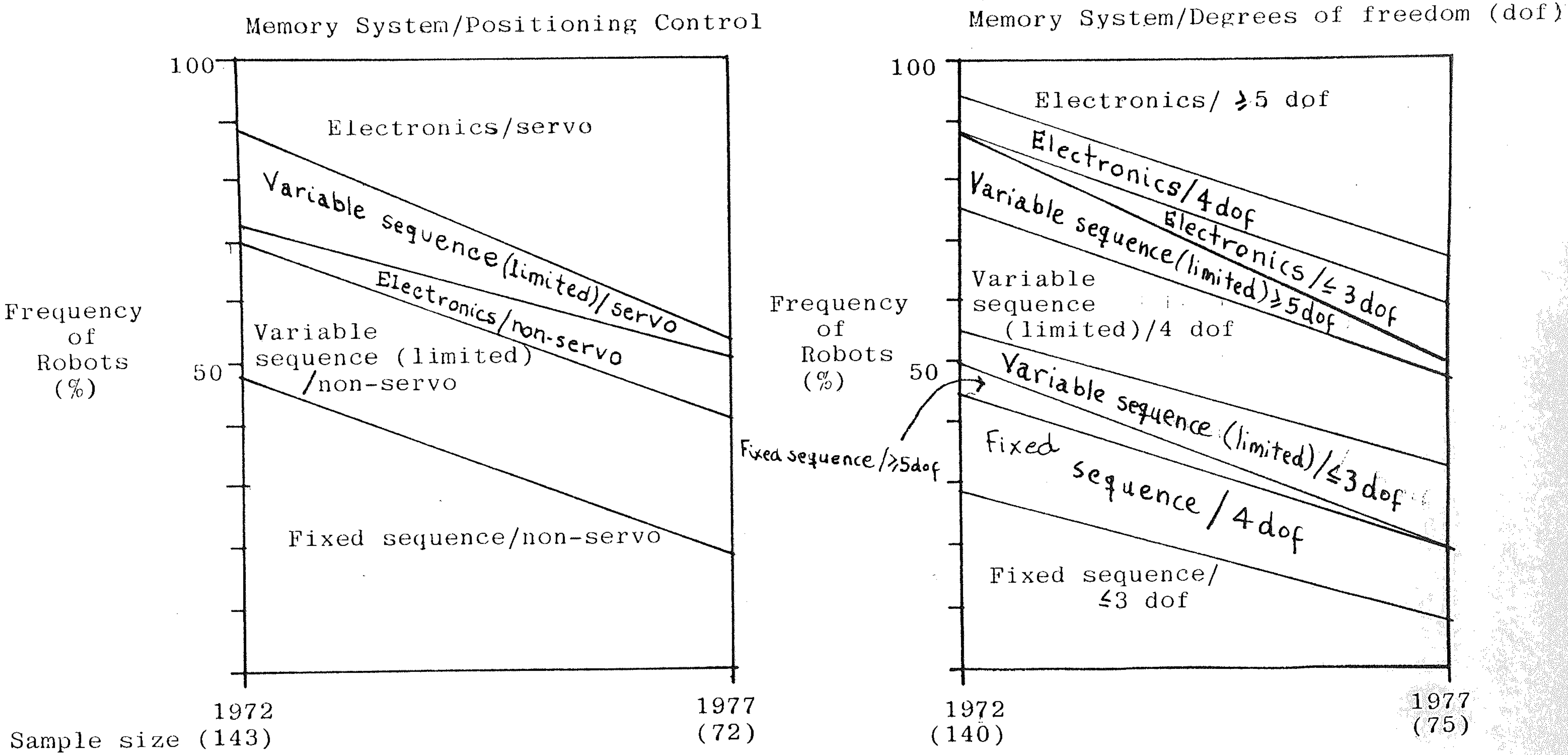


Figure A2.6 - Pattern of Change in the Characteristics of Commercial Robot Types - (6) Main Groups (Estimated from Lundstroem et al 1972 and Abraham et al 1977c)



APPENDIX 3

ANALYSIS OF THE GROWTH AND PATTERN OF PAPERS PRESENTED AT THE VARIOUS INTERNATIONAL SYMPOSIA ON INDUSTRIAL ROBOTS (ISIR)

APPENDIX 3

Analysis of the Growth and Pattern of Papers Presented at the Various International Symposia on Industrial Robots (ISIR)

A classifiaction of the papers delivered at the various ISIR was conducted using the following information:

1. Types of paper (topic)

2. Kinds of institution where authors of the papers work.

3. Country of origin of the authors.

4. Sources of finance.

The number of papers was counted for every ISIR with the purpose of inferring: the main areas of development of robot technology, and the institutional and international differences of such development.

The use of scientific and technological papers in measurement of research and development output is generally accepted (UNESCO 1970, p 341). This methodology has various limitations:

A. Not all research is published, particularly that of a proprietary nature. This indicator should be biased towards research and experimental development in universities and other laboratories, and against applied work in industry.

B. The publication of development work involves varying time-lags. Applied work in industry is likely to be reported later than that of universities and other laboratories.

C. The quality of papers varies widely in a symposium, and across symposia. These differences should be less significant at higher levels of aggregation.

D. The quantity and kind of papers may be affected by the editorial policies of the symposia organisers, and by limitations to the size of the meetings. Thanks to the growth in development work, the symposia have become more specialised in research and development.

A3.1 The Development of Robot Technology

The papers presented at these symposia, except for the 10th ISIR held in Italy in 1980, were classified into four categories: research, experimental development, innovation and applications.

1. Research papers report theoretical work done with little or no direct connection with experimental work. They are mainly concerned with the understanding of the robot technical systems. Research papers were subdivided further into artificial intelligence, control and mechanics.

2. Experimental development papers report work done on robots or robot component prototypes. This work is directed towards improving the prototypes performance. These may eventually be ready for use in practical applications or lead to another generation of devices to be tested further. Experimental development papers were subdivided into: robot prototypes, control systems, software, mechanical systems, sensors, peripherals, and applications research.

3. Innovation papers are those papers describing successful prototypes which are either being introduced into the market, or being used in a normal operating system inside the firm. To be classified as successful, a prototype should be used on line production with a purpose other than to develop it further. Innovation papers were classified into: robot models, control systems, software, mechanical systems, sensors, peripherals and applications/ flexible manufacturing systems.

4. Papers on applications are those describing case studies of robot applications and other investigations orientated towards the use of robotics in productive activities. These papers were grouped into five categories: assessment and forecasting, robot selection and workplace studies, suppliers experiences, users experiences, and flexible manufacturing systems.

The number of papers delivered which belong to each of the above categories are given in Table A3.1. Figures A3.1 to A3.6 and Tables A3.2 and A3.3 show the main information derived from this analysis.

A3.2 Institutional Differences in the Contribution to Robot Symposia

The institutions (i.e. the employers of the authors of the papers given) were classified into four categories: industry, university, government, and others. This last category embraces first of all, research institutions and secondly all kinds of joint work between different institutions. Tables A3.4 and A3.5, and Figure A3.7 show the main information derived from this analysis.

A3.3 International Differences in the Contributions to Robot Symposia

Symposia papers were also classified according to the authors' and institutions' country of origin. The international character of the symposia was clearly established in Switzerland - the first time the symposium was held outside the USA. Since then, the number of countries participating and their contribution, have increased steadily (see Table A3.6). Growth in the number of papers has mainly resulted from the activity of host countries, except in the case of Switzerland in 1972, and from expanding international participation (see Figure A3.8). This means that the change in focus and the institutional differences between symposia were largely caused by the characteristics of the host countries. Tables A3.7 and A3.8 show the information derived from this analysis.

A3.4 Sources of Finance

The institutions where the authors of the papers are employed are not necessarily the source of finance for the projects. Information on the sources of finance was, unfortunately, not available in the majority of cases. Table A3.9 was made under the assumption that if the source of finance was not acknowledged, the resources came from the same place where the project was undertaken. Almost all acknowledgements of financial support referred to governments. This table is therefore, more useful as an indicator of where the government certainly had a role, rather than of where it had not. The USA, FRG and UK were the countries that more often acknowledged a source of finance.

A3.5 Conclusions

The total number of papers has increased 6.6 times since 1970 through a series of peaks starting in 1974, followed by a second in 1978, and by a third in 1980. Four periods of symposium activity can be distinguished. The landmarks which identify these periods are closely linked to the meetings in Japan.

First Period (1970-1973): papers on applications from American industry played a major role.

Second Period (1974-1976): papers on applications rapidly gave way to papers on experimental development when the symposium was held in Japan for the first time in 1974. This coincided with the first peak in the number of papers, and with a small rise in research and innovation papers. Universities and other research institutes, and joint programmes increased their contribution. Experimental development took off in the USA.

Third Period (1977-1979): a small decline in 1976 was followed by an impressive surge in the number of papers in 1977 in Japan. This was also accompanied by an increasing importance of experimental development and innovation papers, and a definitie decrease in the importance of papers on applications. The contributions from industry, university, and others became virtually equal and constant. Experimental development took off in the FRG.

Fourth Period (1980): an increase in the number of papers after the 1979 fall marks the beginning of a new period. The joint contribution of the FRG, USA and Japan falls below thirty five percent.

TABLE A3.1 - Classification and Number of Papers Delivered at the Various International Symposia on Industrial Robots (ISIR)

TYPES OF PAPERS \ SYMPOSIUM YEAR	1st 1970	2nd 1972	3rd 1973	4th 1974	5th 1975	6th 1976	7th 1977	8th 1978	9th 1979	10th 1980*	TOTAL
RESEARCH	1	0	1	5	8	7	8	11	13	-	54
Artificial Intell.	1	0	0	1	4	2	1	2	5	-	16
Control	0	0	1	3	2	3	3	7	4	-	23
Mechanics	0	0	0	1	2	2	4	2	4	-	15
EXPERIMENTAL DEVELOPMENT	2	7	6	19	14	16	33	35	24	-	156
Robot Prototypes	2	2	2	6	4	3	5	7	3	-	34
Control Systems	0	1	0	4	1	3	4	4	1	-	18
Software	0	0	0	0	1	1	6	3	7	-	18
Mechanical Systems	0	0	0	0	1	1	5	1	0	-	8
Sensors	0	3	3	7	4	3	12	11	11	-	54
Peripherals	0	0	0	0	0	0	0	2	0	-	2
Applicatons Research	0	1	1	2	3	5	1	7	2	-	22
INNOVATION	0	0	1	8	8	2	11	12	5	-	47
Robot Models	0	0	1	3	5	1	8	8	0	-	26
Control Systems	0	0	0	0	0	1	1	2	0	-	4
Software	0	0	0	0	1	0	0	1	4	-	6
Mechanical Systems	0	0	0	0	1	0	0	0	1	-	2
Sensors	0	0	0	0	0	0	0	1	0	-	1
Peripherals	0	0	0	0	0	0	1	0	0	-	1
Applications and Flex. Manufacturing Syst.	0	0	0	5	1	0	1	0	0	-	7

Continued/....

TABLE A3.1 - (Continued)

SYMPOSIUM YEAR / TYPES OF PAPERS	1st 1970	2nd 1972	3rd 1973	4th 1974	5th 1975	6th 1976	7th 1977	8th 1978	9th 1979	10th 1980	TOTAL
APPLICATION	12	20	27	12	13	14	22	23	9	-	152
Asses't. & F/casting	5	11	4	3	2	1	5	5	2	-	38
Robot Selection & Workplace Studies	1	3	11	5	4	6	13	8	1	-	52
Suppliers Experien-ces	1	2	7	4	6	5	3	5	3	-	36
Users Experiences	5	4	5	0	1	2	0	3	0	-	20
Flex. Manufacturing Systems	0	0	0	0	0	0	1	2	3	-	6
TOTAL	15	27	35	44	43	39	74	81	51	64	
CUMULATIVE	15	42	77	121	164	203	277	358	409	473	

* Type of papers not available

Figure A3.1 - Growth and Pattern of Papers Delivered at the Various ISIR

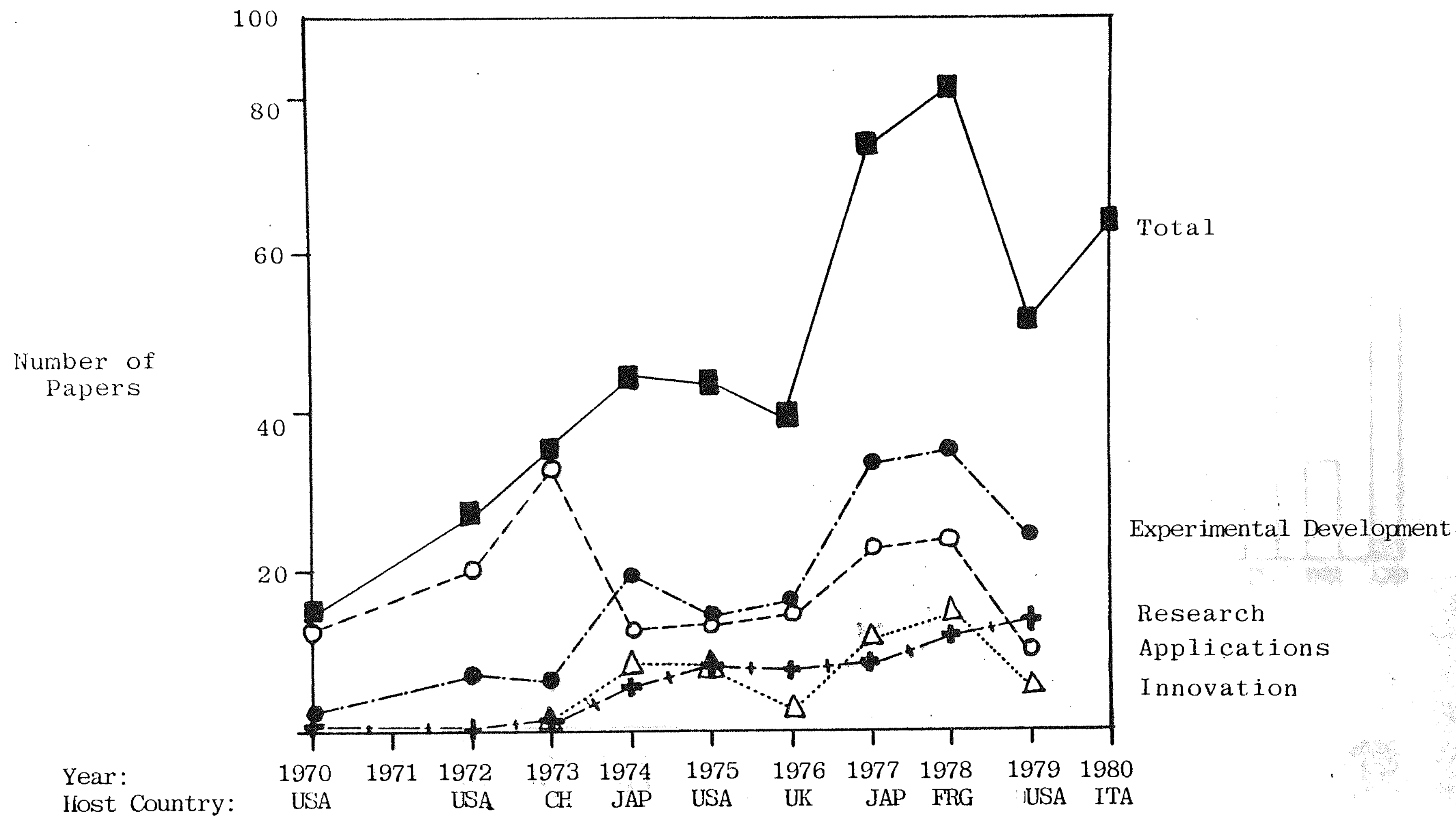


Figure A3.2 - Distribution of the Topics of Symposia Papers

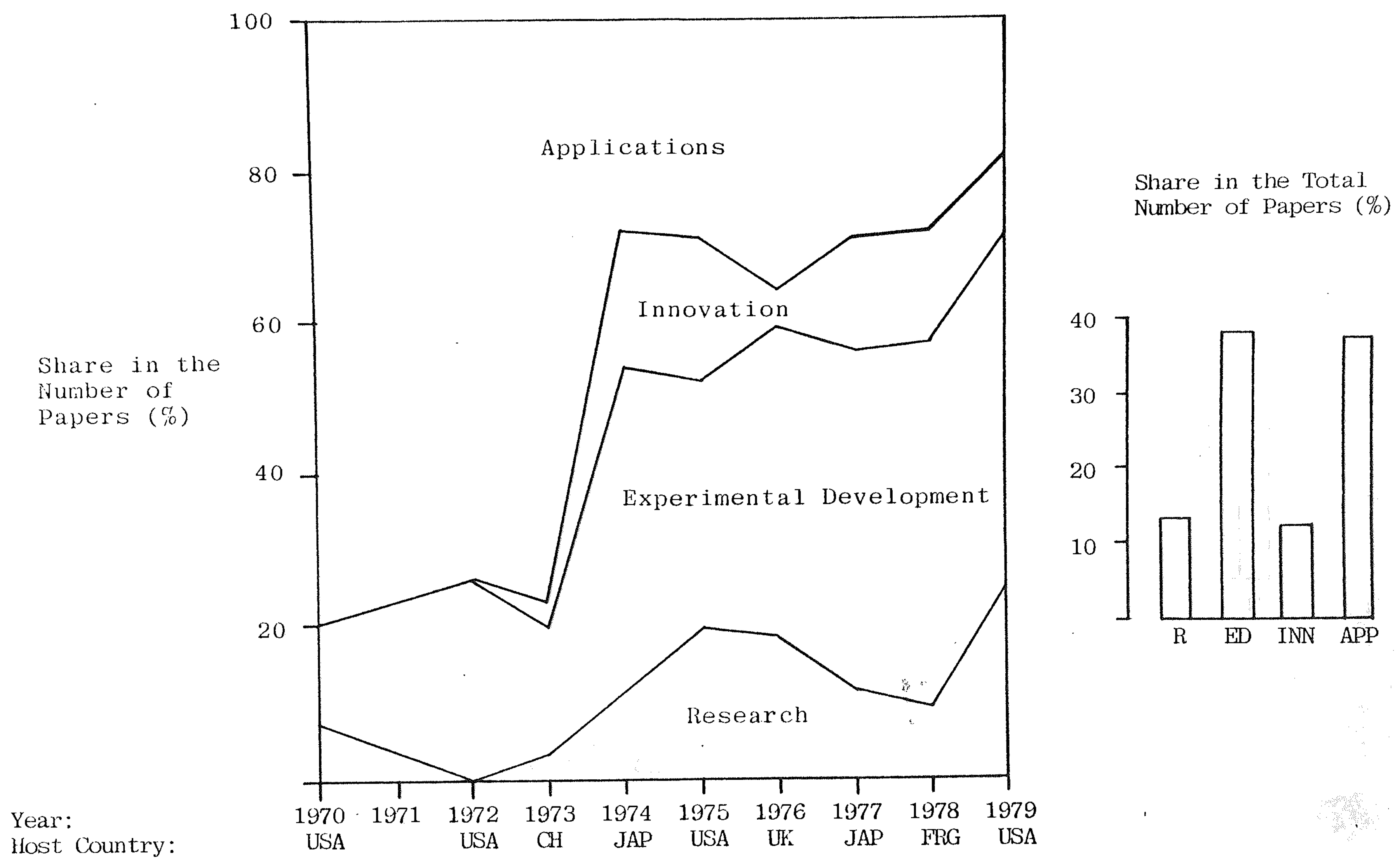
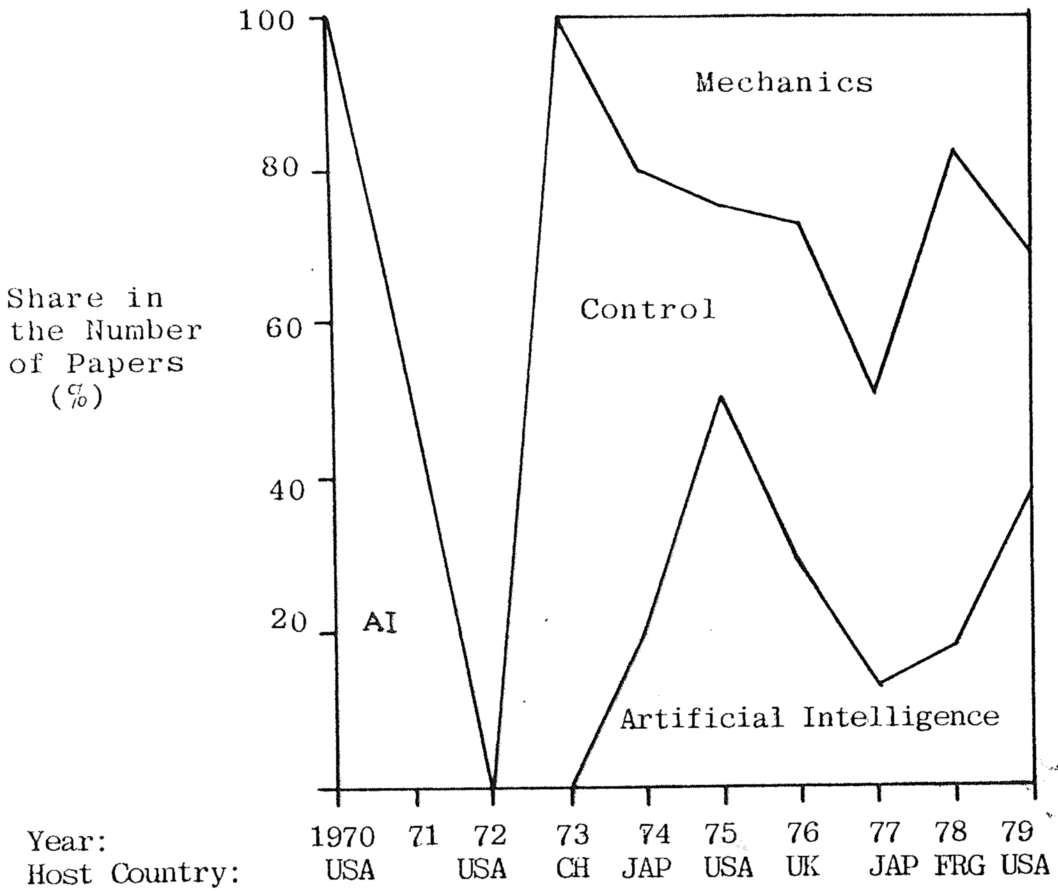


