A STUDY OF NEW PRODUCT MARKET SEARCH AND USER ADOPTION.

Volume I

A Thesis, submitted for consideration for the award of Doctor of Philosophy.

by Michael William Commander

December 1978.

A Study of New Product Market Search and User Adoption.

by Michael William Commander

Submitted for the award of Doctor of Philosophy

December 1978

SUMMARY

The research was carried out in the Aviation Division of Dunlop Limited and was initiated as a search for more diverse uses for carbon/carbon composites. An assumed communication model of adoption was refined by introducing the concept of a two way search after making cross industry comparisons of supplier and consumer behaviour.

This research has examined methods of searching for new uses for advanced technology materials. Two broad approaches were adopted. First, a case history approach investigated materials that had been in a similar position to carbon/carbon to see how other material producing firms had tackled the problem. Second, a questionnaire survey among industrialists examined: the role and identity of material decision makers in different sized firms; the effectiveness of various information sources and channels; and the material adoption habits of different industries.

The effectiveness of selected information channels was further studied by monitoring the response to publicity given to carbon/carbon.

A flow chart has been developed from the results of this research which should help any material producing firm that is contemplating the introduction of a new material to the world market.

Further benefit to our understanding of the innovation and adoption of new materials would accrue from work in the following areas: "micro" type case histories; understanding more fully the role of product champions or promoters; investigating the phase difference between incremental and radical type innovations for materials; examining the relationship between the adoption rate of new materials and the advance of technology; studying the development of cost per unit function methods for material selection; and reviewing the benefits that economy of scale studies can have on material developments. These are all suggested areas for further work.

MATERIALS : INNOVATION : CASE HISTORIES : COMMUNICATION : ADOPTION : ORGANISATIONAL BEHAVIOUR : DECISION.

A Study of New Product Market Search and User Adoption

CONTENTS

Page

PREFACE

The interdisciplinary nature of this thesis makes it unique from traditional type theses. It will become apparent to the reader that a wide range of subject areas have been covered. This arose because the problem could not be treated in isolation, but rather it had to account for the many pressures that were generated by different quarters when working in an organisation such as Dunlop. The thesis content is based on experiences gained whilst working in and for an industrial organisation and this in itself is unique from many theses.

I am grateful to several organisations and many individuals who have assisted in this research. The Total Technology Option of the Interdisciplinary Higher Degrees Scheme at The University of Aston in Birmingham provided me with the opportunity of studying for a higher degree whilst working in industry. Dunlop Limited employed me during this period of research and provided both the problem and also my salary. The Science Research Council also contributed with a Research Studentship.

Mr. S. A. Gregory, as the main supervisor spent many hours with me both guiding and cajoling. Apart from co-ordinating the whole supervisory team, he also inspired me by contributing many useful insights from his wide experience.
Mr. S. N. Woodward from the London Business School acted as one of two associate supervisors for the second and third years of the research. His marketing expertise helped immensely, whilst his general rationale continually put many

aspects of the research in perspective. Mr. N. Smith (ex Dunlop) in the position of associate supervisor from Dunlop spent many useful hours guiding the research to ensure its worth for industrial organisations. Dr. D. J. van Rest, as the IHD tutor not only helped guide the project but also smoothed many of the bureaucratic problems that arose. Without the assistance and determination of Mr. R. Brooks at Dunlop Head Office this project would never have germinated. Thanks are due to him for getting the idea of the research accepted by Aviation Division and also helping it through several turbulent stages. Recognition must also go to Mr. R. Harrison (ex Aston University) who, as associate supervisor during the first year of the research helped formulate its direction. Dr. R. Fisher, who not only took over responsibility of associate supervisor during the last few months of the project also helped throughout in developing my technical understanding of carbon/carbon.

Many other people not directly associated with the supervisory aspects of the research also contributed greatly. In particular, Dr. J. V. Weaver of Dunlop helped immensely throughout the research, giving up much of his time to offer an "arms-length" view of the project as it progressed, and kindly commenting on earlier drafts of this thesis. Mr. M. K. Hussey (Aston University) also gave freely of his time to help with the statistical analysis involved during the research. Professor T. J. Barnby at the Metallurgy Department of the University also helped by allowing participation in a mailing drop to many industrial organisations. Professor J. Pick of the Mechanical Engineering Department also gave freely of his time and helped with the development of some of the case histories.

There are also many people who helped specifically with the compilation of the case histories: Mr. I. Lowe at ICI Plastics Division who made available previously unpublished records of polyethylene; Dr. H. Child of Aston University who helped with the silicon nitride and titanium history; the Admiralty Materials Laboratory who helped with silicon nitride; Professor W. Alexander (ex Aston University) also contributed greatly to the titanium story, as did various people from IMI and ICI; and many people at Dunlop aided the detailed history of carbon/carbon.

Secretarial assistance on the project was provided by the IHD Scheme and various parts of Dunlop. I am grateful to Miss Anne Steel for typing this manuscript to a tight schedule.

A final word of thanks must also go to firstly my wife, Frances, who helped with many of the tedious tasks, and revived me when I was feeling low; and secondly to my Father who has inspired many of my actions.

1

INTRODUCTION

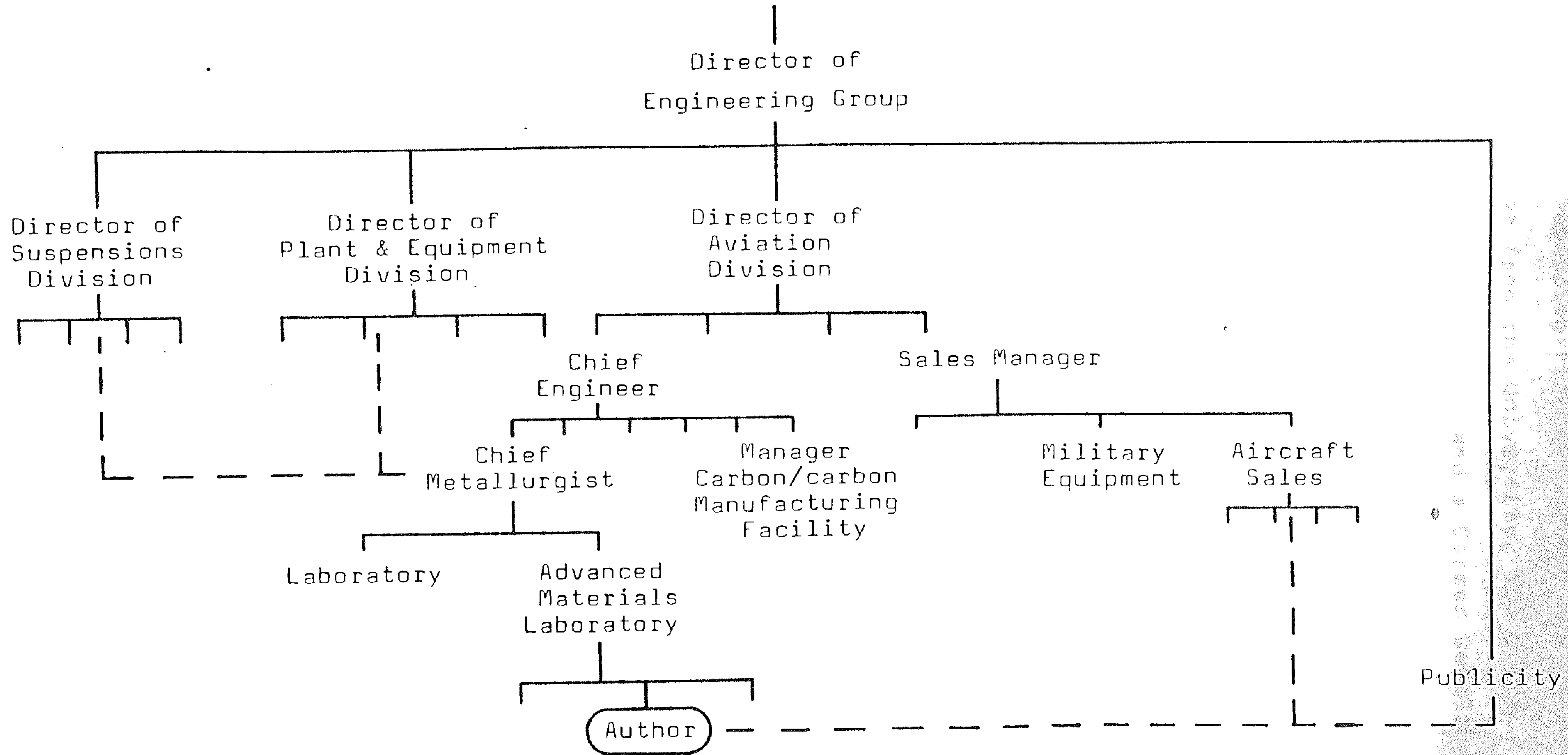
1.1 THE ORGANISATIONAL ENVIRONMENT FOR THE RESEARCH

This thesis describes the research carried out by the author whilst employed within the Aviation Division of Dunlop Holdings Ltd. The division is part of the Engineering Group, which forms one of the major operating units of the company. The author worked in the Advanced Materials Laboratory, as indicated in Figure 1.1, which shows part of the organisational structure for Engineering Group. Much of the work was carried out in collaboration with the Sales and Publicity Departments.

The research initiated by Dunlop and Aston University was guided by the Total Technology scheme - which is itself, a branch of the Interdisciplinary Higher Degrees Scheme.
A supervisory team of five guided the project. The main supervisor was a University chemical engineer who had a keen interest in innovation studies, and the others were a

Figure 1.1

ORGANISATION STRUCTURE FOR PART OF THE ENGINEERING GROUP



Visiting Lecturer in marketing from the London Business School, an I.H.D. tutor from the University, the Chief Metallurgist from Aviation Division and a Career Development Officer from Dunlop Head Office.

1.2 AVIATION DIVISION OF DUNLOP

Dunlop has been associated with aircraft landing gear since the beginning of the century. Aviation Division was formed in 1925, and today provides a wide range of ancillary equipment for all types of aircraft and helicopters. Products include not only tyres and wheels but also brakes, brake control systems, specialised hydraulic and pneumatic components and de-icing equipment. The research reported here is concerned solely with one of the materials used as a brake material - namely carbon/carbon*. Conventional aircraft brake linings are made from sintered cermets (metal and mineral bases), but in recent years, much development work has taken place with new materials such as beryllium[+] and carbon/carbon.