Figure A3.3 - Distribution of the Topics of Research Papers



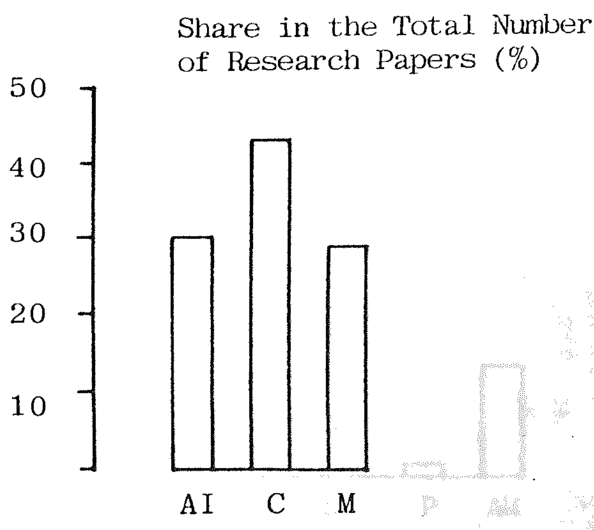


Figure A3.4 - Distribution of the Topics of Experimental Development Papers

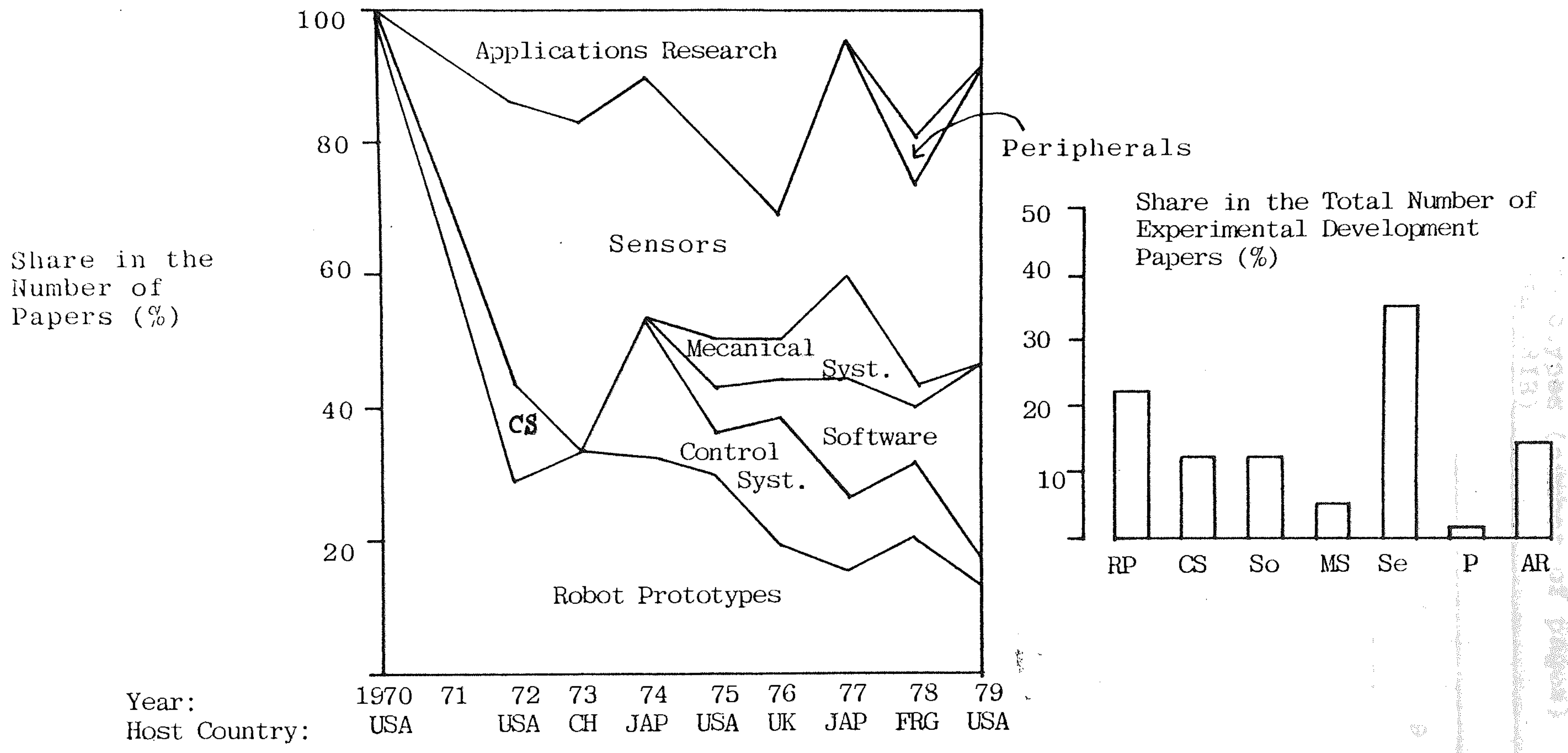


TABLE A3.2 - Distribution of the Topics of Papers Dealing with Robot Prototypes (number of pages) (excluding 10th ISIR)

Remote Controlled Manipulators	Nuclear industry	5	9
	Others	4	
Automatic Vehicles			5
Industrial Robots	Assembly	7	20
	General Purpose	9	
	Others	4	
TOTAL			34

TABLE A3.3 - Distribution of the Topics of Papers Dealing with Sensory Systems (number of papers) (excluding 10th ISIR)

		Integrated with Manipulator	Non-integrated	Sub-Total	Total
Vision	Complex	2	0	2	32
	Simple	21	9	30	
Force	Complex	2	1	3	6
	Simple	3	0	3	
Touch	Complex	4	3	7	7
	Simple	0	0	0	
Multiple		4	0		4
Others		1	4		5
Total		37	17		54

Definitions:

Complex vision: recognition of shapes in a disordered state

Simple vision: detection of edges, holes, corners etc. Workpieces are set in an arranged environment (e.g. backlight, assuming a limited number of positons, non-overlapping objects etc.)

Complex force: Can measure force along two or more axes.

Simple force: " " " " a single asix.

Complex touch: Multiple tactile sensors for detection of shapes

Simple touch: Single tactile sensors for detection of presence or absence of workpieces.

Multiple: More than one type of sensor

Others: Papers describing various sytems.

Similar definitions appeared in Evans et al (1978 , p22)

Figure A3.5 - Distribution of the Topics of Innovation Papers

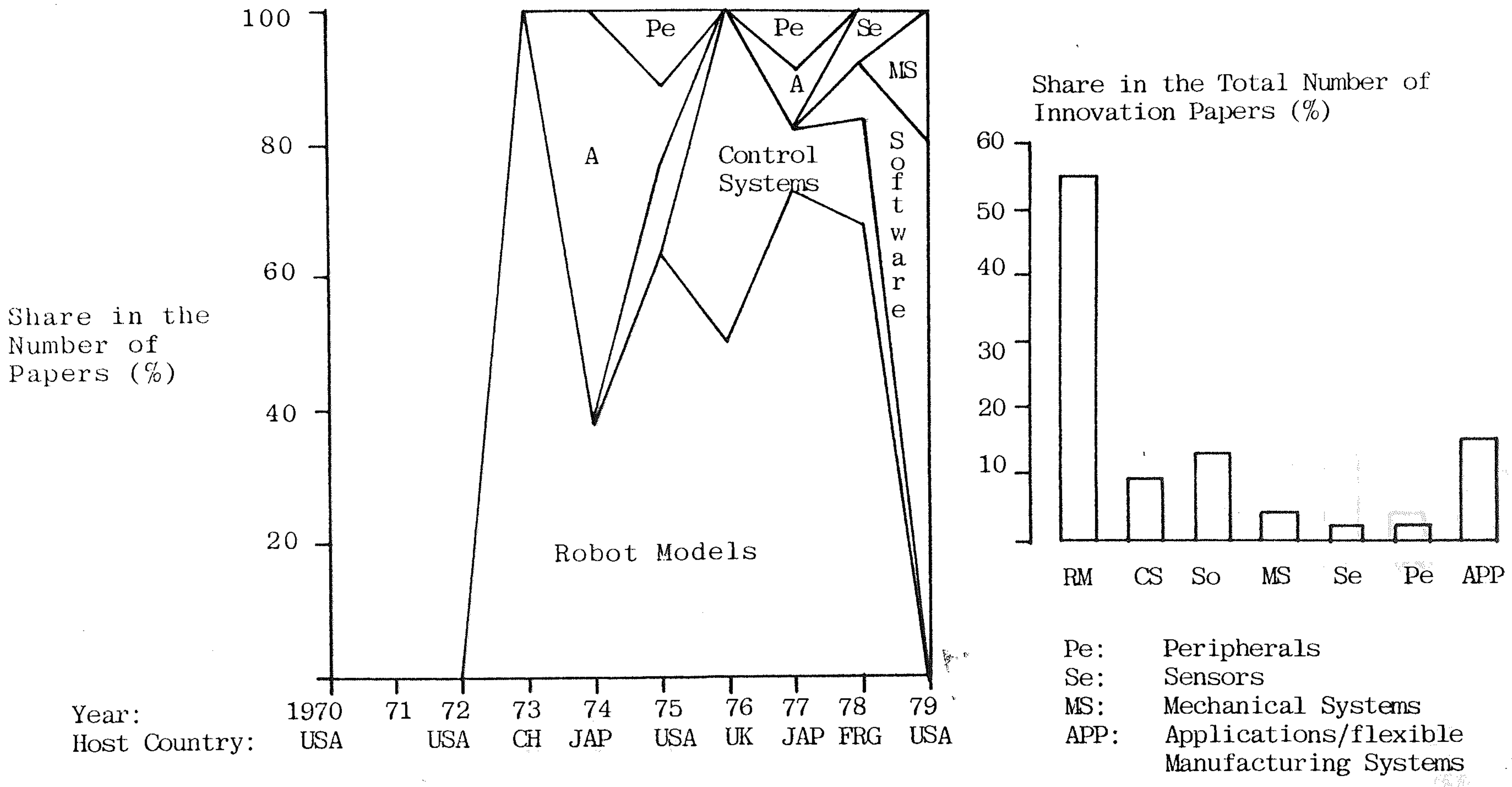


Figure A3.6 - Distribution of the Topics of Applications Papers

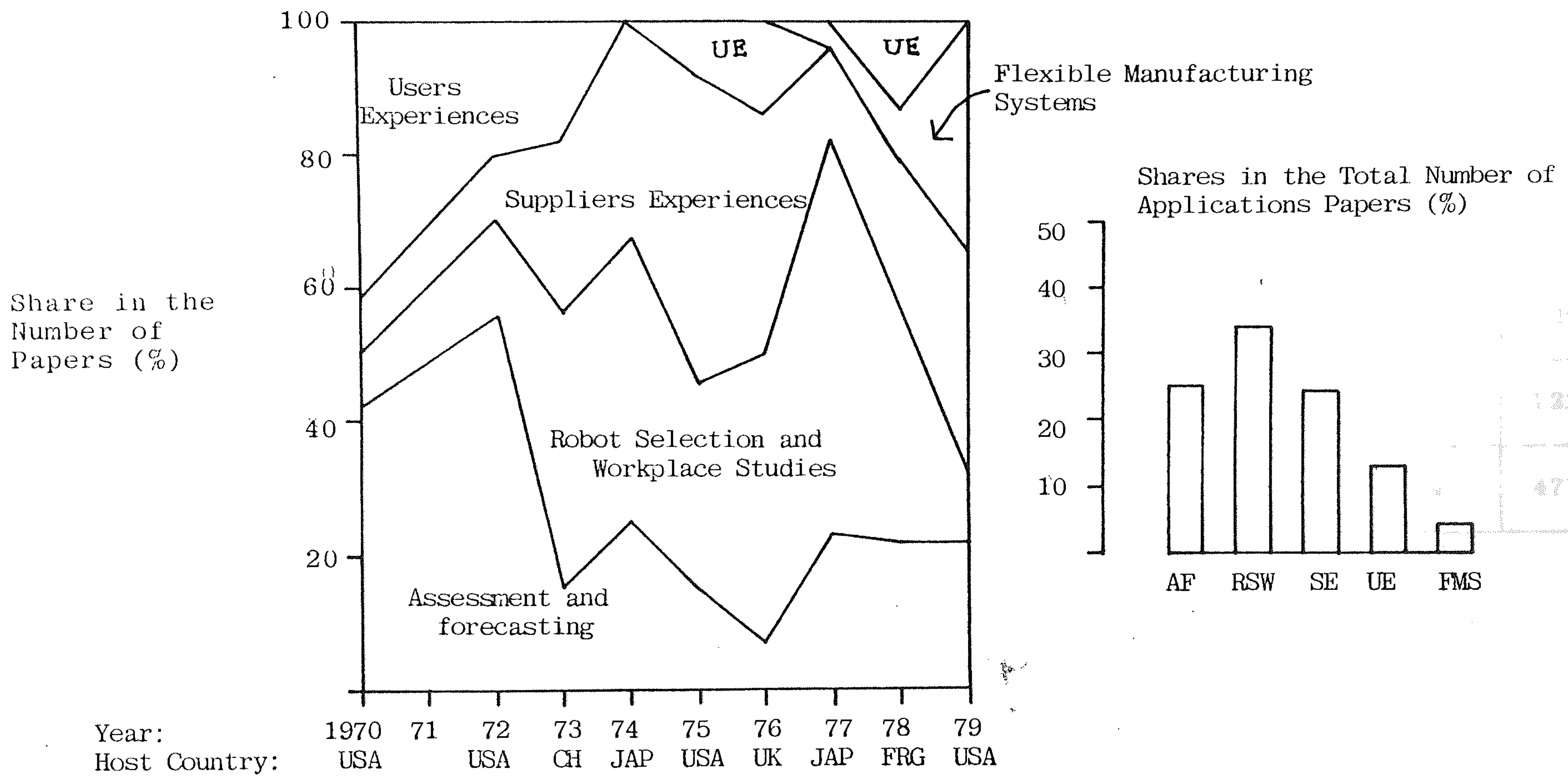


TABLE A3.4 - Institutional Contributions to the Various International Symposia on Industrial Robots (number of papers)

SYMPOSIUM YEAR / TYPES OF PAPERS	1st 1970	2nd 1972	3rd 1973	4th 1974	5th 1975	6th 1976	7th 1977	8th 1978	9th 1979	10th 1980	TOTAL
Industry	7	18	23	20	19	11	24	30	15	20	187
University	5	6	5	10	5	16	20	28	18	31	144
Government	1	2	0	1	4	1	3	2	4	2	20
Others	2	1	7	13	15	11	27	21	14	11	122
TOTAL	15	27	35	44	43	39	74	81	51	64	473

TABLE A3.5 - Institutional Differences in the Focus of Symposia Papers (number of papers) (excluding 10th ISIR)

TOPIC \ INSTITUTION	INDUSTRY	UNIVERSITY	GOVERNMENT	OTHERS	TOTAL
RESEARCH	6	20	4	24	54
EXPERIMENTAL DEVELOPMENT	33	69	6	48	156
INNOVATION	37	2	0	8	47
APPLICATION	92	21	8	31	152
TOTAL	168	112	18	111	409

Figure A3.7 - Distribution of the Different Institutional Contributions to Symposia

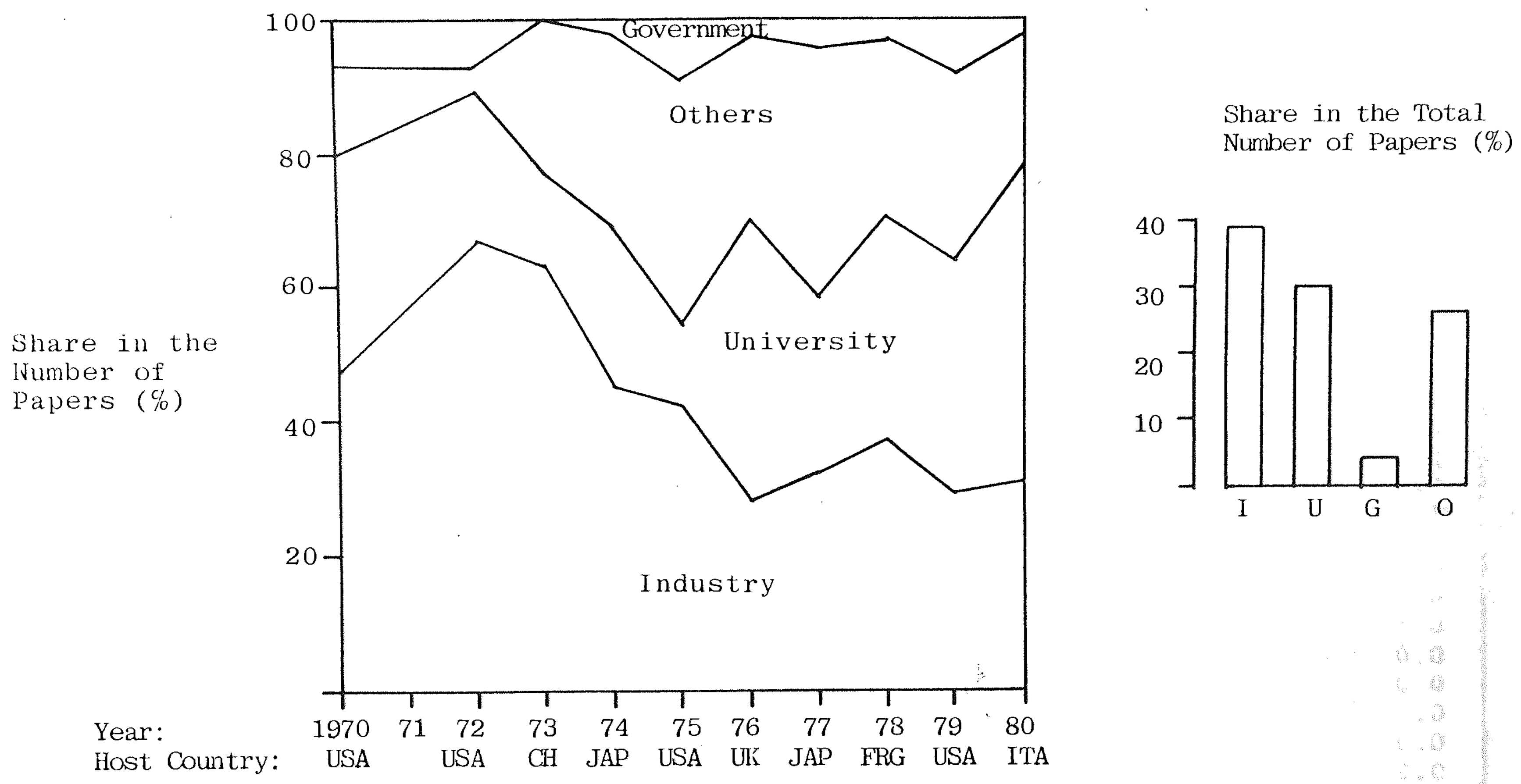
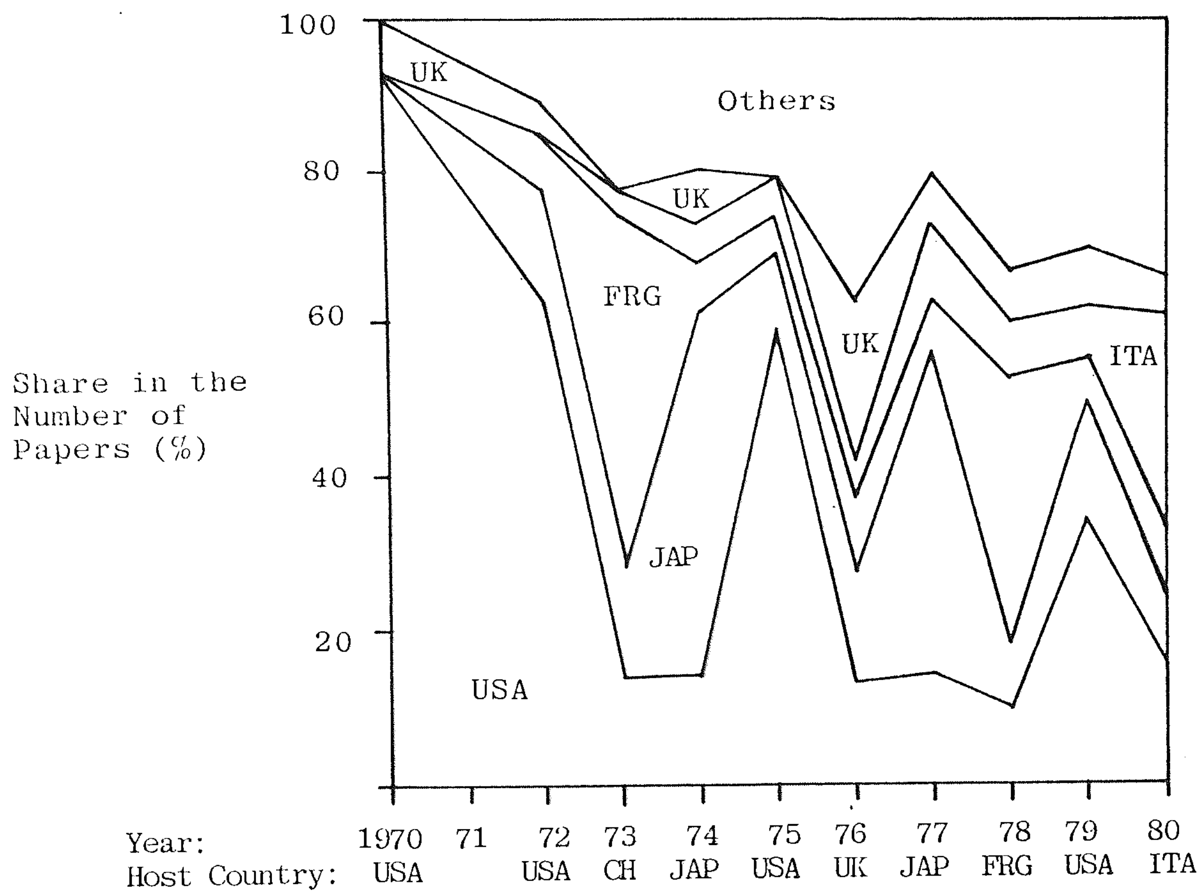