Successful development work with carbon/carbon led to the material being used for the brakes on Concorde; see Figure A.10 of Appendix A. Concorde is presently the major user of carbon/carbon brakes, although some Super VC 10 and Harrier aircraft are also fitted with them. Carbon/carbon

---

* Carbon/carbon is a carbon fibre reinforced carbon composite material. A more detailed description of the material can be found in Chapter 3 and also in the case history of Appendix A.

\+ Beryllium has not been used as a lining material but rather as a structural member carrying other lining materials.

has gained success in this area, largely because of its good strength/weight ratio coupled with some remarkable thermal properties - good conductivity, high specific heat, a high thermal shock resistance, and a high operating temperature capability. Table 1.1 below illustrates carbon/carbon's properties in comparison with some other materials.

Table 1.1 Some typical values of the general physical and mechanical characteristics for carbon/carbon composites are given in the table below. The same properties are compared with aluminium, steel, a metal impregnated carbon and CFRP.

	Carbon-carbon	Aluminium	Steel	Metal Impregnated carbon	CFRP
Density (g/cc)	1.6	2.78	7.86	2.8	1.34
Temperature capability (°C)	2500**	260	750	750	300
Modulus of Elasticity (GN/m^2)	12	70 *	207*	2	109*
($X10^6$ p.s.i.)	1.7	10	30	0.3	16
Flexural Strength (MN/m^2)	100	427*	1990*	9	1410*
($X10^3$ p.s.i.)	15	62	290	1.33	204
Coefficient of Thermal Expansion (10^{-6}/°C)					
Longitudinal	+0.5	+24	+11	+5	-0.7
Transverse	+1.0	—	—	—	-1.0
Specific Heat (cal/gm°C)	.168-.46	.22	.12	.17-.45	
at temps. quoted (°C)	(20-1000)	(15-185)	(20-100)	(20-1000)	

*Strength and modulus quoted are the maximum possible at the upper limit of their temperature capability.
**In inert atmosphere. (900 in oxidising atmosphere).

With the advent of a successful use for carbon/carbon, Aviation Division invested in a manufacturing facility, which opened early in 1975, see Figure 1.2. This has put Dunlop in the position of being the sole commercial manufacturer of carbon/carbon products in the United Kingdom.

Figure 1.2 The Dunlop Carbon/Carbon Manufacturing Facility

Aston University

Illustration removed for copyright restrictions

Aston University

Illustration removed for copyright restrictions

1.3 THE PROBLEM IDENTIFIED

The project was set up during the summer of 1975, just after the manufacturing facility had begun production for the Concorde programme. An air of despondency had settled over the aircraft industry prior to this, with the uncertainty of nationalisation taking place in the near future - see The Engineer 5th September, 1974, page 52. Not only that, Concorde was beginning to look less of a success, as Wilson had by that time suggested, with many airlines not taking up their options to order aircraft. Of the seventy four options originally taken out by the world's major airlines only nine of the sixteen built have been sold - five to British Airways and four to Air France in July of 1972. It was against this background, having realised that reliance on one customer is risky that Dunlop decided to look for alternative users whilst utilising the existing manufacturing facility.

Dunlop was and still is the only commercial producer of carbon/carbon in this country. Such a strong manufacturing position does not however make the search for users any the easier. There are several problems associated with finding other uses for this material. Firstly, it is a comparatively new material, being a spin-off from the technology developed by NASA with their space programme. It was therefore, virtually unknown outside the aerospace industry. Secondly, the manufacturing methods require a high degree of expertise for such an advanced technology material. This, coupled with the fact that the raw materials are expensive and production is part capital and part labour intensive makes the end product very expensive. Thirdly, the Advanced Materials Laboratory - whose function is: to assist with production problems, undertake quality control measurements and investigate new manufacturing methods for conventional steel brakes and carbon/carbon - were unlikely to be able to mount a search for new carbon/carbon users. There were several reasons for this - (a) their traditional function was completely alien to searching for new material users (b) they had no spare people and (c) it is unlikely that such people would have had the ability or correct outlook to perform such a task anyway. Fourthly, there appears to be no systematic approach for a material producer to follow when he does have a new material and mounts a search for new users.

The research project originally intended to find new markets for carbon/carbon but was amended to investigate the communication patterns in a search operation for any new material producer. Those methods that were successful would then be applied to carbon/carbon with the aim of developing new products for the material, essentially outside the aerospace and military sectors of industry. However as the research progressed it became clear that little was known about how decisions are made regarding material selection or how new materials are adopted into an organisation's products and process equipment. Accordingly, an examination of these areas has formed a major part of the research.

2

A PREVIEW OF THE THESIS

2.1 THE WORK

Broadly speaking, the research for this project followed just two paths. The first, a case history approach evolved because material producing companies throughout the world have at some time or another faced the problem "how do we find uses for this new material?" Dunlop were obviously not the first to encounter such a problem, so it seemed reasonable to see how others had tackled the problem, with the aim of learning from their experiences. The second area of research stemmed from the observation that every product producing company makes decisions either explicitly or implicitly about materials. In some cases the decision making role is made by individuals, in others by groups and still others are made by networks of interested parties. The aim of the research therefore was to find out who the decision makers were and how they kept up-to-date with material developments. This work revolved around a survey entitled "Decisions on materials".

2.1.1 CASE HISTORIES

Although case histories on material innovations have previously been compiled by various authors (see Chapter 5) none deal explicitly with the way in which the material producer has found users for his material. The present study investigates the business aspects of innovation rather than the technical, and in particular examines the search operations that have been used to find new products for new materials. Such cases, it was hoped, would show either similar or dissimilar patterns.

A list of candidate materials were drawn up under five headings - the elements, metals and their alloys, ceramics, organic polymers, and composites. These headings are sufficiently comprehensive to give confidence that no obvious materials have been missed, see Table 2.1.

From this list and using the selection criteria shown in Table 2.2, a possible fifteen materials were chosen for study. This selection criteria was favoured for its similarities with carbon/carbon. Of the fifteen chosen materials although introductory information was gathered on many of them, only four were written up: titanium - a metal; silicon nitride - a ceramic; polyethylene - an organic polymer and carbon/carbon - a composite. These are compiled in Appendices A to D.

Table 2.1 Candidate Materials Considered for Case History Study

Elements	Metals	Ceramics	Organic Polymers	Composites
Argon	Aluminium	Aluminised Cement	Bakelite	Carbon Fibre reinforced Carbon
Cesium	Beryllium	Glass Products	Cellophane	Carbon Fibre reinforced Plastic
Selenium	Boron	Magnesia	Celluloid	Fibre reinforced Concrete
Silicon	Cerium	Silicon Carbide	Neoprene	Glass Fibre reinforced Plastic
	Chromium	Silicon Nitride	Nylon	
	Cobalt	Titanium Carbide	Perspex (methyl methacrylate)	
	Foam Metal	Titanium Nitride	PTFE	
	Germanium	Tungsten Carbide	PVC	
	Lead (dispersion hardened)		Polyethylene	
	Molybdenum		Polypropylene	
	Nickel		Rayon	
	Niobium		Silicones	
	Palladium		Terylene	
	Radium			
	Stainless Steel			
	Superplastic Alloys			
	Tantalum			
	Titanium			
	Vitreous Metal			
	Zirconium			

Table 2.2 Selection Criteria for Material Case Studies

The materials should be:-

- new at time of launch
- expensive at time of launch
- of the 'problem-push' type rather than 'need-pull' wherever possible
- those with good, reliable information sources; which was obviously not known until a first selection had been made and some effort had been put into finding information about the history.

Detailed case studies consume a considerable expenditure of time, and a decision eventually had to be made between the time spent gathering further information and writing-up cases, and the benefit accruing from such research. Four cases were deemed to provide sufficient material for analysis when compared with the few other published cases that deal with similar aspects of the innovation process.

The method used to discover information about the materials' history is described individually in the preface to each case study. In general though, information was gathered in the first instance by studying appropriate abstracts and journals - and case histories where available - to build up an overall view of the sequence of events with a material. This was a necessary preliminary as it enabled the compiler to talk sensibly to those directly concerned with the innovation. Contact was then established with various organisations and institutions to try and pin-point the key individuals and organisations involved with the development of the materials. The key individuals were then approached with detailed questions about the history of the innovation. In all cases this enabled a more complete picture to be built up than is published in the literature. Difficulties did however arise. For example, with polyethylene many of the key individuals with ICI had either retired, or died. The individuals that were interviewed were prepared to discuss the innovation but their information was secondhand. Most of the polyethylene history therefore relies on previously unpublished company records. Conversely, a more recent material, silicon nitride, posed problems of a different kind because much of the information is still classified for commercial security reasons.

2.1.2 SURVEY - "DECISIONS ON MATERIALS"

It became apparent whilst working on the case studies that for all the product ideas being suggested to the material producer, there was someone or some function responsible within the potential user's organisation who took the decision to investigate that new material. This person - or persons - was dubbed the "material decision maker". It appeared that to get a new material into a potential user's organisation one had to influence this material decision maker. Because of this, a survey was proposed - the aims of which were to show:

a) whether or not there were persons responsible for material decisions.

b) the number of persons involved in such decisions.

c) the relative importance of material innovation in comparison to product innovation and process innovation.

d) which information sources were effective for material development news.

e) which information channels, within some specified sources were effective for (i) business news and (ii) material development news.

f) the current level of awareness of some "new" materials.

g) the rate of adoption that could be expected for a new material* into a user's products or processes.

h) whether company size had any effect on a) to g).

i) whether a) to h) varied at all across different industrial sectors.

Such a survey necessiatated contacting many individuals in many organisations from a variety of industrial sectors. After due consideration a postal questionnaire technique was chosen rather than personal or telephone interview methods having compared the advantages and disadvantages of the various methods. As an example, the advantages and disadvantages of postal questionnaires are shown in Table 2.3.

Copies of the questionnaire+ with cover letter (see figures 2.1 and 2.2) addressed to the material decision maker were

---

* A new material has been defined as any material regarded as new by the adopting organisation. This allows materials that have been available for many years to be included in the 'new' category provided they are seen as new by the adopter.

\+ The questionnaire shown in figure 2.1 is a copy of that sent to organisations within the aerospace sector of industry. All the questionnaires were identical for each industrial sector except for question 9. The 22nd and subsequent information channels mentioned in question 9 varied according to industrial sector.