TABLE A3.6 - International Contributions to the Various ISIR (number of papers)

Number of countries participating	2	6	13	13	12	14	16	18	13	16	TOTAL
Country / Symposium Year	1st 1970	2nd 1972	3rd 1973	4th 1974	5th 1975	6th 1976	7th 1977	8th 1978	9th 1979	10th 1980	
1 U.S.A.	14.0	17.0	5.0	6.0	25.5	5.0	10.0	8.5	17.5	10.0	118.5
2 JAPAN	0.0	4.0	5.0	20.5	4.5	6.0	31.0	6.5	7.5	6.0	91.0
3 F.R.G.	0.0	2.0	16.0	3.0	2.0	3.0	5.0	28.5	3.0	5.0	67.5
4 ITALY	0.0	0.0	1.0	2.0	2.0	2.0	7.0	5.5	3.0	18.0	40.5
5 U.K.	1.0	1.0	0.0	3.0	0.0	8.0	4.5	5.5	4.0	3.0	30.0
6 SWEDEN	0.0	1.0	3.0	2.0	4.0	4.0	2.0	2.0	3.5	4.0	25.5
7 SWITZERLAND	0.0	2.0	5.0	1.0	0.0	1.0	1.0	4.5	2.5	1.0	18.0
8 POLAND	0.0	0.0	0.0	1.0	0.0	1.0	2.0	3.0	4.0	3.0	14.0
9 U.S.S.R.	0.0	0.0	0.0	1.0	0.0	3.0	4.0	4.0	0.0	2.0	14.0
10 FRANCE	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	2.5	5.0	12.5
11 YUGOLSAVIA	0.0	0.0	0.0	2.0	2.0	1.0	1.5	1.0	1.0	1.0	9.5
12 HUNGARY	0.0	0.0	0.0	0.5	1.0	2.0	1.0	2.0	0.0	2.0	8.5
13 BULGARIA	0.0	0.0	0.0	2.0	1.0	1.0	0.0	0.0	0.0	1.0	5.0
14 NORWAY	0.0	0.0	0.0	0.0	1.0	1.0	0.0	2.0	0.0	1.0	5.0
15 FINLAND	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	3.0
16 BELGUIM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	2.0
17 CZECHOSLOVAKIA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	2.0
18 ZAMBIA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	2.0
19 DENMARK	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0
20 NETHERLANDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0
21 RUMANIA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
22 TURKEY	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0
23 SPAIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.5
TOTAL	15	27	35	44	43	39	74	81	51	64	473

Figure A3.8 - Distribution of the International Contributions to the Various ISIR



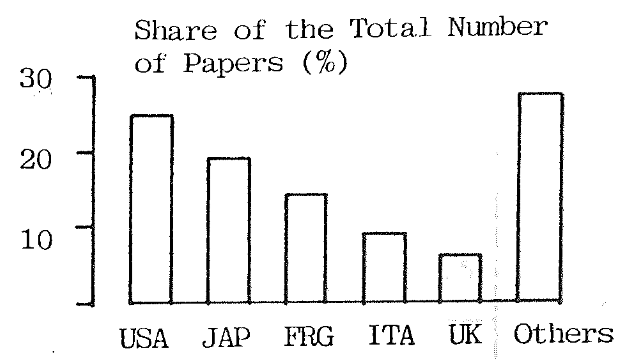


TABLE 3.7 - International Differences in the Focus of Symposia Papers (number of papers) (excluding 10th ISIR)

COUNTRY \ TOPIC	RESEARCH	EXPERIMENTAL DEVELOPMENT	INNOVATION	APPLICATION	TOTAL
U.S.A.	14.5	30.0	7.5	56.5	108.5
JAPAN	4.5	42.0	20.0	18.5	85.0
F.R.G.	3.0	21.0	5.0	33.5	62.5
U.K.	3.5	22.0	1.5	0.0	27.0
ITALY	2.5	7.0	6.0	7.0	22.5
SWEDEN	0.5	1.0	3.0	17.0	21.5
TOTAL	28.5	123.0	43.0	132.5	327.0

TABLE A3.8 - International and Institutional Differences of the Contributions to Robot Symposia (number of papers)

INSTITUTION / COUNTRY	INDUSTRY	UNIVERSITY	GOVERNMENT	OTHERS	TOTAL
U.S.A.	69.5	19.5	10.0	23.5	122.5
JAPAN	42.0	25.0	8.0	18.0	93.0
F.R.G.	29.5	14.0	1.0	27.0	71.5
ITALY	24.0	23.5	0.0	6.0	53.5
U.K.	1.0	24.5	1.0	4.5	31.0
SWEDEN	23.0	1.5	0.0	2.0	26.5
TOTAL	189	108.0	2.0	81.0	398

TABLE A3.9 - International Differences in the Source of Finance of Papers (number of papers) (excluding 10th ISIR)

COUNTRY \ INSTITUTION	INDUSTRY	UNIVERSITY	GOVERNMENT	OTHERS	TOTAL
U.S.A.	58.5	5.5	24.0	20.5	108.5
JAPAN	39.5	21.5	9.0	15.0	85.0
F.R.G.	22.5	8.0	22.0	10.0	62.5
ITALY	12.0	7.0	2.0	1.5	22.5
U.K.	0.5	17.0	8.0	1.5	27.0
SWEDEN	19.0	0.5	0.0	2.0	21.5
TOTAL	152.0	59.5	65.0	50.5	327.0

APPENDIX 4

CHRONOLOGY OF INVENTION AND INNOVATION IN ROBOT TECHNOLOGY FOR DIFFERENT COUNTRIES

APPENDIX 4

Chronology of Invention and Innovation in Robot Technology for Different Countries

The following tables describe the main events related to the invention and innovation of robots. This information was mainly extracted from the issues of The Industrial Robot magazine, from the proceedings of ISIR and CIRT meetings, and from papers published in other technical journals.

The most important sources in technical magazines are divided into two: state-of-the-art reviews, and single technical news. For the first type of papers see: Frost and Sullivan (1974), American Machinist (1975), Stout et al (1976), Albus and Evans (1976), Shah and Pond (1977), Shah (1978), Rooks and Brock (1979), Bylinsky (1979), and Winship (1979). For the second type of papers for example see: The Engineer, Machinery and Production Engineering Journals.

The dates in the tables are only approximate and events not widely publicised are bound to be excluded. There is also a bias towards events in English-speaking countries, especially Britain.

TABLE A4.1 : Invention and Innovation in the United States of America

1954	Invention of "Unimate" by George Devol (Patents being generated for concepts of an industrial robot)	
1958	Development work starts on a "Unimate" robot directed towards machine loading and unloading	AMF starts development work on "Versatran" robot
1959	First prototype of a "Unimate" robot is produced (5 axes)	
1961	First application of "Unimate" (diecasting)	
1962	Unimation Inc. is formed	
1963		AMF introduces "Versatran" (301 PTP system) into the market
1966		AMF starts development work on Continuous Path Control (CP)

Continued/......

TABLE A4.1 : (Continued)

1968		First application of "Versatran" (302 CP system) (RAM)	First application of Sterling Detroit Co. "Robotarm" in diecasting	
1969			Introduction of "Auto-place" robots	Prab starts development of robots.
1970	1st Exhibition of CP controlled "Versatran" by AMF		IBM produces pick-and-place device for internal use	Introduction of Burch Controls Inc. "Brute" robot
1971	Unimation develops "Unimate 4000" to Ford's specifications	GM develops own robot "SAM" for spot welding on moving lines	Westinghouse Electric Corp. starts project on robot arc welding	"Prab" robot introduced into the market
1972	Unimation introduces "Unimate 4000" (6 Axes)	Sundstrand introduces robot into the market	Westinghouse manufactures a prototype for arc welding (7 Axes)	
1973	Robotics Inc. is formed		Westinghouse manufactures a second prototype for arc welding (4 Axes)	
1974				
1975	Cincinnati Milacron introduces mini-computer controlled robot	Auto-place markets programmable pnuematic controller ("Computair")	Sterling Detroit Co. introduces two-armed "robotarm"	Westinghouse arc welding robot is tried on the shop-floor

Continued/....

TABLE A4.1 : (Continued)

1976	Unimation and Ford Mo. Co. starts development of "Unimate 6000" (2-Arms) for assembly	Cincinnati Milacron increases involvement in flexible manufacturing systems	AMF introduces "Versatran model F" of modular construction and microprocessor control		
1977	General Motors trials of the vision system at Delco Electronics	Auto-place introduces first commercial simple vision . system (optosense)	Cincinnati Milacron introduces computed path control		
1978	Unimation introduces: "Apprentice" arc welding robot for shipbuilding, "Unimate 2005F" for arc welding and "Unimate 2006G" for press transfer	Unimation takes over Vicarm and develops "PUMA" robot for assembly and programmed by high level language (VAL)	Ford installs six pairs of "Unimate 6000"	"Modular" robot is introduced by Modular Machine Co.	Prab introduces 5-axes robot
1979	General Motors "Consight" vision system & Cincinnati robot nears commercial introduction	"Versatran" robot licence acquired by Prab	Unimation introduces "Unimate 1000" for diecasting and Multiarm Kawasaki robot system (up to 8 separate arms)	Prab introduces heavyweight "Versatran FG" robot (2000lbs)	
1980	Unimation plans to supply "PUMA" with vision system from Standford Research Institute				

TABLE A4.2 : Invention and Innovation in Scandinavia

1963	"Trallfa" robot project approved (Norway)			
1965	First exhibition of "Trallfa" robot (Norway)			
1967		First robot installed in Sweden (USA robot)		
1968		"Kaufeldt" robot is manufactured and installed for the first time (Sweden)		
1969	First "Tralfa" Installation for spray painting (Norway)	"Kaufeldt" robot is introduced into the market in Sweden.	Electrolux starts development work in Sweden	
1971			"Electrolux" robot is introduced into the market (Sweden)	ASEA starts development work (Sweden)
1973				"ASEA" robot is designed (Sweden)
1974	First installation of "Trallfa" robot for arc welding and introduction of computer control (Norway)			"ASEA" robot is introduced into the market (Sweden)
1975		Introduction of "HIAB-FOCOAB" robot (Sweden)	Retab introduces "Coat-a-matic" robot (Sweden)	

Continued/....

TABLE A4.2: (Continued)

1976		Retab and HIAB-FOCO-AB develop "Coat-a-matic" robot for arc welding (Sweden)	First ASEA/ESAB arc welding stations are installed (Sweden)
1978	Robot "Rosenlew" for TV tube handling is introduced into the market (Finland)		
1979	Trallfa introduces flexible wrist robot (Norway)	Atlas Copco buys "Coat-a-matic" licence (Sweden)	

TABLE A4.3: Invention and Innovation in Japan

1965	The Nissan Corporation starts R & D project on robots			
1967	The Nissan Corporation installs the first robot			
1968	Kawasaki buys licence from Unimation Inc.			
1969	First Kawasaki Unimate is built	Toshiba builds first robots for pressing		
1971	"Star Seiki" is developed			
1972	Kawasaki starts development of inert gas welding (PTP + linear interpolation)	Kawasaki starts development of flexible manufacturing systems in collaboration with Fujitsu Fanuc (1 robot and 8 NC machine tools)	Kawasaki starts development of high performance robots for assembly	
1973	Kawasaki makes agreement with Electrolux to supply Elextrolux robots in Japan	Kobe Steel buys licence from Trallfa		
1974	"Aida" robots are introduced	Fujitsu Fanuc introduces robot with DNC system and "universal" gripper	Fujikoshi develops robot for heat treatment and arc welding	

Continued/...

TABLE A4.3: (Continued)

1974	Yaskawa Electric Mfg. introduces "Electrun" robot for welding	Hitachi Ltd starts development of sophisticated robot for coating	Tokyo Shibaura Electric Co. Ltd., develops vertically-mounted spot welding robot (Toshiba "Tosman" robot)			
1976	Yaskawa introduces "Motoman" 5-axis for arc welding	Hitachi develops computer controlled robot for coating (in collaboration with Japan Parkerising Co.)	Motoda Electronics introduces heavy-weight "PA-451520" robot (250kg)			
1977	Mitsui shipbuilding and Engineering Co. trials with welding robot with image sensor	Hitachi introduces "Mr. Aros" robot for arc welding and proximity sensors	Fujitsu Fanuc trials on Flexible Manufacturing system (1 robot and 5 NC machine tools)	Kawasaki introduces "Press robot"		
1977	Yamaha Motor Co. develops robot for arc welding	Sumimoto Shipbuilding and Mach Co., develops computer controlled robot for assembly of rotors	Komatsu Ltd., introduces modular industrial robot	Mitsubishi Heavy industries introduces modular robot ("Robitus")		
1978	Fuji Electric Co. Ltd., trials on visual identifation and sorting with TV system in inspection	Toshiba Seiki introduces "Tosman 1x15" robot	Kawasaki develops "Multiarm robot 6060"	Kobe Steel introduces "Arcman" for arc welding	Tokico robot is introduced for coating	Mitsubishi Iwata introduces Nachi "Unimau 5000" for coating

Continued/...

TABLE A4.3: (Continued)

1979	Kawasaki Vision system near commercial exploitation	Fujitsu Fanuc introduces "Fanuc O" robot (attached to machine tool)	Hitachi introduces "Hitachi Process" robot (small computer controlled for assembly)	Star Seiki introduces new "Seiki XY" PPD	Kawasaki introduces new "robot 3430" for spot welding and "Multiarm robot 6060"
1979	Dengensha (Sciaky license) Produces own robot "Gymnar" for spot welding	Shim Meiwa introduces sensorless sensing ("SLS") for arc welding	Dainichikiko Co. introduces heavy weight robot "Babot" (350kg)	Toshiba and Nissan develop "Tosman 200" for welding	Kobe steel introduces arc welding robot "Arcman"

TABLE A4.4: Invention and Innovation in Britain

1965	GKN buys "Unimate" licence from Unimation Inc. in USA			
1967	Hawker Siddeley Dynamics Engineering Ltd. (HSDE) buys "Versatran" license from AMF in USA			
1968		B & R Taylor Ltd. develops "Transiva" robot for machine loading		
1971	HSDE trials on "Versaweld" robot for welding			
1973	HSDE introduces modular construction			
1974		Metal Box develops own robot (Transfer arm)	Hall Automation and Binks Bullows introduce "Ramp" robot for coating	British United Shoe Machiner (BUSM) buys licence from USA
1975	Auto-place makes agreement with Compair Maxam and Climax-France to distribute robots in Britain and Western Europe	Hall Automation starts development of arc welder in collaboration with B.O.C.	"Retab" robots are introduced to Britain	Phillips R + K introduces "Area-4" from Italy
1976	Introduction of Star Seiki-robots		"Mouldmate" PPD is designed and built	

Continued/....

TABLE A 4.4: (Continued)

1977	Aida and Kuka begin business in the UK				
1978	Euro Electronic Instruments Ltd., introduce pick-and-place device	Olivetti "Sigma" robot is introduced in the UK			
1978	Prab agreement with Acheson colloids to distribute robot in Britain	Hall Automation develops new control unit with non-volatile solid state memory	BOC develops simple sensors for arc welding	Hall Automation and BOC trials of new arc welding robot	
1979	Fujitsu Fanuc agreement with Hydro Machine tools for the distribution of robot in Britain	Head Wrightson Mach. Co. (DAVY Corporation Co.) introduces arc welding robot	Hall introduces "Little Giant" handling robot	ASEA and Nottingham Univ (WIAG) develop adaptive deburring system	
1979	Mouldmation introduces punched tape sequence controller	Cincinnati Milacron robot is introduced to Britain	GKN introduces Minirobot for palletising	GKN Lincol electric buy licence from Yaskawa and introduces Linc Man for arc welding	Agency for "Renault" robots starts business
1979	Hall Automation developing "Magic Dragon"	Agreement between Unimation (Europe) and WIRS for marketing arc welding robots	Russell of Leicester (B. Elliott Group) introduces two robots of Japanese origin ("Press hand" and Husky")	British Federal Welder and Machine develops a robot for arc welding	

Continued/....

TABLE A4.4 : (Continued)

1980	Unimation plans for manufacturing of PUMA robots with support from DOI and NRDC (£660,000)	Hall Automation is taken over by GEC	Newtool of Fakenham introduces "SIMBOT" robot (British design)	British Robotic System starts development of assembly systems
	Fairey Group agreement with six Italian companies to market and manufacture robot welders, diecasters, and paintsprayers	Ingersoll Engineers introduces turn-key system		

TABLE A4.5: Invention and Innovation in the Rest of Western Europe

1966	VFW "Transfer automat" is introduced in the FRG					
1967	Industrial Marine starts development of robots for pressing (Italy)					
1969	SIV starts development of spot welding robot "Deltix 6" in Italy	VFW "Transfer automat" is sold to Japan from the FRG				
1971	VFW-Fokker buys "Versatran" license in the FRG	"Norda" robot is introduced in Italy				
1972	VFW-Fokker re-introduces the "Transfer Automat" in the FRG	"Unimate", "Trallfa", and "Aida Autohand" are being supplied to the FRG market				
1973	First use of electrical drive, non-ferrous disc type motors, in the FRG	Olivetti develops modular assembly robot "SIGMA" in Italy				
1974	Keller & Kanappich (KUKA) distributes forging shop, arc welding, and machine loading robots in the FRG	Industriale Marine (MAS) introduces "Area-4" robot in Italy				
1975	VFW Fokker develops gantry type robot for TV handling with support from the Ministry for Research & Technology in the FRG	Camel and Basfer robots are introduced in Italy	Volkswagen starts development of robot family (FRG)	IWKA Keller & Kanappich starts development of "Kuka" robot in the FRG	Comau Industriale is formed in Italy (Consortium of machine manufacturers for FIAT)	DEA starts development plans in Italy

Continued/....

TABLE A4.5: (Continued)

1976	Olivetti OSAI introduces Sigma robot into the Italian market	Pfaff-Pietzsch Industrieroboter introduces robot "PM-12" in the FRG				
1977	Volkswagen introduces four robots in the FRG	"Elfin" robot is introduced in Italy	Sciaky develops modular robot system in France	SAF + Languepin introduce "Robolang" unit for spot and arc welding in France	Comau introduces "Polar 6000" spot welding and handling robot in Italy	Zahnradfabrik Friedrichshafen introduces modular robot (FRG)
1978	Installation of first VW robot welding line in the FRG	Siemus buys license from Fujitsu Fanuc in the FRG	Nordson buys license from Basfer (separate teaching arm) in Italy	Utita Lathe manufacturer develops robot in Italy	Olmat, AISA, SLS, and Speroni robots are introduced in Italy	
1978	Ranault (ACMA-CRIBIER) develops four types of robots in France	IWKA Keller & Knappich (Kuka) introduces "Famulus" robot	"Robox" robot is introduced in Italy			
1979	Brown Bovery Vision System near commerical exploitation (Switzerland)	"Jobot" robot is introduced in Italy by JOBS	Bertin & Co. in collaboration with Exico introduces robot for water jet cutting in France	D.E.A. introduces Robot "PRAGMA A3000" for assemby (Italy)		

Continued/...

TABLE A4.5: (Continued)

1979	Reis introduces new general purpose robot (FRG)	Renault (ACMA-Cribier) developing parts identification vision system
1980	Hitachi starts marketing robots through Durr in the FRG	Sciacky buys license from Mitsubishi Heavy Industries ("RG Module" Type robot) in France

APPENDIX 5

CHRONOLOGY OF RESEARCH AND EXPERIMENTAL DEVELOPMENT IN ROBOT TECHNOLOGY FOR DIFFERENT COUNTRIES

APPENDIX 5

Chronology of Research and Experimental Development in Robot Technology for Different Countries

The following sections describe the main development projects conducted in the most important laboratories around the world (source of finance is also given for some of the projects). This information was extracted from papers published in the ISIR proceedings, from different reviews on international R & D (Frost and Sullivan 1974, Albus and Evans 1976, Gonsalves and Kurlat 1977, Ferreti 1978, Winship 1979, Rooks and Brock 1979, and Bylinsky 1979), and from private reports on visits to various countries (Rooks 1974 a,b,c, and d; and Rosenbrock 1979 a,b,c,d, and e).

Since ISIR papers report work which has been undertaken long before the publication of the proceedings all dates were corrected two years (*). Thus, dates are only an approximation and the latest projects have less coverage.

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* According to Brock (1980), ISIR papers are outdated by 18 months. A two year period was chosen for simplifying purposes.

A5.1 Research and Development in Japan

Hitachi Limited

1. Central Research Laboratory

1970 "HI-T-HAND EXPERT -1": robot with tactile sensors for packaging solid blocks.

1971 "HIVIP Mk. 1": Vision prototype (2 vidicon cameras) with drawing recognition, object recognition and object handling capabilities.

1972 "HI-T-HAND EXPERT-2": robot with tactile sensors performing an extremely precise insert operation (pistons in cylinders that have a clearance of only 20 microns) and tightening of bolts.

1973 "HITACHI HAND-EYE SYSTEM": objects to be recognised and handled are limited, and the environment is controlled (short cuts to hand-eye coordination).

1974 HAND-EYE system is tried in arc welding and in inspection of printed circuit boards.

1974 Robot with tactile sensors is tested in motor car assembly line putting wheels on vehicles.

1975 Integrated intelligent robot with multiple sensory feedback and two arms (tactile and vision sensors) developed in collaboration with the Production Engineering Laboratory.

2. Mechanical Engineering Research Laboratory

1972 Robot for underwater inspection (support from the Japan Society for the Promotion of Machine Industry).

1975 Automatic container handling device with tactile sensor.

1975 Automatic pouring system for cast iron.

1976 Materials handling device for irregularly shaped heavy work.

1978 Multipass welding of nozzles with an industrial robot.

3. Hitachi Research Laboratory

1972 Unattended travelling vehicle with optical guidance (in collaboration with Taga Works).

1975 Arc welding robot with sensor "Mr. Aros" (in collaboration with Narashino Works).

1975 Development of basic control programmes for robots with artificial intelligence (in collaboration with Narashino Works).

1976 Computer controlled robot for painting.

1977 Structural synthesis of robots.

4. Production Engineering Research Laboratory

1975 Industrial robots with linkage mechanisms.

1978 Robots for assembling a variety of mechanical parts.

1979 Working on small intelligent assembly robots.

Mitsubishi Electric Corporation

1. Research and Development Division

1971 Eye-in-hand robot with mini computer control for recognition and orientation of parts in two dimensions (two man years).

1974 Eye-in-hand robot with 6 axes and recognition and orientation of parts in three dimensions for assembly (e.g. insertion of small electric motor brushes into their housing in 15 seconds approx.) (3 man years)

1975 Automatic transistor bonding system with vision (T.V. camera).

Agency of Industrial Science and Technology (Ministry of International Trade and Industry)

1. Electrotechnical Laboratory (In general aiming at flexible and highly intelligent robots for use in manufacture

1966 Industrial robot with vision and computer control project in the Systems Research Group.

1967 Hydraulically powered single hand robot with visual system (in collaboration with the Tokyo Institute of Technology).

1972 Design of articulated manipulator with torque control ability by the Automatic Control Division (in collaboration with the Manufacturing Development Laboratory of Mitsubishi Electric Corporation).

1973 Robot with laser tracking, vision (mono and colour), tactile systems, and computer control for recognition and orientation of solid objects.

1975 Versatile finger system (Automatic Control Division in collaboration with Drive System Co.).

1975 Tactile sensor for a moving robot (in collaboration with the Tokyo Institute of Technology and Nippon Mining Co. Ltd.).

1976 Robot (7-axes), visual and tactile sensing, and locomotion system for turning a crank or inserting a peg into a hole.

1977 Working on two-hand coordinated manipulator for sawing and drilling.

1977 Working on pattern and voice recognition.

1979 Flexible complex manufacturing system provided with laser.

2. Mechanical Engineering Laboratory (In general working towards creating human-controlled robots for dangerous environments)

1974 Force control actuator system and adaptive manipulator.

1975 High precision manipulator with visual sense

1976 Involved in research in a two-hand coordinated system with 3-dimensional pattern recognition to be operative by 1985.

Tokyo Institute of Technology

1. Department of Physical Engineering (70% subsidised by the Ministry of Education and 30% from Industrial contributions) (working on duplication of humans and animals)

1972 Reticular locomotive robot.

1974 Active cord mechanisms with tactile sensors.

1975 Softgripper for versatile robot hand.

1976 Micromanipulator with a piezoelectric tactile sensor.

1978 Micromanipulator with multi degrees of freedom and a piezoelectric tactile sensor.

2. Department of Control Engineering

1972 Programming and teaching method for an industrial robot (in collaboration with the Machinery Division of UBE Industries Ltd).

1975 Robot with visual signal processing system.

1975 Robot system for tapping work(in collaboration with four companies).

3. Research Laboratory of Precision Machinery and Electronics.

1972 Simple vision for robots.

1977 Features for discrimination of complex shapes.

Kawasaki Heavy Industries

1972 Computer control of robot with vision (position, orientation and pick-and-place of flat parts making use of problem orientated language "Robotlan") (Technical Research Laboratory).

1972 High Performance robot for arc welding and assembly (Industrial Robot Systems Department).

1978 Kawasaki vision system.

University of Tokyo

1. Department of Precision Engineering (research aims: speeding-up arm movements, development of high level languages, better sensors, teaching methods, and operation in hostile environments).

   1972 Remote control system with image registration (in collaboration with Tokyo Electrical Engineering College).

   1979 Development of robotic arm (6-axes) as a standard tool for R & D (Arm built by Sumitamo Heavy Industry) (Financed by the Science Council of the Education Ministry: £50,000).

2. Department of Mechancial Engineering for Production.

   1972 Study of tactile sensor for shape recognition.

Waseda University

1. Mechanical Engineering Laboratory (95% financed by the Ministry of Education and the rest from private funds) (In general concentrating on prosthetic devices and artificial intelligence. Aim to build robot capable of walking, talking, seeing and hearing).

   1972 Anthropomorphous (2-arms) manipulator with cooperational control: "Melarm".

   1973 Tactile type hardness sensor for versatile hand.

   1976 Artificial walking machine "Wabot".

   1976 Artificial leg and arm.

2. Systems Science Institute

   1970 Study of the application of robots.

   1971 Analysis of the characterisitics of robots in the market.

   1972 Robot system design for labour saving and safety (supported by the PALS Committee of JIRA and JMSA trade associations).

   1973 Robot and computer control system design (in collaboration with the Kawasaki Heavy Industries and Oki Electric Industries, and supported by the PALS Committee of JIRA and JMSA).

   1975 Robot applications for improving the quality of working life.

Nagoya University

1. Department of Electrical Engineering

   1970 Robot and tactile sensor for slip detection (in collaboration with Aichi Inst. of Technology).

1971 Adaptive grasping for an industrial robot.

1972 Sensors for an industrial robot.

1973 Control of grasping (in collaboration with Aichi.Inst. of Tech.).

1974 Simple vision systems for industrial robots.

1977 Robot with simple distance sensor and minicomputer control (supported by the Ministry of Education).

1978 Colour sensing for an industrial robot.

A5.2 Research and Development in USA

SRI International Inc. (formerly Stanford Research Institute, Stanford University)

1969 Stanford hand-eye project (machine perception research).

1970 Experiments in scene analysis and robot vehicle "Shakey" (Artificial Intelligence Centre sponsored by the Advanced Research Project Agency of NASA. SRI project 8259).

1973-75 Exploratory research on advanced automation (sponsored by National Science Foundation under project NSF G1-38100X1 and 12 industrial affiliates).
- (i) Tactile and simple force feedback in packaging a box with water pumps (slow but potentially fast if controlled by dedicated computer).
- (ii) Gripper with sensory fingers for part recognition.
- (iii) Manipulator path control software (kinematic control, resolved motion rate control, and visual servoing).
- (iv) Wrist force sensory system for "Stanford arm".
- (v) Experimental vision systems.

1976 Demonstration of the use of force feedback for riveting application and binpicking using electromagnets as grippers.

1976 Servoing with visual feedback. Eye-in-hand Unimate 2000A (later converted to Unimate 2000B) with microcomputer control. Currently debugging software for microprocessor control of this arm. System tested for screwing two bolts in pump case (sponsored by the NSF APR 75-13074 and 10 industrial affiliates).

1977 Vision system (hardware and software) (sponsored by NSF APR 75-13074 and 16 industrial affiliates).

1977 Eye-in-hand project continues.

1977 Interactive compiler for more productive programming of computer controlled robots (in collaboration with Phillips Research Centre in Britain).

1979 Bin-picking experiments using a voice-controlled Unimate with electromagnetic end effectors (one-sentence spoken commands relating to portions of an assembly job) (sponsored by NSF and 18 industrial affiliates).

1979 Bowl feeding system with visual feedback (avoid the use of mechanical orientation devices).

1979 Robot assembly of cylinder heads onto a small compressor with vision.

1979 Robot with vision for recognition, picking up and orientation of parts on conveyor belt.

Artificial Intelligence Laboratory, Computer Science Department, Stanford University

1967 Optical feedback in computer control of arm (machine perception research: identification and picking-up of parts in random positions).

1971 Visual perception by computer.

1973 Computer description of curved objects.

1973-75 Computer integrated assembly systems project:
(i) Indirect force feedback trhough changes in the current of dc actuators
(ii) Assembly system tested for water pumps.
(iii) Different approaches to vision. Survey on sensors.

1975 Laser sensory system for three dimensional scene analysis.

1976 Task description language for assembly (Problem orientated language: AL).

1979 Pointy system: robot with vision for location, picking up and assembly of screwed parts onto the body of a valve

The Charles Stark Draper Laboratory Inc. (formerly The Charles Stark Draper Lab of MIT)

1970 Early model of wrist force sensor for teleoperator.

1971 Multimoded remote manipulator system (sponsored by NASA and AEC Space Nuclear Systems Office) (in collaboration with MIT)

1973 Force vector assembly concept (indirect sensing of force for gross motion control).

1974-75 Exploratory research on industrial modular assembly (sponsored by NSFG1-39432X and G1-4378) (in collaboration with MIT):
(i) Survey on sensors.
(ii) Force information in assembly process (vector force sensing for assembly operations. Close tolerance peg-in-the-hole problem).

(iii) Pedestal and wrist force sensors for automatic assembly (measurement of work forces of insertion operations in 6-axes).

(iv) Latest model of wrist force sensors (developed a force feedback strategy based on active accommodation).

(v) Mathematical model for the compliance wrist.

(vi) High speed robot assembly of precision parts using compliance instead of sensory feedback.

1976 Programmable robot assembly station for assembly of automobile alternators (17 parts) (Computer controlled, 4-axes manipulator with compliance wrist, six interchangeable tools, and two assembly fixtures).

1977 Cycle time analysis programme of assembly systems (sponsored by NSF APR 74 - 18173 - AO3).

1977 Remote Centre Compliance wrist on trials.

1978 Monitoring of applications for the RCC.

MIT Artificial Intelligence Laboratory

1973 Vision systems for robots (Machine perception research A-TR-281 and AD-775-439).

1973 Scene analysis in a non-hierarchical structure.

1975 Parts recognition, positioning and orientation techniques with solid state arrays.

University of Rhode Island

1973 Visual robot instruction (sponsored by NSF APR 74 - 13935).

1974 New robot programming devices (sponsred partly by NSF APR 74 - 13935).

1975 Algoriths to visually acquire workpieces (sponsored by NSF APR 74 - 13935).

1976 Three approaches for acquiring workpieces using robots (sponsored by NSF APR 74 - 13935).

1977 Complex vision system. Recognition and orientation of parts randomly heaped on a chute (sponsored by NSF APR 74 - 13935).

1978 Complex vision system. Work on reduction of the time response (sponsored by NSF APR 74 - 13935).

1978 A contour adapting vacuum gripper.

1978 Hardware computation of image features based on local gradient direction histograms.

1979 Complex vision system (Binary image and standard T.V. camera).

General Motors Research and General Motors Manufacturing Development

1973 Computer vision for simulated assembly tasks (orientation, positioning and assembly of wheels on hubs).

1975 Machine perception project.

1976 Programmable computer vision system.

1976 Programmable Universal Machine for Assembly: PUMA project for human and robot assembly (in collaboration with Unimation Inc.). Tested for assembly of printed circuit boards.

1977 Consight: vision based robot guidance system (first practical approach to vision. Demonstrated recognition of multiparts in a scene where some parts are partially occluded or abult).

1979 Consight and PUMA project continue.

1979 Dynaslide system for feeding and orientating.

1979 Compound compliance devices.

Westinghouse Electric Corporation

1. Research and Development Centre

1973 Robot for arc welding with contouring teach mode.

1973 Requirement analysis and justification of intelligent robots (partially supported by the NSF).

1976-79 Adaptable Programmable Assembly Systems (APAS) Project. Biggest effort to produce automated assembly: pilot production line with seven robots for assembly of five different electronic motors (partially supported by the NSF).

IBM

1. Thomas J. Watson Research Centre

1972 Experimental system for computer controlled assembly with sensory feedback.

1973 Computer controlled robot for mechanical assembly for subassembly of typewriters (problem orientated language ML).

1979 Assembly automation and parts description languages.

Texas Instruments

1979 Assembly automation with vision sensors (a robot with T.V. cameras for assembly of pocket calculators has been designed).

GTE Laboratories Inc.

1973 Video target locator.

1973 Minicomputer controlled robot for T.V. tube handling.

1975 Structured software system for industrial automation (use of simple vision and problem oreintated language Alpha).

National Bureau of Standards

1973 Hierarchical control (cerebelar model articulation controller).

1974 Control strategies for industrial robots.

1977 Hierarchical control of robots using microcomputers.

1977 Mobile simple vision system.

1978 Measurement and control model for adaptive robots.

Unimation Inc.

1975 Assembly experiment. Two armed robot "Unimate 6000" (in collaboration with Ford Motor Company).

1976 Robot path controlled by off-line computer (in collaboration with CONDEC).

1978 Automatic control of an IR by vision.

Cincinnati Milacron Inc.

1973 Computer controlled robot.

1976 Computed path control.

1977 New wrist.

1977 Software.

1978 Off-line programming

Jet Propulsion Laboratory

1975 Robot vision system (laser + T.V. manipulator for Marsian surface).

1979 Remote sensing: proximity, slip, and touch sensors (e.g. plastic skin for robot hands).

1979 Shuttle remote manipulator system.

1979 Speech command (voice recognition).

Lockheed - California Co.

1979 Vision controlled fastening of aircraft structures.

United Space Boosters Inc.

1979 Utilisation of a robot system on the solid rocket booster components for the NASA space shuttle programme.

Johnson Space Centre

1979 Shuttle Remote Manipulator System (SRMS).

A5.3 Research and Development in Britain

Nottingham University

1. Department of Pruduction Engineering and Production Management, Department of Electrical Engineering, and Wolfson Industrial Automation Group (WIAG).

1968 Flexible automated assembly systems (1st Programmable assembly system for assembly of Post Office relays).

1970 Visual feedback to programmable assembly machinea (with support from the Science Research Council).

1972 SIRCH robot

1974 Versatile variable mission assembly machine.

1974 Novel techniques for tactile sensing (with support from the SRC).

1975 Computer graphic simulation of robot systems (with support from the SRC).

1976 Three dimensional part identification with tactile sensors.

1977 Versatile parts feeding package with vision feedback (in collaboration with Tecquipment Ltd. and support from the SRC).

1977 Robot blacksmith (in collaboration with Hitachi Ltd.

1978 Recognition and orientation through teletext.

1978 Opendie forging (in collaboration with Hitachi Ltd)

1978 Interactive computer graphics.

1979 Ring forging with an industrial robot.

Edinburgh University

1971 Picture processing (machine perception project).

1972 Versatile computer controlled assembly system.

1974 Machine vision.

1977 Assembly description languages (with support from the SRC).

Surrey University

1972 Opto-pnuematic manipulator arm (simple vision by photo-diode).

1975 Microprocessor control and pneumatic drive for a manipulator.

1977 Electro-pneumatic industrial manipulator.

Birmingham University

1. Department of Mechanical Engineering

1973 Simple and accurate positioning system.

1975 Robots for cold forging (petro forging).

1977 Fettling of castings (with support from the SRC).

Warwick University

1975 Tactile, sonar, and parallax sensors (with support from the SRC and NRDC).

1977 Mobile robot project (with support from the SRC).

University College London

1976 Mechanical manipulation for the investigation of disordered environments.

1978 3-degrees of freedom manipulator.

1979 Real time teaching and recognition system for robot vision.

University of Wales

1977 Vision System (with support from the British United Shoe Machinery and the Post Office).

National Engineering Laboratory (fully supported by the British Government)

1975 Computer control of arc welding (Unimate 2000B/5-axes/interpolation) (supported by DoI Mech.Eng. and Mach. Tools requirements Board).

1978 Robots for arc welding (in collaboration with the Welding Institute).

A5.4 Research and Development in the Federal Republic of Germany

Berlin Technical University

1973 Flexible manufacturing system (two milling machine tools plus a transfer automat robot) (in collaboration with SIEMENS).

1975 CNC control of robots with a modular programming language (supported by the Federal Ministry of Research and Technology under the Humanisation of work programme).

1975 Model for a flexible manufacturing cell for rotor parts (in collaboration with Gilldemeister-Max Muller and support from the FMRT).

1976 Visual system (image converter with photo-electric sensors).

1976 Flexible manufacturing cell for rotor parts (in collaboration with the Gildemeister/Max Muller and support of the FMRT).