Table 2.3 Comparison of the Advantages and Disadvantages of Postal Questionnaires. (As indicated by A. Wilson in his book "The Assessment of Industrial Markets", 1973, Cassel/Associated Business Programmes)

Advantages	Disadvantages
- Economic	- Identifying respondents can be difficult.
- Reach respondents who might otherwise be difficult to interview.	- Judging whether respondents or non respondents are important can be difficult.
- No geographic barriers.	- Only a finite number of questions can be asked.
- Questions needing consultation can be answered.	- Ambiguity of questions may be present.
- Enables the respondent to move at his own pace.	- Whole of questionnaire visible.
- Can give complete anonymity.	- "Position bias" should be taken into account.
- Questions requiring the consideration of a number of options can be presented easily.	- Inability to adjust survey direction or questions without a complete re-circulation.
- Interviewer bias and time bias reduced.	

then sent out in two batches. The first experimental batch went out with a University mailing drop to all the Birmingham member companies of the C.B.I. The mailing drop was the introductory stage of the Metallurgy Department setting up a Materials Technology Exchange Unit. One thousand copies were sent out based on the Metallurgy Department's interests and consequently there was no control on which companies the survey would reach. It was just as likely to go to a retailer

Figure 2.1

DECISIONS ON MATERIALS

(Aston University)

Please return to :

M.W. Commander
I.H.D. Office
The University of Aston in Birmingham

Returned by ....

Of ....

Function ....

1. The aim of this questionnaire is to help formulate a picture of the effectiveness that various information channels have in promoting new structural materials, and to discover the awareness of some currently 'new' materials. The findings of the questionnaire will be made public to interested parties.

Do you wish to have a copy of the findings ? Y☐ N☐

If Y, the address is : ....
....
....

2. What involvement do you have in deciding which structural materials are to be used in your products, and, or processes within your organisation ?

sole decision maker ☐ member of decision team ☐

no involvement ☐ other capicity (please specify)
....

(As an example, decision makers could be engineers, designers, buyers etc).

3. If you are a member of a decision team, how many are in the team ? ....

4. Which area of innovation are you interested in ?

material ☐ process ☐ product ☐ other ☐

5. How effective, as information sources (for new material developments) do you find the following ? (PLEASE TICK)

Information Source	Very Effective	Effective	Not Effective	Don't Use
Journals				
Newspapers				
Conferences				
Exhibitions				
Colleagues				
Television				
Company Representative				
Patents				
Internal company channel				
Government information service				
Other (please specify)				

6. How familiar are you with the following materials ?
PLEASE TICK ONE BOX FOR EACH MATERIAL

Material	Use	Have Investigated for use	Familiar	Unfamiliar
'Antiphon MPM' - a metal/plastic/metal sandwich				
Boron Nitride				
'Carbon/Carbon' - a carbon fibre reinforced carbon composite				
Carbon Fibre Reinforced Plastic				
'Cem-fil' - Glass reinforced concrete				
'Hi-sil' - high strain silicon				
Kevlar				
'Lamina' - bronze surfaced steel				
'Retimet' - foam metal				
Samarium Cobalt				
Silicon Nitride				
Superplastic alloys				
Tantalum				
Titanium				
Vitreous Metal				

7. What 'new' structural materials have recently (within last 10 years) been incorporated in your products/processes ?

....
....
....

8. What was the time period between your awareness of this material's existence and its incorporation in one of your products/processes ? (PLEASE TICK)

Material	Less than 1 yr	1-2 yrs	2-5 yrs	5-10 yrs	10-17 yrs	17-25 yrs

please turn over

Figure 2.1 Cont'd.

9. How do you rate the following for keeping in touch with (a) business developments and (b) materials developments ?

Please indicate by inserting one number in each box

i.e. 5 - essential | 2 - rarely useful
4 - worthwhile | 1 - no use
3 - occasionally useful | 0 - not used

(a) Business Developments		(b) Material Developments
	Abstracts (give name)	
	BBC's Tomorrows World	
	Chartered Mechanical Engineer	
	Composites	
	The Daily Telegraph	
	Design Engineering	
	The Engineer	
	Engineering	
	Engineering Materials & Design	
	The Financial Times	
	The Guardian	
	Materials Engineering	
	Materials Science & Engineering	
	Metallurgist & Materials Technologist	
	Metals & Materials	
	Nature	
	New Scientist	
	Plastics Engineering	
	The Sunday Times	
	The Times	
	Whats New in industrial products & Equipment	
	Aeronautical Journal	
	Aircraft Engineering	
	Aviation Week & Space Technology	
	Other - Please specify.	

Dear Material Decision Maker

This questionnaire is part of a survey conducted by the University of Aston in conjunction with Dunlop Ltd. The survey is concerned with the effectiveness of information channels for the promotion of new materials.

I would be grateful if you would complete the enclosed questionnaire and pass the extra copies to any interested colleagues.

It is designed to be answered by persons responsible for selecting materials for their products and, or processes.

All replies will be treated as confidential and will be used for statistical purposes only so that information contained will not be associated with any one firm or person.

Yours sincerely

M W Commander

Enc: pre-paid envelope

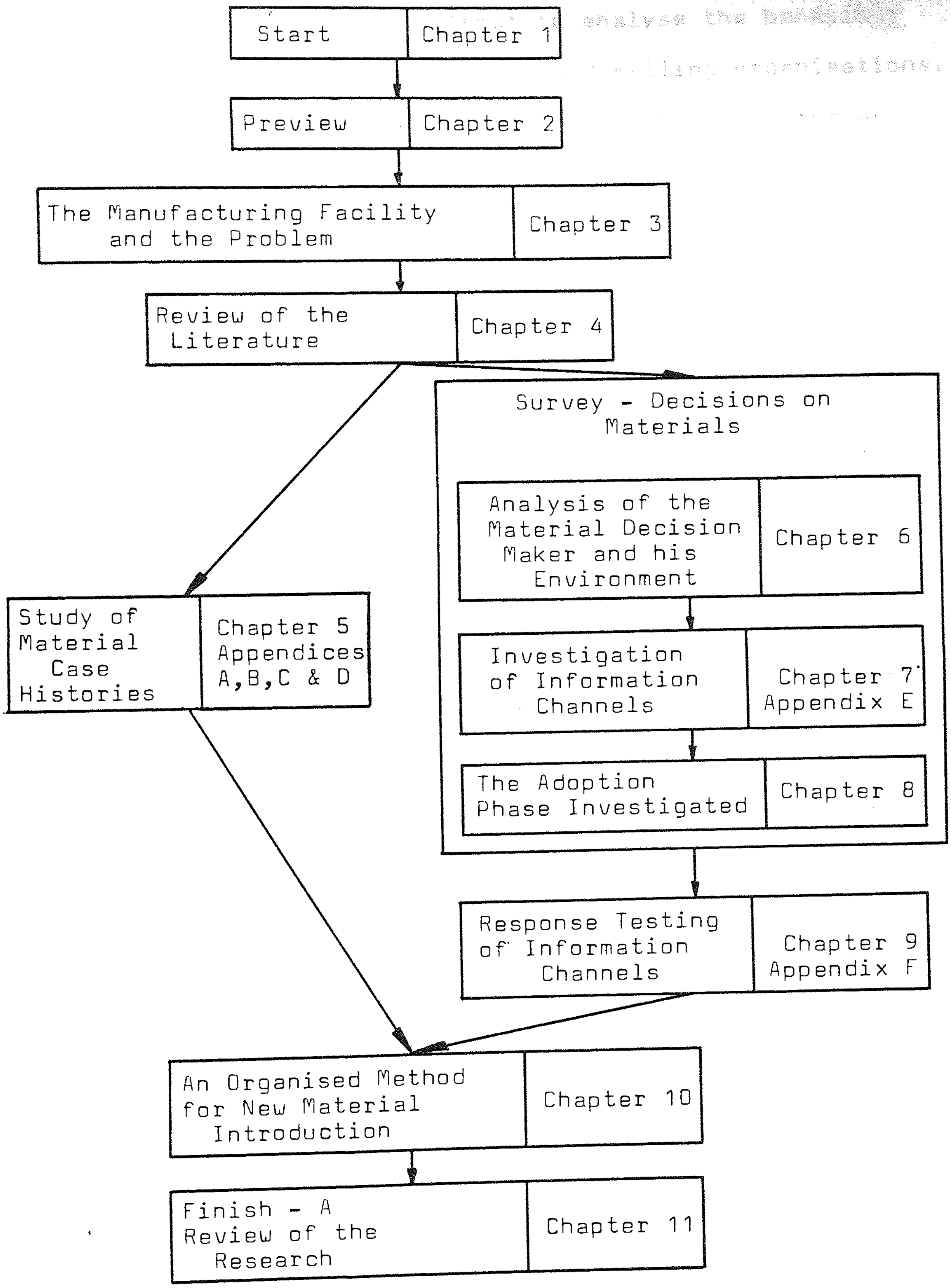
Figure 2.2 A Copy of the Cover Letter Despatched With the Survey or wholesaler as it was to a manufacturing concern. However, this initial survey constituted a free pilot study based on the Midlands. For the purposes of this project 442 copies of the survey were sent out throughout the UK based on sectors likely to use new materials. The majority of these were sent to identified individuals within the organisations. Nine different sectors were aimed at - aerospace, general engineering, material producers, nuclear and power industries, road transport, research establishments, small marine (i.e. pleasure craft), marine and medical. The response to batches one and two was 8·5% (i.e. 85) and 31·4% (i.e. 139) respectively. The results of the survey have been classified for seven identified sectors and one other, headed 'other', which comprise those few responses that were obtained from the marine and medical sectors but which by themselves could not be dealt with.

The results from the survey indicated amongst other things that some technical journals were rated quite highly by the material decision maker as being effective in keeping him up-to-date with material developments. In order to test these results a number of journals were approached, and a variety of publicity was given to Dunlop's carbon/carbon by five different journals (see Appendix F). A technical brochure and samples of carbon/carbon were held in readiness for despatch to respondents.