Institut fuer Informationsverarbeitung in Technik und Biologie (IITB), Karlsruhe

1975 Path control for a redundant type of robot.

1976 Direct digital control (with support from the FMRT DV5.505 + F683.19).

1976 T.V. sensor for an industrial robot (with support from FMRT BFTHdA01VV135-B13-TAP006 + ARGE-HHS).

1976 Identification of silhouettes (with support from the FMRT ARGE-HHS 01VV 046-2K 7AP 0004).

Institut fuer Produktionstechnik und Automatisierung (IPA) Stuttgart

1969 Industrial robots: problems and opportunities.

1970 Study of the state-of-the-art of robots in West German industry.

1971 Analysis of automatic handling systems

1971 Survey of the characterisitics of robots world-wide.

1971 Survey of the workplace requirements for robots.

1972 Comparison of required and available robot characteristics.

1973 Design of machine tools for automatic handling.

1974 Computer aided selection of robots.

1975 Test stand for industrial robot performance.

1976 Performance evaluation and standardisation of terms.(with support from the FMRT ARGE-HHS).

1976 Flexible assembly (with support from the FMRT ARGE-HHS).

1976 Tactile sensor controlled IR for machining (FMRT ARGE-HHS).

1976 Multi-processor control system for an IR.

1976 Planning robot introduction by computer (FMRT ARGE-HHS).

1977 Advance tactile sensitive robot for grinding (FMRT BMFT-TAP0004).

1977 Fully flexible manufacturing cell.

1978 Deburring and fettling by sensor controlled IR

1978 An APAS using compliance and visual feedback.

1978 Concepts for standardisation of feeding systems.

1978 Potential for robots in new fields.

1979 Automatic positioning of parts with vision and tactile sensors.

1979 Vibrating bowl feeders with modular design.

University of Aachen

1976 Adhesive pallet (in collaboration with Sachs System-Technik and support from the FMRT).

Volkswagenwerk

1976 VW robot programme (with support from the FMRT ARGE-HSS).

Bosch

1976 Optoelectronics identification sensors (support from FMRT ARGE-HHS).

Karlsruhe University

1977 Vision system (support from FMRT SRT V5.505).

IBP Pietzch

1976 Electropneumatic robots (with support from the FMRT 01VC024 213TAP0002).

1978 Flexible ordering and feeding of workpieces using intelligent workplace recognition devices.

Pfaff Industrie Maschineu

1976 Adjustable jaw geometry grippers (with support from FMRT ARGE-HHS).

SIEMENS

1976 SIEMENS Robot

Zahnradfabrik Friedrichshafen

1976 Flexible systems with modular handling system (with support from the FMRT and the DFVLR).

A5.5 Research and Development in Italy

Milan Polytechnic

1. Artificial Intelligence Project

1973 Emergency recovery for intelligent robots.

1975 Multimicroprocessor control of robots (in collaboration with the Institute of Electrotecnia and Electronics of Milan Polytechnic - IEEMP).

1975 Programming an industrial robot in Italian.

1977 Sensing system for Supersigma robot (in collaboration with the IEEMP).

1977 Multipurpose Assembly Language MAL (in collaboration with the IEEMP).

1978 Distributed robot programming.

1978 Microcomputer based stepping motor drive.

1978 User defined control structures in programming languages for robots.

1978 Precision measurement by stereo vision system.

1978 Programme abstraction and error correction for intelligent robots.

2. Institute of Mechanics and Machines

1975 Design of multipurpose mechanical hands (supported by the Italian National Research Council - INRC).

1976 Prehension of a robot mechancial hand (supported by the INRC).

1978 A new mechanical structure for robots.

1978 General prehension elastic system (in collaboration with Alpha Romeo).

Olivetti Systems for Industrial Automation (OSAI)

1973 Sigma assembly robot project.

1975 New parts orienting device.

1976 Sigla assembly language.

Centro.Richerche FIAT

1978 Industrial robots with sensory feedback for continuous arc welding.

Genoa University

1976 Position steering by statistical controllers (in collaboration wit Lehigh Univ., USA)..

1978 Linguistic approach to measurement of 3-D motions of kinematic chairs.

1978 Control of anthropomorphous manipulator dynamics.

Elsag

1978 Formal language for 3-D objects description in robot vision.

SEPA

1976 IDRA-12 Fully static memory sepa control system for CP robots.

1978 New advanced control system for PTP robots.

Instituto Progetti di Macchine e Tecnologie Meccaniche de Bologna

1978 Multi-finger gripper.

A5.6 Research and Development in France

IRISA/ENSM/SAGEM

1976 Recognition and sorting of pieces (supported by grant DGRST No. 77-7-009S)

1976 Infrarred sensors.

Laboratorie d'Automatique de Montpellier

1977 Optimal pattern recognition method.

1977 Artificial skin sensor.

1978 Vision-movement interaction in handling by robot.

1978 Computer-aided design of robots.

1978 Force controlled robot.

Laboratoire d'Automatique Toulouse

1978 Multisensor system for mobile robot "HILAIRE".

1978 Task-specific planning in a blocks-world assembly experiment.

1978 Dynamic control of manipulator.

A5.7 Research and Development in Switzerland

Ecole Polytechnique Federale de Lausanne

1974 Rules for building robots.

1975 Description and control of the state of a robot.

1976 Force feedback control.

1976 Vision system (polar coding).

1976 Vision system (sponsored by SCERS 880 project).

1977 Visual recognition and handling (in collaboration with Swiss Institute of Technology and Linkoeping University Sweden)(Supported by SCERS 880 project).

1978 Design of APAS (in collaboration with Waseda University Japan).

1978 Dynamic parameters for robot arm.

1978 HYDRA robot controller.

Brown Boveri Research Centre

1976 Flexible opto-electronic sensor

1977 Optoelectronic sensor

1979 Vision System (near commercial exploitation) Identification, orientation and pick-and-place of objects in two dimensions.

A5.8 Research and Development in Scandinavia

Production Engineering Laboratory, NTH-SINTEF, Norway (Foundation for Industrial research at the Norweigan Institute of Technology)

1976 Flexible manufacturing cell (4 machine tools, one Cincinnati robot, and peripheral equipment).

Academy of Finland and Helsinki University of Technology

1975 Digitally implemented sensing and control for standard robots.

1976 Object recognition and handling with a robot with vision (2-dimension and stationary parts).

1977 Reduction of visual data by a programme controlled interface.

Linkoeping Institute of Technology Sweden

1978 Subassembly of an axle to a gear box by robot.

ASEA Sweden

1977 Adaptability for industrial robots.

APPENDIX 6

THE GROWTH IN ROBOT SUPPLY AND MANUFACTURE

APPENDIX 6

The Growth in Robot Supply and Manufacture

A compilation of estimates of the number of firms and robot models, and of the nominal capacity of manufacture of various firms is given below. Tables A6.1 and A6.2 show figures selected from a wide ranging sample, some of which vary significantly. Several sources of error may be noted. The type of firm (distribution agency, licensee or manufacturer), the type of robot, and the method of estimation, were not specified by the sources and are likely to be different. Thus, these tables can only be used to illustrate broad trends like the tendency for less robot establishments after a sudden burst in market entries. As this happened, successful firms grew substantially (Table A6.3).

TABLE A6.1 - Approximate Number of Firms Marketing Industrial Robots

	1962	1968	1972	1973	1974	1975	1976	1977	1978
W. Europe		2[A]	8[A]	16[A]	21[A]			40[F]	
USA	1	2[A]	20[A]	31[A]	45[A]			40[F]	
Japan		1[A]	40[A]	52[A]	70[A]			120[E]	
World Wide	1	5[A]	68[A]	99[A]	136[A]	150[B]	170[C]	200	140[D]

Notes:

A Grefermann et al (1975, p75)

B Ciborra et al (1976, p.188)

C Compressed Air (1976)

D Belyanin and Rozin (1978)

E Yonemototo and Shiino (1977, p.171)

F Warnecke and Schraft (1977a p.25)

TABLE A6.2 - Approximate Number of Robot Models

	1962	1973	1974	1975	1976	1977
W. Europe		23-35[A,F]		69[G]		
USA	1	16-21[A,F]		36[G]		
Japan		91-112[A,F]		120[G]		
Worldwide	1	142-156[A,F]	250[B]	250[C]	200[D]	200[E]

Notes:

- A Hasegawa (1973, p.59)
- B Ghali (1974, p.114)
- C Ghali (1975)
- D Compressed Air (1976)
- E Warnecke and Schraft (1977a)
- F Heginbotham (1973, p.R1-10)
- G Tassel (1975)

TABLE A6.3 - Nominal Capacity for Robot Manufacture in Various Firms and Countries (Robots per annum)

FIRM	1972/3	1974	1975	1976	1977	1978	1979	1980	1981
Unimation	180-240 [A]	240 [B]	300 [C]		360 [D]	480 [D]	540 [E]		
AMF		60 [F]							
Kawasaki Heavy Industries		60 [B,F]			200 [G]		200-225 [H]	300 [I]	
Fujitsu Fanuc							120-180 [J]		
Electrolux						100 [K]			
Volkswagen						156 [L]			
Hall Automation						24-36 [M]	36-48 [N]	108 [N] (Planned)	162 [N] (Planned)
Cincinnati Milacron (Planned)								400 [O]	
Unimation PUMA UK (Planned)									120 [P]
Japan's five largest manufacturers							400-450 [H]		
Scandinavia (Sweden and Norway)	120-180 [Q]								

On average, economies of scale start to become significant at the 2000 robots per year level (R)

Continued/....

Notes for Table A6.3:

A Tassel (1975)

B Engelberger (1974b; p.145)

C Lamb (1975)

D Cakebread (1978)

E McNeil (1979, p.60)

F Frost and Sullivan (1974, p.73)

G Wider (1977, p.37)

H BRA (1979, p.154)

I Brock (1980)

J Barson (1979, p.11)

K Dale (1979)

L Hartley (1978, p.68)

M Hall (1978)

N Rooks (1979,p.164)

O Scarbrough (1980, p.18)

P Duffy (1979b)

Q Engellau (1972,p.49)

R Average from figures given by Hall (1978) and Cakebread (1978)

APPENDIX 7

THE INTERNATIONAL DIFFUSION OF INDUSTRIAL ROBOTS

APPENDIX 7

The International Diffusion of Industrial Robots

Estimates of the number of robots installed at different points in time in different countries vary widely. Several problems exist: the definition of a robot is not precise and standardised; robots sold are not always installed and others may have been discontinued after unsuccessful trials; and in-house development and use of robots is less well-known. The number of robots sold was chosen as an indicator of the robot population. To improve the accuracy of these estimates several sources were used.

Disaggregated figures fo robots sold per make per country were collected for the years 1974, 1976 and 1978 (see Tables A7.1, A7.2 and A7.3). These are only samples of the population in each country and are more representative of Western Europe (Sweden in particular) than they are of USA and Japan. The different makes of robots were divided into classes with the purpose of giving some information on the extent of use of PPD's. This is bound to be less representative than the information on SR's and servo controlled robots.

As many estimates of the aggregaged figures of robots sold or of the robot population per country per year were collected. A selection of these estimates was then made using the disaggregated information as an aid. Selection of a range rather than single estimates were preferred with the purpose of giving information on the variance of the data. If a source was thought to be more reliable than the rest, this was the only chosen (see Table A7.4).

Further information on the international differences of robot usage is given with reference to spot welding in the motor car industry; the single most successful application of robot technology (see Table A7.5, A7.6 and A7.7).

TABLE A7.1 - The International Diffusion of Robots by 1974 - A Sample
(Cumulative number of robots sold)

MAKE \ COUNTRY	Scandinavia (Sweden)	FRG	Italy	UK	France	Others	W. Europe	Japan	USA	Others	W/wide
Medium and High Technology Robots (HTR's and MTR's)											
Unimation	31(25)[A]	30[A]	79[A]	T,A 14-16	11[A]	5[A]	C,B 140-222	100[C]	500[C]	4	772-822
AMF (Versatran)	3(3)[D]	D,A 5-6	9[D]	D,E 42-50	3	4	F,Q 100-125	75[Q]	250[Q]	8[D]	433-458
Trallfa (G)	56(46)	69	23	20	27	8	203	33	9	6	251
Asea (H)	8(8)						8				8
Retab (A)	1(1)					1	2				2
SIV Robots (M)							30				30
ARO (A)		10					10				10
Yaskawa (N)								300			300
IWKA KUKA (O)		30					30				30
Total: MTR & HTR	99(83)	144-145	111	76-86	41	18	523-630	508	759	18	1836-1911

Continued/....

TABLE A7.1 - (Continued)

COUNTRY / MAKE	Scandinavia (Sweden)	FRG	Italy	UK	France	Others	W. Europe	Japan	USA	Others	W/wide
Simple Robots (SR's)											
Electrolux (I)	78(64)	15	1		1	3	98	5		1	104
Kaufeldt	85(80)[A]	1[A]		1[A]			87				A,J 267-300
Aida (A)		5					5				10
Fibro (A)		5					5				5
VFW Fokker (A)		1									
B & R Taylor (Transiva) (L)				6							
Prab (Q)									50		
Snow Manufact'g (R)									100		
Autoplace (P)									>250		
Total: SR	163(144)	27	1	7	1	3	195	5	> 400	1	386-419
Total: MTR & HTR & SR	262(227)	171-172	112	83-93	42	21	718-825	513	1159	19	2222-2330

Continued/....

TABLE A7.1 - (Continued)

MAKE \ COUNTRY	Scandinavia (Sweden)	FRG	Italy	UK	France	Others	W. Europe	Japan	USA	Others	W/wide
Pick-and-Place Devices (PPD's)											
DTS (EKOMAT) (K)	26(18)						26				26
Total: PPD	26(18)						4000-5000 s				
Total	288(245)	171-172	112	83-93	42	20	4718-5825	513	1159	19	2248-2356

Continued/....

Notes for Table A7.1

A Warnecke et al (1974, p111)

B Unimation (1975, p29)

C Frost and Sullivan (1974, p70)

D Information provided by Hall Automation (Hall 1978)

E Birnie (1974b, pG18)

F Birnie (1974a, pE2-17)

G Information provided by The De Vilbiss Company Ltd. (Mooney 1978)

H Information provided by ASEA Electronics Division (ASEA, 1979)

I Information provided by George Kuikka Ltd. (Ryott 1976)

J Lassi (1974, p441)

K Information provided by Direct Transport Services (Sweden) Ltd (Sjoelin 1978)

L Estimate for 1973 (Hunter 1973, pR-292)

M Alessio (1974, pG-21)

N Yoshinari et al (1974, p475)

O American Machinist (1975, p101)

P Estimates for 1972 (Adams 1972, p203)

Q Frost and Sullivan (1974, p73)

R Frost and Sullivan (1974, p83)

S Tassel (1975)

T See Appendix 10

TABLE A7.2 - The International Diffusion of Robots by 1976 - A Sample
(Cumulative number of robots sold)

MAKE \ COUNTRY	Scandinavia (Sweden)	FRG	Italy	UK	France	Others	W. Europe	Japan	USA	Others	W/wide
Medium and High Technology Robots (MTR's and HTR's)											
Unimation	81(74)[A]	>18[B]	>58[B]	20[M]	>52[B]		>225	186[B]	>175[B]	>15[B]	CN 1000-1400
Trallfa (D)	95(71)	91	46	28	29	11	300	72	29	53	398
Asea (E)	55(55)	5		2	2		64		1	2	67
Olivetti (F)			>12				>12				>12
Hall (Ramp)				2[M]							
Total: MTR & HTR	231(194)	>114	>116	52	>83	11	>601	>258	>205	>70	1477-1877
Simple Robots (SR's)											
Electrolux (G)	159(127)	24	1	4	4	4	196	14		6	216
Kaufeldt (I)											>400
Showa Kuatsuki (VFW Fokker Transferautomat) (K)								100			
Autoplace (L)									>500		>500
Total: SR	159(127)	24	1	4	4	4	196	114	>500	6	>1116
Total: MTR & HTR & SR	390(321)	138	117	60	>87	15	>797	>372	>705	>76	2593-2993

Continued/....

Table A7.2 - (Continued)

MAKE \ COUNTRY	Scandinavia (Sweden)	FRG	Italy	UK	France	Others	W. Europe	Japan	USA	Others	W/wide
Pick-and-Place Devices (PPD's)											
Mullard (M)				10							
Hall (M)				1							
DTS (EKOMAT) (H)	40(31)						40			3	43
Starseiki (M)				1							
Sterling Detroit (J)											300
Total: PPD	40(31)						40			3	343
Total	430(352)	138	117	72	>87	15	>837	>372	>705	>79	2936-3336

Continued/....

Notes for Table A7.2

A Information provided by George Kuikka Ltd. (Electrolux are suppliers of Unimate in Scandinavia) (Ryott 1976)

B Information is limited to automobile spot welding applications. Provided by Unimation (Europe) Ltd (Cakebread 1978)

C Engelberger (1976a, pJ4-56)

D Information provided by the De Vilbiss Company Ltd. (Craine 1978)

E Information provided by ASEA Electronics Division (ASEA 1979)

F Estimates for 1975 (D'Auria and Salmon 1976)

G Information provided by George Kuikka Ltd (Ryott 1976)

H Information provided by Direct Transport Services (Sweden) Ltd (Sjoelin 1978)

I Estimate for 1975 (American Machinist, 1975, p99)

J Canner (1975, p171)

K Toussaint (1976, pG1-4)

L Potter (1975, p56)

M See appendix 10

N Information provided by Unimation (Europe) Ltd. and valid for January 1977 (Cakebread 1978)

TABLE A7.3 - The International Diffusion of Robots by 1978 - A Sample (Cumulative number of robots sold)

MAKE \ COUNTRY	Scandinavia (Sweden)	FRG	Italy	UK	France	Others	W. Europe	Japan	USA	Others	W/wide
Medium and High Technology Robots (MTR's and HTR's)											
Unimation	100(91)[A]	50[A]	A,B 200-288	A,C 50-70	70[A]	80[A]	D,E 500-658	F 400-500	G 942-1300		B 2100-2200
Trallfa (H)	154(105)	148	110	45	47	18	522	117	47	86	772
Asea (I)	117(110)	25	4	14	19	26	205		4	16	225
Hall Automation	4(4)[A]			J,A 20-50		6[A]	30-60				100[J]
IWKA KUKA (A,K)		75-100					75-100				75-100
Volkswagen (L)		100					100				100
Renault (A,M)					25-30		25-30				25-30
Nordson			13[A]		8[A]	1[A]	22[A]				>22
Olivetti (A)			20				20				20
FIAT (A)			10				10				10
Cincinnati Milacron (A)	1	4					5				>5
Siemens (F. Fanuc) (A)		5					5				5
Total: MTR & HTR	376(310)	407-432	357-445	129-179	169-174	131	1519-1737	517-617	993-1351	102	3459-3589

Continued/....

TABLE A7.3 (Continued)

MAKE \ COUNTRY	Scandinavia (Sweden)	FRG	Italy	UK	France	Others	W. Europe	Japan	USA	Others	W/wide
Simple Robots (SR's)											
Electrolux	A,N 155-252 (252)	25[A]	10[A]	O,A 6-10	2[A]	28[A]	226-327	25[P]	300[Q]		551-652
Aida (R)				1			20	500			> 520
Prab (X)							10-15		270		280-285
Kaufeldt (U)	(400-500)						400-500				400-500
MAS (Area 4) (a)			60	10			70				100
Rosenlew (A)	56				2		58				58
Total: SR	611-808 (652-752)	25	70	17-21	4	28	784-990	525	570		1909-2115
Total: MTR & HTR & SR	987-1184 (962-1062)	432-457	427-515	146-200	173-178	159	2303-2727	1042-1142	1563-1921	102	5368-5704
Pick-and-Place Devices (PPD's)											
Star Seiki (T)				15			> 15	10000			12000
Rimrock (w)				1			>1		36		>37
Italpress (Y)		10-20		1			11-21				11-21

Continued/....

TABLE A7.3 (Continued)

MAKE \ COUNTRY	Scandinavia (Sweden)	FRG	Italy	UK	France	Others	W. Europe	Japan	USA	Others	W/wide
Buhler (Z)				3			> 3				> 3
Mouldmate (V)				6		2	8				8
Montech (S)				>50			> 50				> 50
Total (PPD)		10-20		76		2	88-98	10000	36		12109-12119
Total	987-1184 (962-1062)	442-477	427-515	222-276	173-178	161	2391-2825	11042-11142	1599-1957	102	17477-17823

Continued/....

Notes for Table A7.3

A Estimates compiled by the firm Rosenlew and quoted in Rosenbrock (1979 c)

B Information provided by Unimation (Europe) Ltd (Cakebread 1978)

C Information provided by Unimation (Europe) Ltd. (Cakebread 1979)

D Mortimer (1978, p17)

E Addition of highest figures

F In 1977 Kawasaki Heavy Industries had produced 200 robots (Wider, 1977, p37). In 1979 this company had sold 700 units and had a capacity to manufacture 200-225 per annum (BRA 1979, p154). Thus 400-500 is a good estimate for the cumulative sales by 1978

G Assuming no sales to 'others' USA estimates results by substraction from worldwide sales

H Estimates based on a 31% annual growth calculated from the number of Trallfa robots sold worldwide by 1974 and 1976. Information provided by De Vilbiss Company Ltd. (Craine 1978)

I Information provided by ASEA Electronics Division (ASEA 1979)

J Large (1978)

K Mueller (1978, p80)

L Hartley (1978, p68)

M The Engineer (1979)

N Estimate based on a 26% annual growth calculated from the number of Electrolux robots sold in Scandinavia by 1976 and 1977. The number of units by 1977 in Sweden was 200 (Rooks 1977, p27)

O Information provided by George Kuikka Ltd (Dale 1979)

P Estimate based on a 44% annual growth calculated from the number of Electrolux robots sold in Japan by 1976 and 1975

Q Ryott and Gemvik (1978, p122)

R Information provided by Marubeni Corporation Ltd. (Curry 1978a and 1978b)

S Information provided by Derek W.S. Durance (D.W.S.D. 1978)

Continued/....