2.2 THE THESIS - THE STRUCTURE OF THE RESEARCH

The research for this thesis has been based upon the work described above and the flow chart of figure 2.3 indicates the topics that have been covered, and should also help the

Figure 2.3 The Structure of the Research



reader find his way through the thesis. After the first three introductory chapters, Chapter 4 examines much of the pertinent literature in an attempt to analyse the behaviour that can be expected of both buying and selling organisations. This establishes the current state of our understanding as regards material innovations and their adoption, and indicates the areas in which we are lacking. Chapter 5 deals with the innovation process that has been experienced by several producers of new materials. On the basis of trends suggested by the four cases compiled a further six were selected from the literature to examine these trends. A précis of each of these appears in Chapter 5, whilst Appendices A, B, C and D contain the four major case studies. The search methods that are available to material producers in their quest for users are illustrated, as are the different categories of need applications that can lead to a successful innovation, or otherwise.

Chapters 6, 7 and 8 have all been written around the results obtained from the survey - decisions on materials. Chapter 6 deals with the material decision maker. His function has been identified within the various industrial sectors and the variation of material decision team size noted. Material innovations are not as well documented as say product innovations, but the results in Chapter 6 compares the importance of material innovation with that of product and process innovations. Chapter 7 reports the results of the study on information sources and identifies those information channels regarded as effective by the material decision maker. The comparison between effective channels for business developments and material developments is highlighted and the differences between the various industrial sectors are noted. Chapter 8 presents some further information on the users of materials, in particular describing the adoption rate that can be expected for new materials in the different sectors of industry. These results are compared with the overall awareness that firms have of new materials.

The result of the carbon/carbon publicity in various journals is reviewed in Chapter 9, whilst Chapter 10 pulls the results of the research together and suggests an organised method for new material introduction.

Chapter 11 concludes the thesis by reviewing the achievements and use of the research and suggesting areas where further useful developments could be made.

3

THE MANUFACTURING FACILITY AND THE PROBLEM

3.1 CHAPTER PREVIEW

This chapter describes the production method and marketing activities used by Aviation Division for the exploitation of carbon/carbon. Such a description sets the background scene for this project, and as such makes no apology for repeating many of the technical details that are described in the carbon/carbon case history of Appendix A. The lack of marketing expertise in the field of new materials points the way to the problem. And the detailed identification of the problem does no more than identify some possible methods of answering the question "how should we search for uses for a new, advanced technology material?"

3.2 PRODUCTION OF CARBON/CARBON - THE FACILITY AND THE PROCEDURE

The manufacturing facility chosen by Aviation Division was completed in 1975. The process for manufacturing structural carbon, involves permeating the appropriately shaped assembly of carbon fibre with a carbonaceous gas. At temperatures up to 2000°C the gas is cracked - depositing carbon on the individual carbon fibres and thus joining them together within a matrix of carbon. This process is generally termed chemical vapour deposition (C.V.D.).*

In the case of Concorde brake discs the process starts with a woven fibre cloth, whose precursor was rayon. Other forms of carbon fibre can be used depending on the article; for example chopped strand mat, felt, tow, etc. The precursor material might also vary - it may be rayon or a synthetic polymer such as polyacrylonitrile (PAN). The choice of precursor and the form of carbon fibre affects not only properties but also the price of the final article.

Several layers of cloth are cut to shape, cleaned and laid up between graphite jigging platens to form a pile some 25% thicker than the final thickness required. Figure A.5 of Appendix A illustrates the production process. The work piece is then processed in a vacuum furnace (see figure A.6) for several weeks. During this time, the discs will be removed from the furnace at several stages. Firstly after

---

* There are other methods to manufacture carbon/carbon composites and these are briefly described in the case history of Appendix A.

an initial bonding run, the jigging platens will be removed once the work piece has been consolidated. The discs will again be removed from the furnace at later stages for machining operations. This is necessary because the pore size in the composite reduces as the carbon is deposited. A point is reached when no more gas can permeate the composite because a surface crust of carbon has closed off all the pores. This crust must be removed periodically by machining, which will allow fresh gas to penetrate the bulk of the material when placed back in the furnace. Even with this repeated machining the density of the final composite may vary from say 1·7 g/cc at the outer surface to 1·5 g/cc at the centre.

Following the infiltration process, the composite may undergo a heat treatment operation to modify the properties of the material. This operation again takes place in a furnace at temperatures between 2000^{o}C and 2800^{o}C, and has the effect of increasing the thermal conductivity, whilst decreasing the overall strength of the composite. In some instances the heat treatment operation may precede the final one or two infiltrations.

After the final machining operations, the edges of the disc are given an anti-oxidant treatment, and drive clips are fitted to the rotors - see figure A.7. The end result is a composite having a 30% fibre volume fraction - 70% is deposited carbon with a pore size of 10-15 microns. The density of the finished material varies according to the thickness of the composite - about 1·6 g/cc for 13 mm thick material, and 1·45 for 25 mm thick material. Thinner composites obviously take less time to process and will be correspondingly cheaper. The same applies with composites of lower density - if only one or two infiltration runs are necessary the processing costs will be that much less.

3.3 PROPERTIES OF THE COMPOSITE

A composite material such as that described above, has anisotropic properties, being made from distinct layers of cloth. This anisotropy causes the properties of the material to vary depending on the orientation of the fibres.

Some of the general physical and mechanical properties of the material are shown in Table 1.1 of Chapter 1 and compared with other materials. A more detailed breakdown of the properties that can be expected on the Concorde brake discs are given in Tables A.4, A.5 and A.6 and figure A.8. In general though, carbon/carbon composites exhibit a unique combination of features, and these are listed as follows:-

- Chemical inertness to most corrosive agents
- High thermal and electrical conductivity (with heat treatment)
- Low thermal expansion coefficient
- High resistance to thermal shock
- Low density
- High specific heat
- Absence of melting behaviour
- Good machinability
- Non toxic
- High operating temperatures - 2500°C in inert atmosphere, otherwise 900°C with anti-oxidation treatment.
- Biocompatible

The items which have been made so far are generally of simple shape - plates, discs, cones, tubes, rods, etc. although some success has been achieved with moulded items (see figure A.9).

Generally tolerance maintenance is not as good as say, steel, and low temperature creep and movement after machining is noticeable, but not so much as with plastics.

3.4 AVIATION DIVISION MARKETING ACTIVITIES

Aviation Division do not have a marketing department as such. They do have a sales department which is responsible for the acquisition of orders and sale of equipment to the aircraft industries in general.

It is not Dunlop's aim to sell specific items to the user - their aim is to promote the idea of being in the aircraft equipment business. It is assumed that the manufacturers of airframes and aeroengines know that Dunlop are in the business of supplying equipment. An airframe/aeroengine manufacturer will therefore enquire if Dunlop is able to supply a particular part whenever necessary. Enquiries may come from the UK, Europe or the USA. As a summary of Dunlop's business in these three areas they can expect to receive enquiries:

- definitely from the UK manufacturers
- generally from the European manufacturers and American manufacturers.

The procedure for acquiring business is generally as follows:-

- Dunlop will receive a design specification (or ACS - aircraft control specification) from the customer, which will give very specific details of the item they require.

- Dunlop will submit a proposal to the customer within thirty days. This may be a detailed document covering the statement of compliance (interpretation of the ACS paragraph by paragraph), description and operation of product, the design philosophy, a weight statement, reliability statement, relevant drawings and alternatives or variations.

- If Dunlop's technical and commercial proposals prove to be competitive and subsequent negotiations on contract terms and conditions are considered by both parties to be satisfactory, then an order will result.

This method of tendering for business is general to the aerospace and military industries, who specify their needs and let the equipment manufacturer's compete for the contract. Such a system works quite well in this particular environment but it is only to be expected that a company orientated to supplying the needs of the aviation industry would have problems introducing a new material. The senior management of the company probably recognised this for it would explain why the sales department has never been asked to sell carbon/carbon.

This illustrates the problem that a company orientated to a specific market might have, in trying a new venture in an unknown market. They have fixed ideas of working within their known sector but no experience for tackling new areas. In Aviation Division's case this is not quite true because a new foamed metal 'Retimet' had been launched by the company some years ago. The development, production and marketing of this material was put in the hands of one man in the laboratory. It was a case of developing a material with no end product in mind, and indeed it was introduced on the BBC's Tomorrow's World as a material looking for a problem to solve. Even the response to such publicity was under-estimated and a lack of follow-up material added to the problem. Insufficient analysis of the Retimet's properties together with a lack of information about the material at the right time illustrate just two of the problems that Dunlop had whilst trying to introduce this new material. As a result, this product has never been regarded as a success even by the company. It is probably fair to say that they did not want to go through the same process with carbon/carbon and have therefore tackled the problem in an entirely different way.

During the early part of 1973, the Electrical Research Association (ERA)* at Leatherhead were approached with the aim of carrying out a market research study on carbon/carbon. This independent research organisation were asked to search for and identify new product areas for the material - no limitation was placed on ERA in terms of the market sectors to search. Their final report was received by Dunlop in January 1974. It detailed six potential applications - only one of which was followed up by Dunlop with any enthusiasm. In view of carbon/carbon's many attractive features,

---

* Dunlop is not a member of the ERA, but ERA's association with Dunlop's carbon/carbon is discussed in the case history of Appendix A.

Dunlop engineers were disappointed about the projected market need's for such a material.

An effort was made to develop uses for the material in-house. The design team within Aviation Division were given the known properties of the material and came up with a couple of promising uses - bearings and engine seals (also suggested by ERA). Whilst the design work has been carried out for some of Aviation Division's own products, the ideas have never been followed up with much enthusiasm - they have never reached the prototype testing stage. Apart from this there has been no internal circulation of data about the material to other manufacturing sites of Dunlop - except to the Research Centre.

3.5 DETAILED IDENTIFICATION OF THE PROBLEM

Aviation Division were in need of some new profitable products which could be made from carbon/carbon. There were no spare people to look for new uses either from the Advanced Materials Laboratory or the Sales Department - and there was nobody within the rest of the organisation with the experience of looking for uses for such high technology materials. Furthermore, the company generally lacked the people capable of championing products through to successful, commercial fruition. The development of carbon/carbon brakes for Concorde is an exception to this, with Mr. Bayly (then Director of Aviation Division) and Mr. Stimson (Engineering Manager Wheels and Brakes) both promoting the product. However, the few non-aerospace projects that have seemed feasible for carbon/carbon have had no one to promote them through the company and the lack of such a person has largely contributed to the unsuccessful development of carbon/carbon products.

It was to the background described above, that the author was asked to bring a fresh approach to "find new markets for carbon/carbon in fields other than the aerospace industry".

This thesis attempts to answer this broad problem in a fairly detailed manner, by splitting the problem into smaller, more manageable areas. There are four major questions arising from this problem which later chapters hope to answer:

- How should a search operation for new uses of a new material be carried out?

Such a question led to a study of other material manufacturers' to see how they had tackled material innovation problems. This has largely been done using a case history approach.

- Are there "material decision makers" within firms, with the responsibility of selecting materials for their products/processes?

If there is such a person, what is his function, does he work in a team or alone, how important does he rate material innovation as opposed to product or process innovation?

- How do organisations find out about new materials, or keep up-to-date with material developments?

Such a question led to a study of information channels to see which ones the material user regarded as effective and whether they varied for different industrial sectors.

- How long does it take for new materials to be adopted by the users?

An investigation of material users in different industrial sectors followed with the aim of finding out: how aware industry is of new material developments; whether some sectors of industry adopt new materials more rapidly than others, and poses the question, "can the awareness/investigation phase of new materials' innovation be shortened?"

4

REVIEW OF LITERATURE

Page

4.1 INTRODUCTION

Although mankind has been using and developing materials for many hundreds, if not thousands of years, it is only during the last two centuries that many of the major discoveries and developments have taken place. Only a handful of materials were known to prehistoric man: carbon, copper, gold, iron, lead, mercury, silver, sulphur, tin and a variety of woods, stones, furs, fibres and feathers. Today 104 elements are known to mankind, forty eight of which were discovered in the nineteenth century and a further twenty two during this century (Gregory). Even more developments have occurred this century with the vast array of alloyed metals and polymers that are now in common use.

To the general layman the development and usage of materials is probably taken for granted. For example most people never think twice of the polyester cotton shirts they wear, the stainless steel cutlery they eat with, or the fibreglass bath they wash in. Materials hidden behind the pressed steel body panels of their cars are even more remote: aluminium cylinder-heads, gearbox components made by powder metallurgy techniques, polypropylene fascia panels, and glass-reinforced nylon fan blades are all accepted as aids to our modern life with no thought given to the technology that lies behind them.

Even though materials are apparently dismissed lightly by the public, the industries behind them are immensely important to the economy of our country. The National Economic Development Office have shown that raw materials and energy provide the physical basis for industrial capital formation and consumption and economic activity in general, as shown in figure 4.1. Furthermore, the relative economic importance of materials has been emphasised by a NEDO report, which shows that approximately one third of the total product cost is accounted for by the materials industries and the remainder by the engineering and construction industries.

Fig. 4.1 Schematic flow of natural resources through to final products. Source: Pick and National Economic Development Office.

Materials and the industries behind them are clearly important to the development of our economy. Although iron and steel are still the most important class of material according to Pick and Becker the development of new materials is playing an ever increasing role in industrial and consumer goods. This is clearly shown by the growth of the plastics industry since 1900 (see figure 4.2).

Figure 4.2 Growth rate of major industrial materials from 1800 AD. (Source: Crowther)

Those organisations concerned with the manufacture of materials and the development of new materials in particular, should therefore be acutely aware of their customers. Materials have been described by N. P. Allen as substances for making useful objects, and this fact should be borne in mind by those organisations responsible for the manufacture of materials. For an organisation contemplating material innovation there are at least nine elements to consider before the innovation can be approached in an organised manner. These are:

- Factors affecting material selection
- Industrial buyer behaviour
- Decision-making unit in the buying organisation

- Groups responsible for promoting materials
- Innovation: models and case histories (these might illustrate the pros and cons that can affect the success of the innovation).
- The prerequisites for stimulating demand
- Search methods for finding users
- Effective communication networks
- The adoption procedures and rates.

The reasons for studying these many facets of marketing should be apparent to all; for the successful planning and implementation of marketing strategies depends to a large extent on understanding the buying behaviour of organisations. This has long been recognised, even if not fully implemented by all organisations. Alexander, Cross and Hill summarised the reasons for studying organisational buyer behaviour in 1961, when they wrote:

> Any attempt to understand the managerial problems of marketing a product or group of products must include at or near its beginning, a study of the persons or establishments that buy or can buy those products. Without a knowledge of his market, the buying units that comprise it, and the working conditions of, and the objectives sought by the purchasers in their operations, the marketing manager finds himself forced to make decisions and formulate programmes in a sort of informational twilight of assumed facts and conditions that can only result in useless error and loss.

Each of these elements have been discussed in the following review.

4.2 FACTORS AFFECTING MATERIAL SELECTION

4.2.1 TECHNICAL AND ECONOMICAL FACTORS

The choice of material for a given product is subject to some basic considerations at the design stage; these are:

1. Strength to weight ratio - although only loosely considered in many cases.

2. Type and mode of load applied to product, i.e. tensile, compressive or shear and whether such loads are dead, fluctuating or shock.

3. Method of manufacture

   - casting
   - fabrication
   - forging
   - machined from solid
   - formed from powder
   - injection mould
   - extrude
   - mould and cure

4. Environment

5. Cost of material and processing

6. Availability

7. Special requirements, such as awkward shape.

The sources of information for mechanical and physical properties of many materials are readily available in handbooks such as Machinery's Handbook, Kent's Mechanical Engineers' Handbook and so forth. Other sources include the British Standards, various research associations and manufacturers' or suppliers' catalogues. These and other groups responsible for the promotion of materials are discussed in a later section (4.9).

Civil and mechanical engineers usually use such conventional tables of mechanical and physical properties of materials when designing structures. If, however, an engineer is designing for light weight, such tables do not, unfortunately, provide a basis for comparison and selection of materials. It has been suggested by H. J. Sharp that in such instances, merit indices or ratios, such as strength to weight or stiffness to weight might be used. There are at least three categories of strength to weight ratio that might be considered:

1. Modulus of elasticity - density ratio compares specific stiffness and is suitable for the comparison of materials for beams. However, many of the common engineering materials have specific stiffness approximately equal, i.e. about

26·2 GPa, see Table 4.1. In other words, no matter how much materials are strengthened, most materials have the same specific stiffness. I - beams of equal weight and depth constructed from these materials would each have the same stiffness in this respect.

Table 4.1 Young's moduli of orthodox structural materials
(Source: J. E. Gordon)

Material	Specific Gravity	E GPa	E / S.G. GPa
Molybdenum	10·5	276	26·3
Iron	7·8	207	26·5
Titanium	4·5	117	26·0
Aluminium	2·7	72	26·7
Silica and common glasses	2·5	69	27·6
Magnesium	1·7	41	24·1
Wood-spruce parallel to grain	0·5	13	26·0

There are, however, a few materials with much greater specific stiffness, beryllium, boron, carbon fibre and some ceramics such as silicon nitride, alumina (J. E. Gordon).

2. Specific tenacity, i.e. tensile strength-density ratio, indicates that titanium alloys are better than aluminium alloys. However, non-metallics, such as glass fibre and carbon fibre reinforced plastics are the most effective in this respect.

3. Yield strength-density ratio is the criterion that may be used for structures of reduced slenderness ratio, where the failure characteristic is compressive yielding or frac-

ture. Specific compressive strength in terms of the yield strength may be used for ductile materials and ultimate compressive strength may be used for brittle materials. This shows titanium alloys to be superior to aluminium and magnesium, but the ceramics are even better.

It cannot be overstressed that engineers are not concerned with the properties of "materials" as such, but rather with the "performance-in-service of products such as components, assemblies and structures", as Pick (1968) has stated. He goes on to suggest that often the data an engineer is handling is that of chemical composition and mechanical properties which are used as measures of reproducibility and quality rather than a description of the in-service properties. The properties and cost of a product depend on many complex interactions - design, inherent material properties, manufacturing operations, surface treatment, etc. - and the optimum design solution is in turn dependent on these interactions. The correct selection of materials for particular applications is therefore important and in many cases better design solutions can be found by using combinations of different materials and/or processes rather than by reliance on a single material.

It is apparent from the aforementioned that design engineers must be helped in the choice of materials by presenting comparative data of different materials. The scale of the complex technical interactions under consideration when materials are being chosen is illustrated by the check list for a metal, taken from Steel and its Heat Treatment, see Table 4.2. Bearing in mind that a comparison of the chara-

Table 4.2 Check List for Characteristics of a Metal

Purpose of this list is to present reasonably complete listing of all properties of a metal so that, when a specific metal is under consideration, those desired properties pertaining to it may be readily selected and their priority determined. The list is of assistance in assuring that no properties are overlooked.

Taken from Steel and its Heat Treatment and quoted by Sharp.

cteristics for several materials will be considered by the designers it is evident that material decisions can become very involved.

It is not surprising, therefore, that design decisions are full of compromises, and in many cases the optimum economic solution is missed either for the manufacturer or user, or both. For example, although a product may have all the desirable features in terms of its physical and fabricating characteristics, it can still be made from materials that are sub-optimum in terms of economics. Comparison of materials by physical and mechanical properties is all very well but a further comparison on a cost basis is also necessary. Many materials are costed on a unit weight basis, others on a volume basis, and still others on a length basis, but this is of no real significance for comparing the price of given properties.

Sharp recognised this dilemma and suggested that materials should be compared by costing their function. It is possible, for instance to compare the cost of primary metals which could be used to support a load of 100 tons, see figure 4.3, and even include the cost of fabrication, see figure 4.4. Ideally, the comparison of such costs would need a computer to handle all the data and Appoo and Alexander at the University of Aston have done much of the pioneering work in this country, using a cost per unit function analysis technique.

The development of this technique is currently being studied by the motor trade but such a selection technique will no doubt be useful to other industries in years to come. A

Figure 4.3 The cost of an adequate yield strength. By calculating the cross-sectional area required to support a load of 100 tons, based on the yield point or proof stress, and converting this to a comparable cost figure, materials may be compared on the basis of cost for a similar yield strength. The cost of converting the ingot or pig to sheet, strip, castings, or forgings is also shown for those quantities of materials needed for similar yield point.

(Source: Sharp)

Figure 4.4 The space required to develop an adequate yield strength. By comparing the cross-sectional area of materials required to support the same load, an assessment is given of the bulk of the material required for an adequate yield strength. It is interesting to compare side by side the 'fabrication costs' from Figure 4.3 (i.e. the cost of conversion from ingot or pig to casting, forging, sheet, or strip, etc., the quantity of material needed to give a similar yield point) with the cross-sectional area of this figure gives a 'fabrication efficiency factor', which is an indication of the efficiency of conversion on a volume basis of the material from the ingot or pig form to the cast, forged, or rolled form, etc.