Notes for Table A7.3 (Continued)

T Information provided by Cole Equipment Ltd (Arnold 1978)

U Estimates for Sweden in 1977 (Rooks 1977, p27)

V Information provided by Mouldmation (Webster 1978)

W Information provided by Rimrock Corp (Nagai 1978)

X Information provided by Acheson Industries Europe (Renkl 1978)

Y Information provided by Italpresse (UK) Ltd (Italpresse 1978)

Z Information provided by Buhler-Miag (England) Ltd (Lorrimore 1978)

a Information provided by Phillips R+K Ltd (Phillips 1979)

TABLE A7.4 - The International Diffusion of Industrial Robots - Aggregated Figures (*)

Region	1965	1967	1968	1969	1970	1971	1972	1973	1974
Sweden			30[A]	50[A]	60[A]	75[A]	100[A]	130-200 [A,J]	164-227 [B,C]
FRG							18-50 [K,L]	50[K]	133[B]
Italy									93-112 [B,C]
UK								50[O]	85[C]
France									30-42 [C,B]
Others									42-55 [B,C]
W. Europe		50[R]		150[R]		350[R]		300-550 [K,R]	547-705[K]
Japan		10[R]		42-50 [T,R]	161[T]	252-500 [T,R]	371-750 [T,K]	546-1100 [T,R]	840-1500 [T,S]
USA	25[R]	100[R]		250[R]	200[S]	600[R]		800-1000 [K,R]	1159-1300 [C,F]
Others									19[C]
Worldwide	25	160		442-450	<1000[C]	1202-1450		1646-2650	2564-3524

* Excluding Pick-and-Place Devices (PPD's)

Continued/....

TABLE A7.4 - (Continued)

Region	1975	1976	1977	1978	1979
Sweden	300–445 [A,D]	400 [A]	500–870 [A,I]	700–1062 [A,F]	1000 [H]
FRG	150–243 [M,D]	>138 [E]	490 [H]	570 [H]	600 [G]
Italy	362 [D]	>117 [E]		300–515 [N,F]	500 [P]
UK	85-93	93 [Q]		147 [Q]	207 [Q]
France	144 [D]	> 87 [E]		173-178 [F]	>178
Others	154 [D]	84 [E]		208 [F]	> 280
W. Europe	1195–1441 [D]	1500 [d]		2093–2805	2765
Japan	1148–1700 [T,M]	1561–2000 [T,d]	2261 [W]	3000–3361 [U,X]	4100–4461 [X]
USA	2059–2200 [Y]	2000-2500 [d,Z]		2500–3000 [U,a]	4000–4800 [b]
Others		>76 [E]		102 [F]	>102
Worldwide	4402–5351	5500 [d]		7593-9166	10967-12128

Continued/....

Notes for Table A7.4

A Fletcher (1979, p222)

B Warnecke et al (1974, p111)

C See table A7.1

D Frost and Sullivan (1975)

E See table A7.2

F See table A7.3

G McNeil (1979, p56)

H Pugh et al (1979, p90)

I Rooks (1977, p27)

J Bojonsson (1973)

K Grefermann et al (1975, p75)

L Warnecke and Schraft (1972, p21)

M Stout et al (1976, p440)

N BRA (1978, p5)

O Heginbotham (1973, pR1-10)

P Duffy (1979a)

Q Estimates from Appendix 10

R Tassel (1975)

S Frost and Sullivan (1974, p3-4)

T Variable sequence and play-back robots only (7% @ 1976 of the figures reported by Yonemoto and Shiino 1977, p171)

U Shah (1978, p21)

W In 1977 500 programmable robots and 200 intelligent robots were produced (Pugh et al 1979, p90)

X In 1978 1100 programmable robots were produced (BRA 1979, p153). The same is assumed to be the case for 1979

Y 900 industrial robots were sold in USA in 1975 (Unimation 1976)

Z Unimation (1976)

Continued/....

Notes for Table A7.4 (Continued)

a Knight (1978)

b Estimates based on a growth rate of 125-150 robots per month (Knight, 1978)

c Ghali (1972)

d Warnecke et al 1976

TABLE A7.5 - Unimation Robots in Spot Welding in the Motor Car Industry (Cumulative)

Country	1976	1977	1978	1979
USA				
Ford Motor Co.	77	112	208	236
General Motors	61	83	87	160
Chrysler	29	48		80
American Motors	8	-		10
JAPAN				
Nissan Motor	88	95		
Toyota (Motor & Shatai)	70	70		
Susuki Motor	13			
Fuji Heavy Ind.	10			
Kanto Motor	3			
Mitsubishi Motor	3			77
ITALY				
Fiat	53	180	232	
Lancia	5	6	6	
SWEDEN				
Volvo	44	58		
FRG				
Daimler-Benz	18	18		
FRANCE				
Renault	27	30		
Peugot	17	19		
Citroen	4			
POLAND				
FSO	15	16		
SOVIET UNION				
Zil	-	12		
UK				
British Leyland	-	31		

Source: Information from Unimation (Europe) (Cakebread 1978) and various other sources

TABLE A7.6 - Growth of Spot Welding Robots in the Motor Car Industry

Year	Sales	Cumulative Sales
1966	8	8
1970	31	39
1971	43	82
1972	62	144
1973	140	284
1974	65	349
1975	122	471
1976	82	553
1977	241	794
1978	182	976
1979	209	1185

Source: Estimated from information provided by Unimation (Europe) (Cakebread 1978) and various other sources

TABLE A7.7 - Chronology of Main Robot Applications in the Motor Car Industry

1962	First installation at Ford Motor Co. and GM
1970	First multiple installation (29) for spot welding of motor car body panels at GM, Lordstown Ohio plant in Chevrolet Vega line. First two robots at Daimler Benz.
1971	Ford's first multiple installation with Unimate 4000 (designed to Ford's specifications) GM develops own robot for spot welding on moving lines (SAM) Volvo starts evaluation of robots
1972	Fifteen robots for Chevrolet Camaro and Pontiac Firebird at GM Nordwood Ohio plant. Twelve robots for spot welding at Daimler Benz, Sindelfingen, FRG.
1973	Kawasaki Heavy Ind. gets order for a hundred robots for spot welding from motor car firms (Nissan and Toyota) Nissan Car Co. Mirayama plant introduces first multiple machine spot welding lines. First Volvo order of spot welding lines (two lines of six robots) First installation at FIAT; eighteen robots for model 132 255 line in Mirafiori plant.
1974	First installation of robot welders on a continuously moving motor car assembly line
1975	Twenty-two robots for Underbody welding of Chevette at GM, Wilmington Delaware
1976	Fiat orders twenty-seven robots for 131 model line
1976	Volvo order thirty robots for Torslanda plant
1977	Ford Motor Co. installs sixty robots for spot welding in a new line of compact cars Fiat orders a hundred robots for the Robogate Systems at the Rivalta and Cassino Plants
1978	Fiat order robots for extension of Robogate System (sidepanel, tackwelding and body framing with no multiple welding) at Rivalta and Cassino BL orders twenty-eight robots for Metro line
1979	Volvo order more than one hundred Cincinnati Milacron robots for spot welding

APPENDIX 8

THE USAGE OF INDUSTRIAL ROBOTS WORLDWIDE

APPENDIX 8

The Usage of Industrial Robots Worldwide

The following tables are a compilation of many sources reporting the relative usage of robots in different applications and sectors of industry in several countries at various points in time. Unfortunately, no uniform basis for estimation exists. Thus, variations must be partially explained by the method of calculation. For example, the distribution of robot applications in Japan is notably different when figures include pick-and-place devices (transfer robots become the great majority). These problems are more acute in tables describing the distribution of robots by industry. Here, some estimates may or may not include pick-and-place devices and some may be based in the supply value rather than the number of robots.

TABLE A8.1 - Distribution of Robot Applications in USA (percentage of robots excluding PPD's)

YEAR	1971	1973
TRANSFER	38.0	41.0
Simple	-	-
Complex	1.0	2.0
Loading/Unloading of Machiery	33.0	33.0
Diecasting Injection Moulding Pressing Metal cutting	18.0 3.0 5.0 7.0	18.0 3.0 5.0 7.0
Other	4.0	6.0
MANIPULATIVE	1.0	3.0
Forging Fettling Grinding Investment Casting Other	1.0 - - - - -	3.0 - - - - -
PROCESSING	19.0	23.0
Metal cutting	-	-
Joining	15.0	15.0
Spot Welding Arc welding	- -	- -
Surface Treatment (Coating)	4.0	8.0
Inspection	-	-
Other	-	-
ASSEMBLY	1.0	2.0
OTHER (unspecified)	40.0	30.0
Sample Size (robots)	600	1000
Source	A	A

Notes: A - Tassel (1975)

TABLE A8.2 - Distribution of Robot Applications in Japan (see notes for differences on the basis for estimation) (percentage of robots)

YEAR	1971	1973	1973	1977	1977
TRANSFER	57.0	52.0	80.2	97.8	61.2
Simple	-	-	-	-	-
Complex	4.0	2.0	21.5	-	-
Loading/Unloading of Machinery	49.0	46.0	58.7	97.3	46.4
Diecasting	9.0	5.0	3.2	4.0	9.8
Injection Moulding	20.0	20.0	2.0	29.8	7.5
Pressing	15.0	17.0	9.8	10.5	13.4
Metal cutting	5.0	4.0	43.7	52.5	15.7
Other	4.0	4.0	-	0.5	14.8
MANIPULATIVE	12.0	10.0	5.6	-	6.7
Forging	12.0	10.0	4.4	-	6.7
Fettling	-	-	-	-	-
Grinding	-	-	-	-	-
Investment Casting	-	-	-	-	-
Other	-	-	1.2	-	-
PROCESSING	9.0	20.0	6.88	1.1	13.9
Metal cutting	-	-	-	-	-
Joining	7.0	10.0	2.8	0.9	3.7
Spot welding	-	-	-	-	-
Arc welding	-	-	-	-	-
Surface Treatment (Coating)	2.0	10.0	4.0	0.2	3.8
Inspection	-	-	-	-	6.4
Other	-	-	-	-	-
ASSEMBLY	2.0	5.0	7.3	-	17.9
OTHER (unspecified)	20.0	13.0	-	1.4	0.3
Sample size (robots)	500	1100	?	Approx 58000	665
Source	A	A	B	C	D

Continued/....

Notes for Table A8.2:

A Tassel (1975) (excluding PPD's)

B Stout et al (1976, p445) (likely to include a large proportion of PPD's)

C Estimated from Yonemoto and Shiino (1977) (include a large proportion of PPD's)

D Based on questionnaire survey to 125 companies by Hasegawa (1979, p449) (likely to include PPD's)

TABLE A8.3 - Distribution of Robot Applications in Western Europe (percentage of robots excluding PPD's)

YEAR	1971	1973	1974	1978
TRANSFER	37.0	38.0	41.8	33
Simple	-	-	-	-
Complex	1.0	2.0	1.6	0.8
Loading/Unloading of Machinery	32.0	32.0	34.1	24.9
Diecasting	10.0	5.0	4.8	6.2
Injection Moulding	11.0	10.0	11.2	4.5
Pressing	7.0	12.0	13.0	13.3
Metal cutting	4.0	5.0	5.1	0.9
Other	4.0	4.0	6.1	7.3
MANIPULATIVE	4.0	3.0	2.5	2.6
Forging	4.0	3.0	2.4	2.0
Fettling	-	-	-	-
Grinding	-	-	-	0.2
Investment Casting	-	-	0.1	0.3
PROCESSING	33.0	40.0	40.8	40.2
Metal cutting	-	-	-	0.2
Joining	13.0	20.0	20.0	24.4
Spot welding	-	-	-	-
Arc welding	-	-	-	-
Surface Treatment (Coating)	20.0	20.0	20.8	15.5
Inspection	-	-	-	-
Other	-	-	-	0.1
ASSEMBLY	-	-	-	1.4
OTHER (unspecified)	26.0	19.9	14.8	22.9
Sample size (robots)	350	550	671	1926
Source	A	A	B	C

Notes: A Tassel (1975)

B Warnecke et al (1974, p109)

C Weighted average of UK, Italy, FRG and Sweden (see Table A8.4)

TABLE A8.4 - Distribution of Robot Application in Several European Countries (percentage of robots excluding PPD's)

COUNTRY	Federal Republic of Germany		Sweden	Italy	United Kingdom
Year	1977	1978	1978	1978	1978
TRANSFER	61.0	41.5	33.0	20.1	45.0
Simple		-	-	-	-
Complex		-	2.0	-	1.4
Loading/Unloading of Machinery		21.5	31.0	19.5	39.5
Diecasting		} 11.5	7.0	5.5	6.8
Injection moulding		}	6.0	0.2	6.8
Pressing		10.0	18.0	11.8	8.8
Metal cutting		-	-	2.0	4.8
Other		20.0	-	0.6	16.4
MANIPULATIVE		6.0	-	1.8	5.5
Forging		6.0	-	0.8	0.7
Fettling		-	-	-	0.7
Grinding		-	-	0.4	-
Investment Casting		-	-	0.2	2.7
Other		-	-	0.4	1.4
PROCESSING	39.0	33.5	23.0	69.5	45.6
Metal cutting		-	-	0.6	-
Joining		16.5	11.0	51.4	25.9
Spot welding		-	-	49.0	21.1
Arc welding		-	-	2.4	4.8
Surface Treatment (Coating)		17.0	12.0	17.5	19.7
Inspection		-	-	-	-
Other		-	-	-	-
ASSEMBLY	-	1.0	-	3.9	0.7
OTHER (unspecified)	-	18.0	44.0	4.7	3.4
Sample size (robots)	490	570	700	508	14 7
Source	A	B	C	D	E

Continued/....

Notes for Table A8.4:

A Pugh et al (1979, p90)

B Luetzenkirchen (1978, p185)

C Fletcher (1979, p222)

D Estimated from the applications distribution of Unimate (Cakebread 1978), Trallfa (assumed to be equal to the worldwide distribution). Asea (Asea 1979), Nordson (assumed to be similar to Trallfa), Olivetti (100% assembly), Fiat (100% spot welding) and MAS (100% pressing)

E See Table A9.1

TABLE A8.5 - Distribution of Robot Applications - A Sample of Main Suppliers. Percentage of Cumulative Number of Robots Sold

MAKE	UNIMATE	UNIMATE	TRALLFA	TRALLFA	ASEA	ASEA
Year	1976	1977	1975	1977	1976	1977
TRANSFER	25.7	24.4	-	1.6	44.0	29.9
Simple	-	-	-	-	-	-
Complex	3.5	3.1	-	-	1.5	1.2
Loading/Unloading of Machinery	21.3	20.5	-	0.7	19.8	10.5
Diecasting	14.3	13.8	-	-	6.1	2.4
Injection Moulding	-	-	-	0.7	-	-
Metal cutting	5.7	5.6	-	-	9.1	5.7
Pressing	1.3	1.1	-	-	-	-
Other	-	-	-	-	4.6	2.4
Other	0.9(A)	0.8	-	0.9	22.7	18.2
MANIPULATIVE	4.2	3.7	1.9	2.6	9.1	4.8
Forging	1.7	1.5	-	-	-	-
Fettling	-	-	-	-	1.5	0.4
Inv. Casting	2.5	2.2	-	-	3.0	0.3
Grinding	-	-	-	0.7	4.6	3.2
Others	-	-	1.9(E)	1.9(E)	-	0.4
PROCESSING	5.6	52.2	92.3	78.4	34.9	50.7
Metal cutting	-	-	-	-	9.1	5.6
Deburring	-	-	-	-	6.1	5.2
Others	-	-	-	-	3.0	0.4
Joining	56.8	52.2	-	5.1	25.8	39.9
Spot Welding	55	50.6	-	0.5	4.6	10.5
Arc Welding	1.8	1.6	-	4.6	21.2	29.4
Surface Treatment	-	-	92.3	73.1	-	2.8
Coating	-	-	92.3	72.5	-	
Paint spraying	-	-	45.4	36.0	-	
Enamel spraying	-	-	35.0	24.5	-	-
Glazing	-	-	5.0	4.2	-	-
Under-body coating spray'g	-	-	4.6	6.5	-	-
Other	-	-	2.3(F)	1.3(F)	-	-

Continued/...

TABLE A8.5 (Continued)

MAKE	UNIMATE	UNIMATE	TRALLFA	TRALLFA	ASEA	ASEA
Year	1976	1977	1975	1977	1976	1979
Polishing & cleaning	-	-	-	0.4	-	-
Other	-	-	-	0.2	-	2.8
Inspection	-	-	-	-	-	0.4
Other	-	-	-	0.2	-	2.0
ASSEMBLY	-	-	-	-	-	0.8
OTHER	13.3	19.8	5.8	17.4(G)	12.1	13.7
Sample size	1400	1600	260	432	66	248
Source	B	C	D	H	I	I

Notes:

A Glass handling

B Estimated from information provided by Unimation (Europe) Ltd (Cakebread 1978) (Figures as at January 1977)

C Estimated from information provided by Unimation (Europe) Ltd. (Cakebread 1978) (Figures as at June 1977)

D Estimated from information provided by the De Vilbiss Company Ltd (Mooney 1978)

E Part dipping

F Thermo-plasma coating, glueing, oiling, greasing and TV tube coating

G Pilot plant, testing and research, demonstration and unspecified

H Estimated from Underhaug (1977, p.17)

I Estimated from information provided by ASEA Electronics Division (ASEA 1979) (Figures as at June 1979)

TABLE A8.6 - Distribution of Robots by Industry in USA (see notes for the bases of estimation)

YEAR	1971	1973	1974
Consumer Goods	60.0	45.0	37.0
Motor Car	60.0	45.0	37.0
Domestic Appliances and Sanitary Ware	-	-	-
Intermediate Goods	26.0	28.0	45.0
Glass	4.0	4.0	5.0
Metal Goods	20.0	20.0	34.0
Plastics	2.0	4.0	6.0
Capital Goods	4.0	12.0	13.0
Machinery	4.0	8.0	13.0
Electrical Equipment	-	4.0	-
Electronics	-	-	-
Others	5.0	15.0	5.0
Source	A	A	B

Notes:

A Basis of estimation unspecified (exclude PPD's). From Tassel (1975)

B Calculated as percentage of supply value (exclude PPD's). From Frost and Sullivan (1974, p126).

TABLE A8.7 - Distribution of Robots by Industry in Japan (see notes for the bases of estimation)

INDUSTRY	1970	1971	1973	1974	1975	1976	1977	1978
Consumer Goods	22.0	31.1	30.0	37.0	21.0	31.5	34.0	35.0
Motor Car	22.0	25.7	30.0	35.0	20.0	30.5	34.0	35.0
Domestic Appliances & Sanitary Ware	-	5.4	-	2.0	1.0	1.0	-	-
Intermediate Goods	16.0	12.1	22.0	23.0	37.0	25.5	20.0	19.0
Glass	5.0	-	5.0	-	-	-	-	-
Metal Goods	6.0	12.1	12.0	13.0	26.0	12.5	10.0	11.0
Plastics	5.0	-	5.0	10.0	11.0	13.0	10.0	8.0
Capital Goods	41.0	39.2	38.0	25.5	28.0	29.5	38.0	39.0
Machinery	25.0	27.0	11.0	15.0	15.0	13.0	15.0	14.0
Electrical Equipment	16.0	12.2	27.0	10.0	13.0	16.5	23.0	25.0
Electronics	-	-	-	-	-	-	-	-
Others & unkown	21.0	17.6	10.0	15.0	15.0	13.5	9.0	6.0
Sample size (robots)	?	?	?	?	?	?	?	?
Source	A	B	A	C	C	C & D	D	D

Notes:

A Basis of estimation unspecified (exclude PPD's). From Tassel (1975).

B Calculated as percentage of supply value (exclude PPD's). From Frost and Sullivan (1974, p.120).

C Calculated as percentage of supply value (include a large proportion of PPD's). From Yonemoto and Shimo (1977, p.173).

D Calculated as percentage of supply value (likely to include PPD's). From Hasegawa (1979, p.448).

TABLE A8.8 - Distribution of Robots by Industry in Western Europe (see notes for the bases of estimation)

YEAR	1973	1974	1978
Consumer Goods	35.0	19.0	54.0
Motor Car	35.0	19.0	39.5
Domestic Appliances and Sanitary Ware	-	-	14.5
Intermediate Goods	42.0	19.0	19.2
Glass	2.0	7.0	4.3
Metal Goods	35.0	12.0	11.5
Plastics	5.0	-	3.4
Capital Goods	13.0	23.0	18.8
Machinery	10.0	13.0	9.9
Electrical Equipment	3.0	10.0	8.9
Electronics	-	-	-
Others	10.0	39.0	8.0
Source	A	B	C

Notes:

A Basis of estimation unspecified (exclude PPD's). From Tassel (1975)

B Basis of estimation unspecified (exclude PPD's). From Ciborra et al (1976, p191)

C Average percentage of robots in the UK, Italy and the FRG (exclude PPD's). See Table A8.9.