(Source: Sharp)

very simple explanation of the method of operation will serve to show its potential. Consider the problem of filling a certain volume, say 1 m^3, with the cheapest available material. This is a simple one-dimensional problem, the cost effective material is that which costs the least per cubic metre. Assuming the computer has a list of materials and their related cost per cubic metre stored on file it is a simple task to ask for a print-out of those materials costing less than, say, £2 per m^3. The issue becomes more complex as the dimensions of the problem increase. For example, the material required might also need to have a certain strength to weight ratio, withstand a given chemical environment and be magnetically susceptible. This has increased the selection problem manifold, but providing the relevant data on all materials is filed away, it is not a difficult problem for the computer. Such a system allows the most economic material, either in terms of cost or energy input, to be selected. The development of such systems could have profound effects on material producers developing new materials and should therefore be kept under review.

An example of some of the technical and economic factors that influence material selection has recently been provided by the Production Engineering Research Association (PERA). They were able to identify the factors responsible for the conversion from metals to plastics for eighty-five components for eight main engineering industries. In order of popularity the factors which influenced conversion were: low weight, corrosion resistance, low costs, wear resistance and good electrical insulation. The high energy costs, which have caused price increases in both metal and plastics in recent years were highlighted by PERA. However, metals have risen more than plastics, and as an example PERA quoted that the cost by volume of Nylon 66 has risen by about thirty per cent since 1973, whereas the cost of diecast zinc has risen by more than 250 per cent.

Another technical factor, or in some cases it may be regarded as a political factor, that may affect the selection of a material for a particular use, is whether or not it has a national standard, for some manufacturers will not use a material unless there is a national standard for it. But as Starr has pointed out "it is axiomatic that national standard specifications are not prepared until there is a fairly widespread and steady demand for them". Although some companies, probably the innovators*, will be using new or improved materials for which there is no national standard specification, it is unlikely that the material will diffuse to, say, the late majority until such a specification is available. The time lapse between the decision to take action and the actual appearance of a specification can be as long as three years. Such standards as laid down by the British Standard Institute will contain details of the method of manufacture, chemical composition, heat treatment, the selection of test pieces and mechanical tests. DTD standards are also in use for materials in the aircraft industry

* Adopter categories such as innovators and the late majority are discussed in Section 4.10.4.

that are not covered by the BSI standard. Even the building trade is not exempt from such standards; materials have to comply with Building Regulations and meet the Agrément standards. For example, foam fills for cavity wall insulation must meet the standard as laid down by Agrément Certificate no. 74/209/76/AM 16. A material producer hoping to introduce a new material to a particular industrial sector should therefore be aware of the standards that the industry is obliged to work to, and take appropriate action with their material.

4.2.2 POLITICAL AND SOCIAL FACTORS

Such technical and economic factors affecting material selection may well be overshadowed by political and social pressures of the day when new materials are under consideration. Sambell and Davidge claim the political and social factors to be just as important as the technical and economic factors when it comes to new materials being studied for potential use. Such indirect factors as (a) existing and future material resources, (b) effects on the environment and (c) the required energy inventory can have far-reaching consequences when new materials are being considered. Unless a new material can satisfy all these requirements it is unlikely that it will be chosen by engineers for their particular new product.

Whilst examining these broad factors which can affect material selection decisions, it is as well also to be aware of the consequences that changes from one particular material or process can have on a firm. The effect of new materials and of new processes may well pose serious problems for companies. The following example put forward by Pick (1972) serves to illustrate the problem. A manufacturer of ceramic baths will have some far-reaching decisions to make should he receive an increased demand for plastic baths. He will have to decide whether he is in business primarily to manufacture baths, in which case he will have to invest heavily in plastics technology to maintain his level of business, or a manufacturer of ceramics, in which case he will have to find other outlets to keep his assets employed. If he does neither he may well go out of business. There is also the possibility that the increased demand for plastic baths could be due to fashion, and just as likely to change again to some other material. Such a problem indicates the very real dilemma that firms can face when contemplating long-term investment plans. The technology behind material and process developments is developing at such a pace that firms may well find it difficult to decide which routes to opt for.

Such changes in the choice of materials or processes for manufacturing products could change the whole structure of industries, not just individual firms, and as such is likely to become more of a political decision than technical decision.

4.2.3 CRITIQUE

A computerised cost per unit function analysis technique for the selection of materials is still in its infancy to date, but nevertheless it is probably the most sophisticated selection technique available. When systems such as this are introduced to companies either individually or on a national scale, it will be imperative for material producers to ensure that data on their materials is stored on file in the computers.

Until that time, it is necessary for material producers to be aware of the technical, political and social factors that influence the choice of materials, and prepare information about their materials accordingly. Even then it is likely that political and social factors will play an important part of major material decisions if the trend from product orientated production to materials-and-process orientated production that Pick (1972) forecasts, comes to pass.

4.3 INDUSTRIAL BUYER BEHAVIOUR

Before examining Industrial Buyer Behaviour in depth, the rationale for carrying out such a study should be understood. According to Webster and Wind (1972a) a study of Industrial Buyer Behaviour should:

(i) Identify, guide and evaluate the need for market information and thus suggest the factors which are likely to affect behaviour;

(ii) Aid the analysis and interpretation of existing information;

(iii) Improve the value of predictions about behaviour.

Such admirable sentiments are difficult to argue with and indeed, this study approached the subject with much the same objectives. In addition, this study wished to examine the peculiarities, if there be any, of buying materials, and in particular new materials, into an organisation. It was expected that the literature would provide hypotheses which would be useful to Dunlop for developing a marketing strategy with carbon/carbon.

Unfortunately, whilst there has been considerable theorising about Industrial Buyer Behaviour there has been very little field work carried out. The work presented herein describes both general models of buyer behaviour and also specific models of organisational buyer behaviour (see Table 4.5).

Table 4.5 Models of Buyer Behaviour - a) generic and b) specific to organisations

Generic Models of Buyer Behaviour	Specific Models of Organisational Buyer Behaviour
Marshallian Economic Model	"BUY-GRID" Model - Robinson and Faris
Pavlovian Learning Model	Wind Model
Freudian Psychoanalytic Model	Decision Process Model - Webster and Wind
Veblenian Social Psychology Model	Integrative Model - Sheth
Hobbesian Organisational Model	Box Model - Nielsen

It will be seen that all these models are of the "black box" type, i.e. the buyer (individual or organisation) is the "black box" into which certain inputs or stimuli are placed and the outputs or responses are observed. Almost by definition such "black box" models are descriptive rather than predictive and are of little practical use unless the relationships between the inputs and outputs can be described. Such ideals showing how different variables effect behaviour are very plausible. Unfortunately the models do little more than provide a framework for analysis. It may well be, as McGrath has suggested that "the researchers are attempting to achieve an objective which no general psychological or sociological theory has yet reached - that of predicting human behaviour."

Models of consumer behaviour are undoubtedly different from those of organisational buyer behaviour and as such need modifying before the differences between consumer and organisational purchases can be considered. Webster and Wind (1972a) suggest the major differences are:

(i) Organisational buying decisions are more complex than consumer decisions because more people are involved in the decision process; each person possibly playing a different role, not only for a given purchase, but also from one purchase situation to the next.

(ii) Products (or materials and services) are often of greater technical complexity; considerable technical evaluation is required before a decision to purchase is made.

(iii) Organisational buying decisions often take longer because the high technical content of the product requires thorough and cautious evaluation; decisions once taken are more difficult to rescind in an organisation than in a consumer environment.

4.3.1 GENERIC MODELS OF BUYER BEHAVIOUR

Kotler has identified five generic buyer behavioural models which have been used to develop marketing strategies. Four of these models throw some light on the behaviour of family buyers whilst the fifth sheds light on the organisational buyer. In brief, they are:

(i) Marshallian Economic Model - assumes a rational behaviour to product purchases wherein economics play the over-ruling part. The Marshallian man is concerned chiefly with economic cues - prices and income - and makes fresh utility calculations before each purchase. Such a model requires perfect knowledge but at the same time ignores behavioural aspects.

(ii) Pavlovian Learning Model - purchasing habits are driven by certain cues and are determined by past rewards. This approach, developed from physiological experiments into the salivatory habits of a dog has never been completely vindicated in the behaviour of creatures with a higher mental process.

(iii) Freudian Psychoanalytic Model - the behaviour of the buyer is influenced strongly by deep-seated motives and fantasies. Motivation research such as this seems rather esoteric outside the psychiatrist's consulting room and lacks predictive power.

(iv) Veblenian Social-Psychological Model - the Veblenian man's behaviour is influenced by several levels of society in which he lives - culture, subcultures, social classes, reference groups, face-to-face groups and family. He thus acts in a way which is shaped largely by past and present social groups; purchasing is therefore a group activity.

(v) Hobbesian Organisational Model - corporate man steers a careful course between satisfying his own needs and those of the organisation. It suggests that the buyer is part rational and part emotional in behaviour and this obviously has some relevance in many buying situations.

The Hobbesian Model introduces the dichotomy that faces the organisational buyer, that is, looking after the organisation - a "task" oriented concept - whilst at the same time looking after oneself - a "non-task" oriented concept. Webster and Wind (1972a) put it more formally: "Task models are those employing task-related variables (such as price) whereas non-task models....attempt to explain organisational buying behaviour based on a set of variables (such as the buyer's motives) which do not have direct bearing on the specific problem to be solved by the buying task".

Examples of task and non-task buying behaviour are:

Task (Economic)	Non-task (emotional)
Source searching	Ego enhancement
Supplier appraisal and evaluations	Office politics

Task	Non-Task
Purchase research	Personal risk reduction
Value engineering analysis	Tactics of lateral relationships
Product-cost management	Previous experience
Purchase price analysis	Other emotional activities
Other objective techniques	

(Source: Hill & Hillier)

Neither task nor non-task type models provide the complete picture of organisational buyer behaviour, there should be a combination of both. The ideal model of buyer behaviour should obviously show how the buyer is affected by the organisational and social settings in which they operate (Duncan) and make clear the fact that they are individuals with motives and attitudes which must be considered (Sheth).

It is suggested that a good model of Industrial Buyer Behaviour must consider the individual's characteristics, group (social), organsiational and environmental factors for both task and non-task variables:

Source of Influence	Task Variables	Non-task Variables
Individual	Desire to obtain lowest price	Personal values
Group	Meetings to set product specifications	Off-the-job interactions among company employees
Organsiational	Company policies with respect to product quality	Company policies regarding community relations
Environmental	Expected trends in business conditions	Political factors in an election year

(Source: Webster & Wind 1972a)

4.3.2 SPECIFIC MODELS OF ORGANISATIONAL BUYER BEHAVIOUR

Five models of organisational buyer behaviour are examined below.

BUY-GRID Model: Robinson and Faris

A widely acclaimed model is that of Robinson and Faris, which is based on the results of a two year research programme in three different companies in the USA. It suggests that industrial buying uses an eight stage decision process known as "buy phases":

1) Anticipate (or recognise) that a problem or need exists; co incident with this anticipation is the awareness that a possible solution may be through the purchase of an industrial good.

2) Determine the quality and characteristics of the needed item.

3) Specify description of needed item.

4) Search for qualified potential sources.

5) Examine sources; leads to a decision concerning how the item is to be purchased.

6) Evaluate proposals and select suppliers.

7) Establish an order routine.

8) Performance feedback and evaluation.

The grid matrix is completed by considering three different buy classes - new buy, modified re-buy, straight re-buy - with the eight buy phases, to account for the fact that some stages may be omitted for different buy situations.

Although the model suggests that the buying process is incremental and that there are critical points in that process, it suffers two faults. It has virtually no predictive power, i.e. it fails to identify any cause-and-effect relationships and does not explain interactions between various functional areas.

Wind Model (quoted in Robinson and Faris)

Wind's model, shown in figure 4.5 was developed in the 1960's to try and overcome some of the problems with the BUY-GRID model. Although it still focusses on the industrial buyer it introduces the concept of a buying centre, consisting not only of the industrial buyer, but others directly involved with the purchase decision. Peripheral groups are also shown to influence the buying centre, as are organisational, environmental and competitive factors.

However, the model fails to differentiate the important elements between task and non-task factors, lacks any predictive ability, and makes no attempt at identifying the subunits of the buying centre. A later Wind model (1968) does go some way to overcoming this last criticism when two subunits - a purchasing group and the user department - are identified in the buying centre and various interactions between the buying centre and the suppliers are indicated.

Decision Process Model (Webster; Webster & Wind 1972b)

The Decision Process Model published by Webster in 1965 regards Industrial Buyer Behaviour as a sequential four-stage operation leading to a solution; these are:

Figure 4.5 The Wind - proposed framework for the analysis of the various determinants of the buyer's behaviour

(Source: Robinson and Faris)

(i) Problem recognition - the creation of a buying situation by a discrepancy between desired goals and actual achievements.

(ii) Assignment of buying responsibility and authority - decisions have to be made concerning the make-up and structure of the decision group, both formally and informally.

(iii) Search process - to establish selection criterion and identify product alternatives.

(iv) Choice process - to evaluate and select among the alternatives.

Webster's ideas were further refined and developed with Wind and the model shown in figure 4.6 was published in 1972b. It shows a variety of factors influencing the behaviour of industrial buying decisions including individual, group, organisational and environmental. If the model does not clearly show it, their text indicates that the buying process will involve several people (who may be influenced by others) and be affected by: the character of the organisation; the environment (which in turn affects both the individuals and the organisation); and by each individual's character and personality. Unfortunately, though this model is complex, dealing as it does with task and non-task variables, it is really only a general descriptive model and again lacks predictive power.

<u>Integrative Model</u> (Sheth)

The Integrative Model described by Sheth and shown in figure 4.7 is a comprehensive and complex model; it provides a

Figure 4.6 The Webster and Wind model for understanding organisational buying behaviour

(Source: Webster and Wind 1972b)

Aston University

Figure 4.7 The Sheth integrative model of industrial-buying behaviour

(Source: Sheth)

useful framework for comprehending the interactions between many of the variables involved in industrial buyer behaviour.

Although not explicity defined, the buying centre - shown as (1) - is depicted, and the functional groups taking part are specified. The buyer behaviour process is clearly influenced by task (i.e. product and company) and non-task (psychological) factors, and the fact that buying decisions can be either autonomous or joint is described.

Although the model shows the purchasing agent to be of equal importance to the other members of the buying centre, it is only in the text that Sheth makes clear that the purchasing agent is often a less critical member of the decision-making process in industrial buyer behaviour.

This model appears to be a fair (if not validated) representation of buyer behaviour until one attempts to use it; it is a fine descriptive model but connecting boxes of variables to processing units is of little practical use when trying to predict the behaviour of the buying organisation.

Box Model (Nielsen)

The Box Model developed by Nielsen (see figure 4.8) in the early 1970's attempted to combine elements of organisational-buying behaviour with some ideas from consumer behaviour. Nielsen suggests there are basically four decision levels:

(i) General buying decision - the decision which initiates a project and is therefore not necessarily the consequence of former decisions.

Figure 4.8 The Nielsen box model of industrial-buying behaviour

(Source: Nielsen)

(ii) Concrete buying decision - selection of a definite project, including its objectives, constraints and specifications.

(iii) Selection decision - selection of best products and suppliers.

(iv) Technical buying decision - decisions related to the actual transaction, i.e. drawing up contracts, negotiating final price and payment arrangements and so on.

Although the decision groups involved at each decision level may vary from one level to the next, each group will go through a similar decision process as described in the BUY-GRID model, and decisions taken at one level will obviously affect those taken at the next level. Even though the model takes account of the type of buy (new, modified re-buy and straight re-buy), the various factors that will affect the different decision groups, and the individual's perception of task and non-task influences, it is still a model that lacks predictive qualities.

4.3.3 CRITIQUE

The models described herein illustrate the vast amount of thought that has been given to industrial buyer behaviour to try and get a better understanding of the process. However, the majority of the models examined are either too simplistic to be of general use or else they lack predictive power. This is probably because insufficient empirical work has been carried out to evaluate the input-output relationships between the variables on the one hand

and the actual behaviour on the other. Such a task could no doubt be investigated in the laboratory, but one runs the risk of the subject exhibiting atypical behaviour. The problems encountered in assessing buyer behaviour in the "real" situation are immeasurable, and one is therefore left with "laboratory" results that are certainly more definitive than "real life" investigations, but they perhaps lack generality due to the falseness of the situation.

4.4 DECISION-MAKING UNIT - EMPIRICAL EVIDENCE

A variety of studies have concentrated on the buyer alone when analysing Industrial Purchasing Behaviour, some arguing that he is a rational being (Copeland and Tofte) and others putting forward evidence of his irrationality (Marino, Shoaf, Sawyer and Duncan, for instance). However, as has been previously stated, Industrial Buyer Behaviour is characterised by group participation in the decision-making process. It would therefore seem to be short-sighted to study the buyer alone.

To progress further, it was clear that research had to be conducted into the entire process of buying within a company. Such studies would have to examine the roles of individuals in the Decision-Making Unit (DMU) and determine how each reacted to different purchasing situations (Weigan). The industrial marketing executive must therefore recognise that he is dealing with a number of individuals within a DMU who must be identified, their roles understood, and the criteria which they use in purchasing decisions established (Hill & Hillier).

Howard and Moore identified at least three different departments involved in purchasing decisions: Purchasing (the buyer), Quality Control (the engineers) and Manufacturing (the users). The different backgrounds and job functions generally inhibit all-round satisfaction, and a compromise solution often has to be found to fulfill the company objectives, which in turn can lead to conflict between the groups (Strauss 1962 and 1964). According to Alexander, Cross and Hill, who studied 106 American firms, three or more people influenced the purchasing decision in more than 75% of the firms. In the UK, however, a special study of the British engineering industry showed that for medium sized firms (400-1000 employees) purchasing decisions were subject to more than five influences and that for larger firms (over 1000 employees) at least six influences were identified (McGraw-Hill). Smallbone has also suggested that the size of the DMU will increase as the turnover of the products and size of the firm increases.

Not all members of the DMU have the same degree of involvement in purchasing decisions. The role played by each member depends on their job function, the nature of the buying task and organisation, and even the personalities of the group members. Various authors have classified the roles played by the individuals involved in the industrial buying process for example: as contributors, participants, responsibles and directors (Klass); as influencers, buyers, deciders, and gatekeepers (Webster & Wind); and as those who make the major buying decisions, make recommendations, must approve purchases, affect the conditions of use, and conduct the buying negotiations (Sales Management). Hill and Hillier summarised the views of the various authors diagramatically as shown in figure 4.9. This portrays the concept of a buying centre with various units interacting to make the buying decisions.

Figure 4.9 Units in the buying centre

(Source: Hill & Hillier)

Buckner in a comprehensive study of British industry identified up to three specialist functions involved at each stage of the purchasing decision process with up to ten functional groups having some involvement. He found that for industry as a whole, the people most concerned with purchasing were,

For Plant and Equipment	Board
	Operating Management
	Production Engineers

For Materials and Components	Buying Department
	Design and Development Engineers
	Operating Management

This has been broadly supported by a more recent study carried out by the Financial Times who examined the buying habits of 906 British firms. They found that the people with the dominant influence for initiating and specifying the purchase were:-

For Plant and Equipment	Production Engineers
For Materials	Research and Development and Design Engineers
For Components	Design Engineers
For Commercial Vehicles and Trailers	Transport Managers

The degree of involvement of individuals in the DMU appears to vary according to the type of purchase, the size of the company, and the stage in the industrial buying process:

The type of purchase, new buy, modified re-buy, and re-buy, was found by Brand to relate the various members of the DMU to the purchasing stage, as shown in Table 4.6. This shows the greatest involvement of different functional areas to occur in the new buy situation. Fisher has suggested that the identity of the functions involved in such a situation is related to the product complexity and commercial uncertainty.