TABLE A8.9 - Distribution of Robots by Industry in Some European Countries (see notes for the bases of estimation)

COUNTRY	U.K.	ITALY	FRG
Industry	1978	1978	1979
Consumer Goods	43.6	54.9	63.7
Motor Car	25.9	54.9	37.8
Domestic Appliances and Sanitary Ware	17.7	-	25.9
Intermediate Goods	34.0	17.7	5.8
Glass	12.9	-	-
Metal goods	12.9	15.7	5.8
Plastics	8.2	2.0	-
Capital Goods	10.2	15.7	30.6
Machinery	7.5	-	22.3
Electrical Equipment	2.7	15.7	8.3
Electronics	-	-	-
Others and unknown	12.2	11.8	-
Sample size (robots)	147	?	278
Source	A	B	C

Notes:

A Percentage of robots excluding PPD's (see Table A9.3)

B Percentage of Italian robots sold in 1978 for the Italian market (excluding PPD's). From Varvello (1980, p.26).

C Percentage of robots excluding PPD's. From Brodner and Schacks (1979, p.123).

APPENDIX 9

THE USAGE OF INDUSTRIAL ROBOTS IN THE UK

APPENDIX 9

The Usage of Industrial Robots in the UK

The pattern of robot usage in the UK was inferred from the list of applications given in Appendix 10. This is a representative sample of the UK robot population in particular of SR's, MTR's and HTR's. Information about PPD's alone is also given to illustrate their differences with sophisticated equipment.

TABLE A9.1 - Distribution of Robot Applications in the UK
Percentage of robots sold (excluding PPD's)

Year	1974	1976	1978	1979
TRANSFER	63.8	60.3	45.0	36.5
Simple	-	-	-	-
Complex (A)	1.2	1.1	1.4	1.0
Loading/Unloading of Machinery	55.4	52.7	39.5	31.5
Diecasting	8.4	7.5	6.8	7.0
Injection Moulding	9.6	8.6	6.8	5.5
Pressing	12.1	12.9	8.8	6.5
Metal cutting	4.8	5.4	4.8	3.5
Other (B)	20.5	18.3	12.3	9.0
Other (C)	7.2	6.5	4.1	4.0
MANIPULATIVE	1.2	4.4	5.5	5.5
Forging	-	-	0.7	1.0
Fettling	-	-	0.7	1.0
Investment Casting	1.2	2.2	2.7	2.5
Glass gathering	-	2.2	1.4	1.0
PROCESSING	28.9	30.2	45.6	49.0
Metal cutting	-	-	-	-
Joining	3.6	3.3	25.9	30.5
Spot welding	2.4	2.2	21.1	20.5
Arc welding	1.2	1.1	4.8	10.0
Surface Treatment (coating)	25.3	26.9	19.7	18.5
Paint spraying	9.6	10.8	9.5	9.0
Enamel spraying	14.5	12.9	8.2	6.0
Other (D)	1.2	3.2	2.0	3.5
Inspection	-	-	-	-
ASSEMBLY	-	-	0.7	3.5
OTHER (E)	6.0	5.4	3.4	5.5
Sample size (robots)	83	93	147	200

Continued/....

Notes for Table A9.1

A Packaging and palletising

B Glass cutting machines (33%), Lehrs (17%), glass forming machines (11%), pack-forming machines (6%), T.V. tube processing machines (6%), furnaces (22%), and pedestal welding (spot welding) (6%) mostly by 1974.

C Non-specified transfer operations

D Dry enamel sprinkling, fibreglass spraying, underbody sealing, rust preventive spraying

E Non-specified operation

TABLE A9.2 - Distribution of Applications of Pick-and-Place Devices - A UK Sample (Percentage)

Sample size	59
Year	1978
Simple Transfer (A)	40.7
Diecasting	5.1
Injection Moulding	13.6
Component Transfer in Metal Cutting System	27.1
Component Transfer in Assembly Systems	13.6

Notes: A Workpiece transfer in packaging systems and TV tube transfer

TABLE A9.3 - Distribution of Robots Sold by Industry in the UK
Percentage of robots sold (excluding PPD's)

Industry	1974	1976	1978	1979
Consumer Products	17.7	54.6	43.6	39.5
Motor car (A)	3.6	3.2	25.9	26.5
Domestic Appliances and Sanitary Ware (B)	24.1	23.7	17.7	13.0
Intermediate Goods	42.2	45.2	34.0	30.5
Glass (C)	18.1	20.4	12.9	10.0
Metal Goods (D)	13.3	15.1	12.9	14.0
Plastics	10.8	9.7	8.2	6.5
Capital Goods	12.0	11.8	10.2	12.0
Machinery (E)	7.2	7.5	7.5	8.5
Electrical Equipment	4.8	4.3	2.7	2.5
Electronics	-	-	-	1.0
Others and unknown	18.1	16.1	12.2	18.0
Sample size (robots)	83	93	147	200

Notes:

A Seventy-four percent (39 robots) are in one company only

B Sanitary ware accounts for twenty-three percent

C It can be divided into glass for motor cars (30%), for T.V. tubes and radar tubes (30%), and general (40%)

D Components for the motor car industry accounts for fifty percent of the robots in metal goods

E High precision components for aerospace accounts for fifty percent of the robots

TABLE A9.4 - Distribution of Companies Buying Robots in the UK Percentage of companies buying robots (excluding PPD's)

Industry	1974	1976	1978	1979
Consumer Goods	22.9	23.6	22.5	9.7
Motor car	2.1	1.8	4.2	5.7
Domestic Appliances and Sanitary Ware	20.8	21.8	18.3	4.0
Intermediate Goods	39.6	41.8	38.1	43.3
Glass	16.7	20.0	15.5	11.4
Metal goods	12.5	12.7	12.7	15.2
Plastics	10.4	9.1	9.9	16.7
Capital Goods	18.8	20.1	16.9	18.1
Machinery	12.5	14.6	12.7	13.3
Electrical Equipment	6.3	5.5	4.2	3.8
Electronics	-	-	-	1.0
Others and Unknown	18.7	14.5	22.5	30.5
Sample size (companies)	48	55	71	105
Ratio robots to companies	1.73	1.69	2.07	1.91

TABLE A9.5 - Distribution of PPD's by Industry - A UK Sample (Percentage)

Plastics	11.9
Glass	26.2
Metal goods	61.9
Sample size (PPD's)	42

TABLE A9.6 - Distribution of Companies Buying PPD's by Industry - A UK Sample (Percentage)

Domestic Appliances	9.1
Glass	18.2
Metal goods	27.3
Plastics	18.2
Machinery	9.1
Other	18.2
Sample size (Company)	11

TABLE A9.7 - Distribution of Robots to Companies by 1979

Number of Robots Bought by a Company	Percentage of Companies
$\geqslant 10$	1.9
5-9	2.9
2-4	21.9
1	73.3

TABLE A9.8 - Distribution of PPD's to Companies - A Sample

Number of PPD's Bought by a Company	Percentage of Companies
≥10	27.3
5-9	27.3
2-4	9.1
1	36.4

TABLE A9.9 - Sequential Orders of Robots by Companies

Company placed at least:	Percentage of Companies
one order	100
two orders	12.5
three orders	3.9
four orders	1.0

TABLE A9.10 - Sequential Orders of PPD's by Companies

Company placed at least:	Percentage of Companies
one order	100
two orders	33.3
three orders	25.0
four orders	25.0

APPENDIX 10

LIST OF ROBOT APPLICATIONS IN THE UK *

APPENDIX 10

List of Robot Applications in the UK *

Names of robot users are not given since most of this information was offered under assurances of strict confidentiality. Other sources such as the technical press were also used.

Key notes refer to the situation regarding use as at the end of 1979:

+ Known to be setting up, on order or in development (e.g. in corporate labs) and thought to be not yet in use.

++ Use thought to have discontinued

+++ Use known to have discontinued

BLANK Known to be in use

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* Compiled in collaboration with Dr. David Wield, Research Fellow at the Technology Policy Unit of the University of Aston in Birmingham

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
1	Warley, W. Midlands	4	Star Seiki (PPD)	Injection Moulding	1976 1977 1978:3	Thermoplastic parts for domestic appliances
		1	Mouldmate (PPD)			
2	Worcester	7	Unimate 2000 Unimate 3000	Diecasting	1972:3 1978:3 1979:2	Components for the automobile industry
		1	Rimrock (PPD			
3	St. Helens	6	Versatran	Loading glass cutting machies	1968-69:6 +++	Safety glass for automobile industry
		1	Hall Gantry (PPD)		1975	
4	Derby	2 1	Unimate 2100 Unimate 4000	Investment casting.	1968 1978 1979	High precision castings (turbine blades) for the aerospace industry
5	Manchester	1	Trallfa	Paint spraying	1974	Plastic moulds for automobile industry
6	Bristol	1	Trallfa	Paint spraying	1975	Domestic appliances (tumble dryers)
7	Walsall	1	BUSM	Loading/unloading of presses	1974 +++	Brass components (fittings)
		3	Area-4		1976:2 1978	
8	Peterborough	1	Versatran	Diecasting	1974:1 +++	Domestic appliances

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
9	Merseyside	2	Unimate 2100 Unimate 2000	Lehr loading	1974 +++	T.V. tubes manufacture
10	St. Helens	1	Versatran 500	Lehr loading	1967-74 +++	Glass manufacture
11	Mexborough,	1	BUHLER (PPD)	Diecasting	1978	Domestic appliances
12	Oxford	1	Cincinnati Milacron	Welding (?)	1979 +	Motor car industry
		1	Versatran	Welding (?)	Before 1974 +++	
		1	Trallfa	Spraying	1979 +	
		3	Asea A30A	Arc welding	1978 +	
13	Ashford, Kent	2	Unimate 2105B	Injection moulding	1978 1979	Plastic water tank storage
14	Staffs	2	Versatran 500p	Loading/unloading of glass forming machine	1970 +++	Laboratory glass work
15	Falkirk	4	Trallfa	Enamel spraying and dry enamel sprinkling	1972-1974	Sanitary ware (bath tubs)
16	Lancs	2	Trallfa	Paint spraying	1976 1978	Domestic appliances (tumble dryers)
17	Cardiff	1	Trallfa	Enamel spraying	1971	Sanitary ware (bath tubs)

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
18	Durham	3	Trallfa	Enamel spraying	1972-1973	Domestic appliances (gas and electric cooker parts)
19	Walsall	2	Trallfa	Paint spraying	1972	Domestic appliances (radiators)
20	Ilkeston, Derby	1	Trallfa	Paint spraying	1972	Domestic appliances (wooden parts for radiators)
21	Birmingham	1	Trallfa	Enamel spraying	1972 ++	Sanitary ware (bath tubs)
22	Enfield, Midds.	2	Trallfa	Paint spraying	1973:2	Domestic appliances (gas cooker parts)
		2		Enamel spraying	1974:2	
23	Birmingham	1	Hall Ramp	Spraying of fibre glass	1976 +++	Fibre glass panels for housing
24	High Wycombe, Bucks	1	Trallfa	Paint spraying	1974 +++	Domestic appliances (wooden chair frames and wooden parts for gas fires)
25	?	2	Trallfa	Enamel spraying	1973	Domestic appliances (stores)
26	London	1	MHU Senior Electrolux	Unloading two injection moulding machines	1978	Plastic biros
27	London	1	MHU Junior Electrolux (2 arms)	Loading two gear hobbing machines	1978	Power tools

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
28	?	1	MHU Electrolux	Diecasting	1978	?
29	Harlow, Essex	1	Asea	?	1979 +	?
30	Droitwich	1	Cercast Shell-o-Matic	Investment casting	before 1978	Precision castings
31	Grimsby	1	Hall-Ramp	fibreglass spraying	1976	Boat building (fibre glass yacht builders)
32	London	1	Versatran	Loading pack forming machines	1974 +++	Tin manufacture
		1	Own make (PPD)			
33	Dagenham	1	Unimate	Loading/unloading spot welding machines (Pedestal welding)	1978	Automobile manufacture
34	Birmingham	28	Unimate 2006A 2601A	Spot welding	1978 +	Automobile manufacture
35	Leicester	16	MONTECH (PPD)	Loading metal working machines	1974-1978	Auto turned parts
36	Dundee	4	MONTECH (PPD)	Component transfer in assembly systems	before 1978	Special purpose assembly machines
37	London	4	MONTECH (PPD)	Component transfer in assembly systems	1978	Toy manufacture (precision zinc diecasters and plastic moulders)
		1	Reis (PPD)	Diecasting	1978	

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
38	Andover, Hampshire	1	Hall-Ramp	Paint spraying	1978	Toys manufacturer (plastic)
39	Birmingham	1	MHU Electrolux	Loading/unloading of machines and inspection rigs	1977	Components for motor car industry (intake manifolds)
40	Workington, Cumbria	1	Hall-Ramp	Paint spraying	1977	?
41	Exeter	1	Unimate	Investment casting	1976	Precision castings (turbine components)
42	Birmingham	2	Versatran	Component transfer	1967 +++	Manufacture of Batteries
43	Burnley	1	Versatran 500p	Transver of TV tubes	1974 +++	T.V. Tubes manufacture
		10	Own make (PPD)		1976	
44	Hatfield	1	Versatran 500p	loading of jigs	1967-74 ++	?
45	Enfield, Midds	1	Versatran 500p	Transfer of T.V. tubes	1967-74 +++	T.V. tubes manufacturer
46	Stoke-on-Trent	4	Versatran 500p + 500s	Loading/unloading of furnaces	1967-74 +	Glass parts manufacture
47	Newport, Mon.	4	Versatran 500s	Loading/unloading	1967-1974 ++	Metal parts manufacture

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
48	Bradford	1	Versatran 500p	Machine loading	1967–1974 ++	Metal parts manufacture
49	Birtlex	1	Versatran 500p	Machine loading	1967–74 ++	Metal parts
50	Birmingham	1	Versatran 500p	Machine loading	1967–74 ++	Metal parts
51	Billericay, Kent	1	Versatran 500s	Injection moulding machine	1967–74 ++	Plastics
52	London	1	Versatran 500s	Injection moulding	1967–74 ++	Plastics
53	Liverpool	1	Versatran 500s	Machine loading	1967–74 ++	Metal parts
54	Birmingham	1	Versatran 500p	Diecasting	1967–74 ++	Electric components for automobile industry
55	Doncaster	1	Versatran 500s	Transfer of glass tubes	1967–74 ++	Glass manufacture
56	Slough	1	Versatran 500p	Diecasting	1967–74 ++	High duty castings for the aerospace industry
57	York	1	Versatran 500s	Packing of glass bottles	1967–74 +++	Glass bottle manufacture
58	Derby	1	Versatran 500s	CO_2 welding	1969 +++	Research and development (Railways manufacture)
59	Redditch West Midlands	1	Versatran D301	Pressing	1965 +++	High duty forgings for the aerospace industry

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
60	Birmingham	4	Unimate	Pressing	1974	Metal goods
61	Birmingham	1	Unimate	Transfer	1974	Metal goods
62	Glasgow	1	Versatran D301	?	1967-74 ++	Aerospace industry
63	Derby	1	Versatran D301	?	1967-74 +++	Aerospace industry
64	Clwyd	1	Versatran D301	?	1967-74 ++	Brick manufacturing
65	Dover, Kent	1	Versatran 500p	?	1967-74 +++	Electrical instruments
66	Birmingham	1	Versatran 500c	?	1967-74 +++	Pressing for automobile industry
		1	?	Paint spraying	1979 +	
		1	Asea A30A	Arc welding	1979 +	
67	West Bromwich West Midlands	1	Versatran 500p	Diecasting	1974 +	?
68	?	3	Versatran 500s	Injection moulding	1967-74 ++	Plastics
69	Ipswich	2	Trallfa	Arc welding	1978	?
70	Rugby	1	Asea A30A	Arc welding	1979	Agricultural plough manufacture
71	Birmingham	1	Unimate	Hammer forging	1977	Steel tube industry

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
72	?	1	Asea A30A	Palletising	1978	Chemical industry
73	Birmingham	3	Unimate	Injection moulding	1974 +++	Plastic products (Dustbins)
74	Uttoxeter	1	HAL/BOC	Arc welding	1979 +	Earth moving equipment
75	Birmingham	2	Unimate	Glass gathering and loading onto forming presses	1976	Radar tube manufacture
76	Basingstoke	1	Puma	Assembly	1979 +	Fork lift trucks
77	Oxford	1	Unimate	Spot welding	1974	Automobile industry
		1	Trallfa	Spraying	1974	
		1	Puma	Assembly	1978 +	
		1	Asea A30A	Fettling	1978 +	
		1	Unimate	Spot welding	1978 +	
78	?	1	Trallfa	Spraying	1979	?
79	London	3	Star Seiki (PPD)	Injection Moulding	1978	Domestic appliances
80	Somerset	3	Asea A30A	Arc welding	1979	?
81	Birmingham	12	PPD's	Product transfer in packaging system	1978	Food industry (confection-ery)

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
82	?	1	Asea A30A	Arc welding	1979 +	?
83	Harlow	1	Asea A30A	?	1979 +	?
84	?	1	Asea A30A	?	1979 +	?
85	?	2	Sigma	Assembly	1979 +	Electronics industry
86	Derby	1	Hall	Rust preventive spraying	1979 +	Aerospace
87	?	1	Unimate	Arc welding	1979	Components for vehicle industry
88	Chesterfield	1	Unimate 2005G	Hammer forging	1979	High pressure cylinders
89	?	1	Hall (Little Giant)	Glass transfer	1979	Glass manufacture
90	?	1	Hall Ramp	Paint spraying	1978	Aerospace industry (radar devices)
91	Sheffield	1	?	Fettling	1979 +	Steel industry
92	Leeds	1	?	?	1979 +++	Foundry
93	London	1	Hal/BOC	Arc welding	1979 +	?
94	?	1	Hal/BOC	Arc welding	1979 +	?

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
95	?	2	Nordson	Spraying underseal	1979 +	Automobile industry
96	Liverpool	10	Kuka 6/60b	Spot welding	1979 +	Automobile industry
97	London	1	?	Diecasting	1979	Metal goods
98	Halifax	1	Asea A30A	Arc welding	1979 +	?
99	Gloucestershire	1	Asea A30A	Arc welding	1979	Automobile components industry
100	Berkshire	1	Asea A30A	Arc welding	1978 +	Research Association
101	Rochester, Kent	1	Hal/BOC	Arc welding	1979 +	?
102	Wolverhampton	1	?	Diecasting	1979	?
103	Birmingham	1	Sigma	Assembly	1979 +	Electrical components for automobile industry
104	Norfolk	1	Hall Ramp	?	1979 +	?
105	Glasgow	1	?	Paint spraying	1979	?
106	Dorset	1	Puma	Assembly	1979	?
107	Glasgow	1	Sigma	Assembly	1979	?

Firm Number	Location	Quantity of Robots	Robot Manufacturer	Purpose of Application	Installation Dates and situation re use	Industry
108	Birmingham	1	Unimate 2000B	Transfer	1979 +	?
109	Coventry	1	Trallfa	Paint spraying inside trucks	1979 +	Truck manufacture
110	Birmingham	1	Unimate 2000B	Machine tool loading	1976	Metal goods

APPENDIX 11

CHRONOLOGY OF MAIN PROMOTION ACTIVITIES RELATED TO ROBOT TECHNOLOGY IN VARIOUS COUNTRIES

APPENDIX 11

Chronology of Main Promotion Activities Related to Robot Technology in Various Countries

A list of governmental and other important activities for the promotion of robot technology in Japan, the USA and Western Europe is given below in chronological order. This information was compiled from news coverage and papers on government intervention in the Industrial Robot Magazine, the ISIR proceedings, and the technical and other press. For the purpose of comparison all currencies were converted to pound sterling using current rates of exchange (Financial Times 1980, p17). Hence figures are only an approximation.

1968 Japan Electronics Industry Development Association (JEIDA) establishes a technical committee for industrial robots and starts a wide-ranging survey with government support.

1971 Japan Industrial Robot Association (JIRA) is established at the suggestion of the Ministry of International Trade and Industry (MITI).

Japanese government assigns £40M/8 years development work on artificial intelligence (55% for prive work in industry, 30% in MITI research laboratories, and 25% in Universities).

JIRA sponsors demonstration facility at the Kawasaki Heavy Industries works.

1972 Committee for industrial robots already operates within the Department of Production Engineering of the Sveriges Mekanfoerbund in Sweden (main support for research comes from the Swedish Board of Technical Development).

1973 MITI assigns £20M to be spent on the "Methodology for Unmanned Manufacture" (MUM) project. First phase: design concepts (1976) and second phase: model preparation work (1977-83) (eight private companies are involved).

Technology stimulation programme is proposed in USA administration financial year 1973 budget request for the National Science Foundation (NSF) and the National Bureau of Standards (NBS).

NSF starts programme on advanced automation in industrial, university and other laboratories (e.g. £0.28M/2 years to SRI International and £0.11M to Westinghouse Research Centre (see Appendix 5).

1974 The German Research Society (DFG) donated £20M for engineering research, some of which is directed towards basic research closely related to robotics.

The Federal Ministry for Research and Technology and the Ministry of Labour and Social Affairs launch the "Humanisation of Life at Work" programme (£40M/4 years as follows: £3M/1974, £8M/1975, £11M/1976, and £18M/1977).

A total of £13M/4 years are allocated to robot purhcase and development under the "Manufacturing Technologies" Programme.

1975 The Robot Institute of America (RIA) is founded under the sponsorship of the Society of Manufacturing Engineers (SME).

The Italian Robot Association (SIRI) is founded.

1976 Japan has 65 laboratories and 300 researchers spending approximately £0.71M in development work.

Japan has a government-industry development programme estimated at a level of £7M per year.

1977 In the FRG 140 research projects have already been approved under the HLW programme and have been placed with contractors (companies are assumed to contribute up to 50% of the planned research cost).

The committee on automated small-batch production (ASP) is formed by the Deparment of Industry in the UK.

The British Robot Association (BRA) is founded and receives a pump priming grant from the DoI (£15000/2 years).

1978 Second phase of "MUM" projects start in Japan (£25M/7 years).

Automation Research Council in the USA proposes the expenditure of £125M/6 years from government and industry.

Industrial robot associations are founded in France, Spain, and Denmark. First discussions on the formation of an international federation of industrial robots takes place at the 8th ISIR.

National funding of robotic research amounts to £1.3M per annum in the USA (the total cost of the space shuttle programme manipulator system is £27M).

1979 The US Air Force (USAF) starts "Integrated Computer Aided Manufacture" (ICAM) programme (£42M). Projects include development of robots for the assembly of aircraft bodies (e.g. drilling, rivetting and other fastening operations).

MITI establishes system for leasing of high priced industrial robots for small enterprises.

The Mechanical Engineering and Machine Tool Requirments Board of the DoI in the UK based on the recommendations of the ASP committee sponsors development work on flexible manufacturing systems (£0.23M/3 years and a further £3M for construction of a prototype awarded to the 600 Group Machine Tool manufacturer).

The Science Research Council (SRC) in the UK identifies robotics as a key area in a £10M research programme on microelectronics.

The Manufacturing Technology Committee starts project on robot technology and work transfer (£0.17/3 years) in the UK.

The SRC Roberts Report recommends a £0.75M per annum for experimental development of integrated robot systems in the UK.

The Production Engineering Research Association (PERA) launches a persuasion campaign in the UK (£0.45M expenditure on advice and demonstration facilities).

The Advisory Council for Applied Research and Development (ACARD) recommends to the Cabinet Office of the British Government the launching of a programme on incentives for the installation of robots in UK companies (a 25% Government grant would involve £15M from public funds).

1980 The DoI of the British Government gives interest relief grant (£0.24M) and the National Research and Development Corporation (NRDC) gives venture capital (£0.42) to Unimation for investment in PUMA plant in the UK (50% of the capital needed).

Approval for the expenditure of £2.5/5 year in robot research is given by the SRC. The programme involves industry and university groups working on the areas identified as priority by the Roberts Report: high speed sensory systems, control and guidance techniques, safety, diagnosis and error recovery functions, and standardisation of performance specification and measurement.

APPENDIX 12

THE FACTORS AND IMPLICATIONS OF THE INTRODUCTION OF ROBOTS IN VARIOUS UK FIRMS

APPENDIX 12

The Factors and Implications of the Introduction of Robots in Various UK Firms

A series of unstructured interviews were conducted with users and potential users of robots in the UK. To help the discussions the general checklist given below was used (see Table A12.1). Each interview was then summarised in writing. Later tables synthesizing the information were constructed. Tables A12.2 and A12.3 describe the most important characteristics of the firms visited. Tables A12.4 to A12.9 describe the motives and consequences of robot adoption according to the managers interviewed. Since these tables were made from unstructured interviews, the frequences reported must be regarded as the minimum number of occasions where a factor was considered important. This information is best used for inferring the differences between the adoption of transfer, manipulative, processing, and assembly systems, particularly between transfer and processing robots where samples are most representative (table A12.10 is a list of the robot applications visited).

TABLE A12.1 - General Framework for Interviewing Managers on the Factors and Implications of Robot Adoption

1. GENERATION OF THE IDEA

   1.1 External forces encouraging or discouraging the use of robots

   1.2 Internal motives for the use of robots

2. SPREADING OF THE IDEA

   2.1 Formal and informal procedures for the initiation of the project

   2.2 Factors delaying or speeding the development of the project

3. EVALUATION OF THE IDEA

   3.1 Formal and informal evaluation procedures that the project had to undergo

   3.2 Alternatives to robot technology considered

   3.3 Main factors affecting the decision

   3.4 Description of the present and expected system

4. APPLICATION OF THE IDEA

   4.1 Procedures and stages that the project undergo before the system was commissioned

   4.2 Factors delaying and speeding installation and start up of the system

5. ASSESSMENT

   5.1 Description of the actual system introduced

   5.2 Technical performance of the robot system

   5.3 Managerial benefits and problems

   5.4 Labour benefits and problems

   5.5 Economic results

   5.6 Future perspective for the technology inside the firm

TABLE A12.2 - General Characteristics of Potential User Firms

			FREQUENCY (%)		
			Robot Potential is certain (A)	Robot Potential is uncertain (B)	Total
Firm Size		Small (<100 employees)	–	–	–
		Medium (100-500 employees)	–	–	–
		Large (500-1000 employees)	25	55	47
		Very large (≥1000 employees)	75	46	53
Company's output is expanding			50	18	33
Technological Level	Product (D)	Low technology	–	–	–
		Medium technology	50	36	40
		High technology	50	55	53
	Process (E)	Low technology	–	–	–
		Medium technology	50	73	67
		High technology	50	18	27
Product Volume		Mass production (>1 Million per annum)	50	46	47
		High volume (0.5-1 Million per annum)	50	46	47
		Medium volume (0.1-0.5 Million per annum)	–	9	7
		Low volume (≤0.1 Million per annum)	–	–	–
Value Added		High	–	55	40
		Medium	100	36	53
		Low	–	–	–
Number of firms			4	11	15

Notes: A Medium-to-long term potential, particularly in fabrication (e.g. arc welding and brazing)
B Interviewees thought conventional automation and PPD's were more appropriate in their case
C For examples of products and processes with varying technological levels and value added see Table A12.3

TABLE A12.3 - General Characteristics of User Firms

			FREQUENCY (%)			
			Very Successful (A)	Successful (B)	Not Successful (C)	Total
Firm Size		Small (<100 employees)	–	–	–	–
		Medium (100-500 employees)	13	33	20	23
		Large (500-1000 employees)	25	44	40	36
		Very large (≥1000 employees)	63	22	40	41
Company's output is expanding			89	11	40	46
Technological Level	Product (D)	Low technology	–	11	60	18
		Medium technology	50	56	20	46
		High technology	50	33	20	36
	Process (E)	Low technology	–	11	80	23
		Medium technology	38	78	20	50
		High technology	63	11	–	27
Product Volume		Mass production (>1 Million per annum)	–	11	20	9
		High volume (0.5-1 Million per annum)	38	56	20	41
		Medium volume (0.1-0.5 Million per annum)	25	11	40	23
		Low volume (≤0.1 Million per annum)	38	22	20	27
Value Added (F)		High	50	22	–	27
		Medium	50	33	20	36
		Low	–	4	80	36
Number of firms			8	9	5	22

Continued/....

Notes for Table A12.3

A Successful applications and/or large potential for robots is foreseen

B Successful application but no further installations are planned

C Robots are not in use any more

D For example:

* Low technology (traditional) products: wooden furniture, sanitary ware and glass bottles
* Medium technology products: plastic mouldings, safety glass, TV tubes, and light brass fittings
* High technology products: High duty forgings and castings, electrical domestic appliances, fork lift trucks, and earth moving equipment.

E For example:

* Low technology (traditional) processes: wood working, ceramic casting and glass forming
* Medium technology processes: conventional stamping, machining, casting, and finishing
* High technology processes: screw injection of thermoset plastic and large mouldings, colour TV tube processing and assembly, high precision casting and use of NC machinery

F For example:

* High value added: equipment, chemicals and food
* Medium value added: fabricated metal products and parts
* Low value added: wooden furniture, sanitary ware and glass products.

TABLE A12.4 - Labour Factors Encouraging Robot Adoption According to Managers in User Firms (A)

	FREQUENCY (%)				
	Transfer robots	Manipulative robots	Processing robots	Assembly robots	Total
Unattractive Job	90	100	50	50	73
Monotonous	90	0	0	50	46
Physically strenuous	60	100	13	0	41
Dangerous	30	50	13	0	23
Particularly obnoxious	0	0	50	0	18
Unattractive working conditions	60	100	89	0	68
Fumes, vapours and dust	40	50	89	0	55
Noise	30	0	89	0	46
Hot environment	40	50	0	0	23
Glare	0	0	13	0	5
Negative attitudes to work	40	0	89	0	50
High absenteeism	20	0	75	0	36
High labour turnover	10	0	75	0	27
Frequent breaks	20	0	25	0	18
Shortage of direct labour	20	50	63	0	36
Overmanning	30	0	13	50	23
Problems of industrial relations	10	0	0	0	5
Number of firms	10	2	8	2	22

Notes: A Frequencies were inferred from unstructured interviews. They imply the minimum number of occasions where the factor was important

TABLE A12.5 - Managerial Factors Encouraging Robot Adoption According to Managers in User Firms

	FREQUENCY (%)				
	Transfer robots	Manipulative robots	Processing robots	Assembly robots	Total
Ease of management of direct labour	50	50	75	50	59
Difficult recruitment	30	50	63	50	46
Very long training is needed	20	50	25	0	23
Difficult labour lay-off and variable product demand	10	0	13	50	14
Large implications of absenteeism	10	50	0	0	9
Ease of supervision, monitoring and control of performance	50	50	50	50	50
Ease of production scheduling and planning	40	0	25	0	27
Number of firms	10	2	8	2	22

TABLE A12.6 - Economic Factors Encouraging Robot Adoption According to Managers in User Firms

	FREQUENCY (%)				
	Transfer Robots	Manipulative Robots	Processing Robots	Assembly Robots	Total
Increase economic efficiency	100	50	100	100	96
Increase output per shift	50	50	63	100	59
Improve product quality	30	50	50	0	36
Reduce rejection levels	30	50	25	0	27
Number of firms	10	2	8	2	22

TABLE A12.7 - Labour Impacts of Robot Adoption According to Managers in User Firms

	Transfer Robots	Manipulative Robots	Processing Robots	Assembly Robots	Total
Direct labour displaced					
Total					
Average	12.5	2.0	4.2	24.5	10.0
Range	0-32	0-4	0-14	13-36	0-36
Per robot					
Average	2.3	1.0	3.4	8.0	3.0
Range	0-6	0-2	0-14	3-13	0-14
Per robot per shift					
Average	1.2	0.5	1.4	7.0	1.7
Range	0-3	0-1	0-6	1-13	0-13
	FREQUENCY (%)				
Reduction of direct labour skills	50	50	50	100	55
Difficulty of matching indirect labour skills to robot requirements	20	100	75	0	46
Total reliance on outside service	40	100	75	0	55
Improvements in job remuneration					
Higher wages	40	0	38	100	41
Higher status	40	0	25	100	36
Losses in job remuneration					
Social contact more difficult	0	0	13	100	14

Continued/....

TABLE 12.7 - Continued

	Transfer Robots	Manipulative Robots	Processing Robots	Assembly Robots	Total
Policies for labour dispacement (A)					
Transfer and natural wastage	50	0	20	100	44
Redundancy	0	0	40	50	19
Positive labour acceptance	60	100	75	50	68
Number of firms	10	2	8	2	22

Notes

A Only those companies where labour wad displaced were counted

TABLE A12.8 - Economic Impact of Robot Adoption According to Managers in User Firms

	FREQUENCY (%)				
	Transfer Robots	Manipulative Robots	Processing Robots	Assembly Robots	Total
Reductions in direct manufacturing costs	90	100	88	100	91
Labour costs	70	100	88	100	82
Material costs	30	50	38	0	35
Energy costs	20	0	0	0	10
Increases in output per shift	56	100	71	100	70
Increases in the utilisation of capacity	56	100	71	100	70
Reduction of rejection levels	33	100	43	0	40
Reduction in cycle time	11	0	29	0	15
Increases in product quality	44	100	71	0	55
Significant increase in indirect costs	67	100	71	0	59
Satisfactory payback	50	100	75	100	68
Number of shifts					
Average	2.8	2.3	2.1	2.0	2.4
Range	2-4	2-3	1-3	1-3	1-4

Continued/....

TABLE A12.8 (Continued)

	Transfer Robots	Manipulative Robots	Processing Robots	Assembly Robots	Total
Payback required (years)					
Average	2.4	?	3.1	2.5	2.8
Range	2–3	?	2–5	2–5	2–5
Payback achieved if satisfactory (years)					
Average	0.7	?	2.1	1.1	1.6
Range	0.6–0.8	?	1–2.9	0.6–1.6	0.6–2.9
Number of firms	10	2	8	2	22

TABLE A12.9 - Managerial Effects of Robot Adoption According to Managers in User Firms

	FREQUENCY (%)				
	Transfer Robots	Manipulative Robots	Processing Robots	Assembly Robots	Total
Design and development effort was very demanding	90	100	38	100	73
Need for special peripheral equipment	80	50	38	100	64
Need for special tooling	60	100	13	100	50
Need for special safety guards	50	50	25	100	46
Need for changes in components and products	20	0	13	50	18
Training was needed	50	100	88	50	68
For indirect labour	40	100	88	50	64
For direct labour	20	50	13	50	23
For management	0	50	0	0	5
More difficult maintenance management	50	50	88	50	64
Long and difficult period of debugging	70	100	25	100	59
Poor reliability	70	50	50	0	55
Control system	70	50	50	0	55
Driving system	30	50	17	0	25
Easier management of direct labour	50	50	50	50	50
Easier supervision, monitoring and control of performance	50	50	25	100	46

Continued/....

TABLE A12.9 (Continued)

	FREQUENCY (%)				
	Transfer Robots	Manipulative Robots	Processing Robots	Assembly Robots	Total
Changes in the organisation of labour and management	50	0	13	100	36
For direct labour	50	0	13	10	36
For indirect labour and management	0	0	0	0	0
Easier production scheduling and planning	30	50	38	0	32
Number of firms	10	2	8	2	22

TABLE A12.10 - List of Robot Applications Discussed in the Interviews

1. Paint spraying of plastic moulds for automotive industry (one robot)
2. Paint spraying of tumble drier drums (one robot)
3. Vitreous enamel and paint spraying of cooker parts (four robots)
4. Varnish spraying of wooden gasfire cabines (one robot)
5. Vitreous enamel spraying and dry enamel sprinkling of bath tubes (four robots)
6. Vitreous enamel spraying of cooker parts (three robots)
7. Loading of glass cutting machines (seven robots)
8. Loading and unloading of glass forming machines (two robots)
9. Glass gathering and loading into press (two robots)
10. Transfer of TV tubes from anode button machine to annealing lehr (one robot)
11. Loading and unloading of TV tubes into chemical treatment machines (one robot)
12. Packaging of glass bottles into cardboard boxes (one robot)
13. Loading and unloading of brass stamping presses (four robots)
14. Loading and unloading of forging press (one robot)
15. Unloading of diecasting machines (seven robots)
16. Unloading of injection moulding machines (five robots)
17. Dipping and stuccoing of wax patterns for investment casting (two robots)
18. Component transfer in special purpose metal cutting machines (sixteen robots)
19. Assembly in fork lift truck maufacture (one robot)
20. Arc welding of components for earth moving equipment (one robot)
21. Mould finishing in sanitary ware manufacture (one robot)
22. Sorting of chocolates into trays in special purpose system (twelve robots)

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

ACARD: Advisory Council for Applied Research and Development

ADEPA: Association pour le Development de la Production Automatisee

AEC: Atomic Energy Commission

AF: Assessment and Forecasting

AI: Artificial Intelligence

AL: Assembly language

AMF: American Machinery and Foundry

APAS: Adaptable Programmable Assembly Systems

App: Applications

AR: Applications Research

ARGE HHS: Programme for the development and diffusion of handling devices and peripheral equipment of the FRG

ASP: Automated small-batch production

BMFT: Ministry for Research and Technology of the FRG

BRA: British Robot Association

BRS: British Robotic Systems

BUSM: British United Shoe Machinery

C: Control

CAD: Computer-Aided Design

CAM: Computer-Aided Manufacture

CBRA: Annual Industrial Robot Conference of the British Robot Association

CIRT: Conference on Industrial Robot Technology

CISM: International Centre for Mechanical Sciences (Centre International de Sciences Mecaniques)

CM: Cincinnati Milacron

CNC: Computer Numerical Control

Comp Path: Computed path control

CONACYT:	National Council for science and Technology of the Mexican Government
CP:	Continuous path control
CS:	Control systems
CSDL:	The Charles Stark Draper Laboratory
CUP:	Cambridge University Press
DEA:	Digital Electronic Automation
DEC:	Digital Equipment Corporation
DFG:	German Research Society
dof:	Degrees of Freedom
DoI:	Department of Industry in Britain
ECE:	Economic Commission for Europe
ED:	Experimental Development
FMC:	Flexible Manufacturing Cell
FMRT:	Federal Ministry for Research and Technology of the FRG
FMS:	Flexible Manufacturing Systems
G:	Government
GAMI:	Groupement pour l'Avancement de la Mecanique Industrielle
GT:	Group Technology
HA:	Hall Automation
HLW:	Humanisation of life at work
HSDE:	Hawker Siddeley Dynamics Engineering
HTR:	High Technology Robots
I:	Industry
ICAM:	Integrated Computer-Aided Manufacture
ICIRT:	International Conference on Industrial Robot Technology
IEEMP:	Institute of Electrotecnia and Electronics of Milan Polytechnic
IFToMM:	International Federation for the Theory of Machinery and Mechanisms

IITB:	Institut fuer Informationsverarbeitung in Technik und Biologie
IITRI:	Illinois Institute of Technology Research Institute
ILO:	International Labour Office
INN:	Innovation
INRC:	Italian National Research Council
IPA:	Institut fuer Produktionstechnik und Automatisierung
IPRODE:	The Institution of Production Engineers
IR:	Industrial Robot(s)
IRT:	Industrial robots that handle tools
IRW:	Industrial robots that handle workpieces
ISIR:	International Symposium on Industrial Robots
IVF:	Swedish Institute of Production Engineering Research
JEIDA:	Japan Electronic Industry Development Association
JIRA:	Japan Industrial Robot Association
JMSA:	Japan Metal Stamping Association
JPL:	Jet Propulsion Laboratory
JSPMI:	Japan Society for the Promotion of Machine Industry
M:	Mechanics
MAG:	Metal Active Gas
MAL:	Multipurpose Assembly Language
MEMTRB:	Mechanical Engineering and Machine Tools Requirements Board of the DoI in Britain
MIG:	Metal Inert Gas
MIT:	Massachusetts Institute of Technology
MITI:	Ministry for International Trade and Industry of the Japanese Government
ML:	Assembly Language
MMA:	Manual Metal Arc Welding
MS:	Mechanical Systems

MT:	Manufacturing Technologies
MTR:	Medium Technology Robots
MUM:	Methodology for Unmanned Manufacture
NBS:	National Bureau of Standards
NC:	Numerical Control/Numerically Controlled
NEL:	National Engineering Laboratory
NRDC:	National Research and Development Corporation in the UK
NSIR:	National Symposium on Industrial Robots
NSF:	National Science Foundation in the USA
O:	Research institutions other than University, industrial and governmental
OSAI:	Olivetti Systems for Industrial Automation
P:	Peripherals
PALS:	Pressing and Allied Operations Labour Saving and Safety Promotion
PERA:	Production Engineering Research Association
PPD:	Pick and Place Device
Proc:	Proceedings
PTP:	Point to point control
PUMA:	Programmable Universal Machine for Assembly
R:	Research
RAM:	Random access memory
RCC:	Remote centre compliance
R&D:	Research and Experimental Development
RIA:	Robot Institute of America
ROM:	Read only memory
RP:	Robot Prototype
RPS:	Random programme selection
RSW:	Robot selection and Workplace Studies
Se:	Sensors
SE:	Suppliers Experiences

SIRI:	Italiand Robot Association
SME:	Society of Manufacturing Engineers
So:	Software
SPL:	Systems Programming
SR:	Simple Robots
SRC:	Science Research Council
SRI:	Standford Research Institute
SRMS:	Shuttle Remote Manipulator System
TA:	Technology Assessment
TI:	Texas Instruments
TIG:	Tungsten Inert Gas
TPU:	Technology Policy Unit of the University of Aston in Birmingham
U:	University
UE:	Users Experience
VAL:	Assembly language
WIAG:	Wolfson Industrial Automation Group

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