Table 4.6 DMU Members involved by Type of Purchase

Purchasing Stages	New Purchase	Change in Supplier	Repeat Purchase
Recognition of need to purchase	Board, General Management	Buyer	Stock control system
Determination of product characteristics	Technical Personnel	As specified when new purchase	As specified
Description of product characteristics	Technical Personnel	As specified	As specified
Search for suppliers	Technical Personnel	Buyer	Approved suppliers
Assessing qualifications of suppliers	Technical Personnel	Technical Personnel and buyer	Approved suppliers
Acquisition of proposals	Buyer and Technical Personnel	Buyer	Purchasing Staff
Evaluation of proposals	Technical Personnel	Buyer	Purchasing Staff
Selection of supplier	Technical Personnel General Management, Buyer	Buyer	Purchasing Staff
Selection of order routine	Buyer	Buyer	Purchasing Staff
Performance feedback and evaluation	Technical Personnel and Buyer (informal)	Buyer (informal) System (formal)	Buyer (informal) System (formal)

(Source: Brand)

Platten found that design and development engineers participated in 20% of the decisions involving the purchase of materials and in 30% of the decisions involving component parts. Directors have been shown to play a declining role and departmental managers an increasing role in the purchase of materials as the size of the company increases, according to the Financial Times. However, in industries such as food, drink and tobacco, textile and clothing and to a lesser extent in the construction material and timber and paper sectors of industry, directors show a significant involvement at all stages of the decision process for the purchase of plant and equipment and materials; whereas in the chemical and metal manufacturing sectors of industry decision process is predominantly departmental. Different departments have been found to be important in different sectors of industry, for example: research and development carry the major weight at the initiation and technical stages of the decision-making process for materials in the chemical industry; design engineering is important in the engineering sector; and in addition to the directors' strong involvement in the textile industry, the production department plays an above-average role and the purchasing department a lower than average role. Production and engineering personnel (or other management) were frequently found to discuss expensive purchases with suppliers before involving the purchasing department according to a study by Thain et al. Shankleman, in a survey for the New Scientist, gave more detail of the degree of involvement that various individuals had at various stages of the buying process. He found that decisions on the need for product type were shared between management and engineers; decisions as to supplier choice were shared between management, engineers and buyers; decisions regarding selection and specification of brand were shared between management and engineers with minor buyer involvement; and that placing the order was done by the buyer alone.

Both Buckner and The Financial Times study indicated that purchasing tends to be centralised in most companies. Over half the persons involved in purchasing having company-wide responsibilities, although the purchase of materials and components is marginally less centralised than other types of purchase, plant and equipment, commercial vehicles and private cars for instance.

Weigan has recognised that decision-making units often have decision influences affecting the team (i.e. consultant engineers, professional colleagues in associate or competitor companies, insurance firms, testing laboratories, construction firms or government units, for example) who may influence the purchasing habits of the organisation.

The Financial Times study illustrates just how important this can be in construction industry. In that industry, purchasing habits for materials are strongly influenced by outside organsiations at the specification stage - over 70% of the construction companies who replied to their survey relied on architects to specify not only the basic type of characteristic building materials, but also the detailed specification of the material. Brand has also suggested that when companies are searching for potential suppliers preference will be given to those known by the people inside the purchasing company or to professional colleagues employed in other companies. The search for potential suppliers is also likely to be restricted to known companies because of time pressure. Brand, Buckner and Sheth have all suggested that the involvement of the buyer in the decision-making process is minimal until the technical problems have been solved, although Brand feels their influence may grow as they gain increasing recognition by senior management. In a small study carried out by Lister, he found that the purchasing executive played an important role in 20% of the cases studied. James A. Jobling carried out a relatively simple survey of the purchasing procedures for industrial glass among forty eight companies in the UK. Although the research was not elaborate it does provide further evidence of the importance of the purchasing function when buying materials, as can be seen from the results shown in Table 4.7. It clearly indicates, however, the overall importance of design, for actually specifying the material. Even though the buyer is most active when one source of repeat purchases is changed for another (see Table 4.6) it should not be overlooked that in the new-buy situation it is he who invariably selects supplier and negotiates the contract. Alexander, Cross and Hill claim that this places him in a far more significant position than the other individuals influencing the buying of industrial goods. The Financial Times study suggested that the purchasing department played a dominant role in the DMU for basic commercial functions (such as identifying and maintaining files on potential suppliers, price negotiation, delivery and supply, final selection of supplier, and changing supplier for commercial reasons) in the buying of materials.

Table 4.7 The Role of Purchasing in the buying of Industrial Glass

	% of respondent companies where purchasing is involved	Ranking of purchasing in relation to other functions	Other functions in order of importance when purchasing is not ranked No. 1 (Percentage scores are given)	
Who is most likely to start projects leading to the purchase of industrial glass when:				
a) It is for use in production of a new product in the customer company?	17	4	Board and general management	56
			Design and development Engineering	46
			Finance	29
b) Required to change the design of an existing product?	17	3	Design and development Engineering	71
			Board and general management	35
			Production engineering	17
c) Required because of a change in a production process?	10	5	Production engineering	46
			Production management	42
			Design and development Engineering	29
			Board and general management	23
d) It is considered that a change in supplier is advantageous?	81	1		
Who surveys alternatives and decides the kind of materials?	56	1		
Who determines the design and specifications?	2	6	Design and development Engineering	75
			Board and general management	23
			Production management	15
			Research	10
			Production engineering	4
Who evaluates samples submitted?	17	3	Design and development Engineering	65
			Board and general management	27
Who chooses suppliers from whom to obtain quotations?	83	1		
Who decides which supplier gets the order?	79	1		
Which sectors in customer companies receive sales reps?	85	1		

(Source: Jobling)

Furthermore, they suggest that commercial factors play a more significant role than technical factors in the choice of a material supplier, probably because the purchase of materials is much more "routine" than for plant and equipment.

This review of the DMU could not be concluded without examining the individuals who see salesmen for industrial purchases. The Financial Times' report shows that for materials and components, the purchasing manager is responsible for seeing salesmen with design engineering staff playing only a minor role. For plant and equipment, the production manager is most likely to see the salesmen although the purchasing manager does still play an important role (see Table 4.8).

Table 4.8 Who sees Salesmen for Industrial Goods

	% of companies		
	Plant and Equipment	Materials	Component Parts
Managing Director	23	14	-
Other Director	34	24	17
Production Director	29	17	-
Production Manager	46	33	36
Purchasing Director	22	20	-
Purchasing Manager	37	72	68
Other Purchasing Staff	-	28	31
Design Engineering Manager	20	21	25
Research & Dev. Manager	-	20	-

Compiled from data quoted by The Financial Times

4.4.1 CRITIQUE

All the studies of Industrial Buyer Behaviour and the decision-making unit have a fundamental weakness when it comes to analysing how materials are bought by organisations. This flaw stems from the fact that the buying of materials is regarded as a repetitive operation, which it generally is, but previous research has apparently neglected the fact that the introduction of a new material into an organisation does not follow the repetitive pattern. Although the research indicates those people responsible for (i) deciding which materials are to be used in a new product and (ii) drawing up the specification of a chosen material, it gives a false indication of the person to approach in an organsiation when a new material is being introduced, i.e. the purchasing staff. It is unlikely, for instance, that a material supplier would get a new material adopted into the buying organisation by approaching the purchasing department, who would fail to understand the technical advantages of such a material. On the other hand, the purchasing manager is undoubtedly the right person to approach if the material producer has a commercially better material (i.e. he is selling an improved brand of material at a lower price). A new material cannot be adopted into a new product until its technical feasibility has been established and that can only be done by the design and development people in a company. Indeed, experience in the aviation industry has shown that materials and components are "sold" by the technical salesmen approaching mainly design engineering people, who will then proceed with their technical assessment. To suggest that new materials can be sold by the material salesmen seeing the purchasing manager of a company is surely misleading.

4.5 GROUPS RESPONSIBLE FOR PROMOTING MATERIALS

It is important for material producers to be aware of the various groups around the country who can help the promotion of a material by providing information to potential users. The institutions, e.g. the Institute of Metals, Institute of Metallurgists and The Rubber and Plastics Institute are undoubtedly bodies to whom information about new materials should be fed, but there are many other organisations that could be of help.

Most of the groups mentioned below are affiliated to a particular professional body or industrial concern and are sponsors to a particular category of material. There are other groups set up to deal with particularly pressing material problems: for instance, the High Temperature Materials Committee set up by the Ministry of Aircraft Production, dealt specifically with problems associated with high temperature materials during the second world war (Whittle).

Occesionally, relatively informal groups are established by professional engineers in a particular locality to discuss and exchange information about experiences with materials. One such group was the Midland Materials Engineering Group established in the mid-1960's but now less active. This was essentially a club for industrialists, formed because the members believed the engineering societies lacked intimate knowledge of materials and their associated engineering problems.

More recently another group has been formed in the Midlands at the University of Aston to promote an interchange on materials between industrialists on a more formal footing. The Materials Technology Exchange Unit was established in 1977 in the belief that many firms had relatively simple materials problems but lacked the expertise to solve them themselves, or indeed knew where to turn for advice. As such, it is a body which attempts to deal with materials problems of any kind rather than being affiliated to a particular class of material.

The following list of groups, although not comprehensive, indicates the range of bodies in this country who affiliate themselves with materials to varying degrees.

The Aeronautical Quality Assurance Directorate

The AQD is responsible for the quality assurance of most aircraft related products including aeronautical materials. It also sets and maintains standards of performance. Physical and mechanical listing of many materials is possible. Development of new inspection and testing techniques for materials undertaken. AQD services generally limited to the Services and firms engaged on defence contracts although other bodies may be considered if facilities elsewhere are unavailable.

Admiralty Marine Technology Establishment

Formerly known as the Admiralty Materials Laboratory, it was set up to provide the naval service with a centre for research, development and investigation in materials science and affiliated fields.

The Agrément Board*

The Agrément Board has the backing of the Building Research Station and the Fire Research Station, and was set up by the Government in 1966 to test new building methods and materials and to certify those which reach an acceptable standard. Products for which an existing British Standard Specification already exists will not normally fall within the scope of the Agrément Board's services. Manufacturers wishing to have a product assessed should apply to the Board and pay a fee representing the full cost of the work to be undertaken.

Aluminium Federation

Exists to serve the interests of firms and individuals concerned in the preparation and use of aluminium and its alloys. Library and information service available to outside users. Publications available.

* Prospective users of the Agrément Board should be aware that although Agrément certificates guarantee the quality of a product, the system is snubbed by manufacturers because the products are not recognised under the Building Regulations (see New Scientist, 22nd June, 1978, p. 830.).

Asbestos Information Committee

The committee was formed by four companies in the industry, and provides technical and general information on all aspects of asbestos. Publications available.

Brick Development Association

Promotes the use of clay and calcium silicate bricks and initiates research projects. Structural advisory service available. Publications available.

British Cast Iron Research Association (BCIRA)

BCIRA provides an advisory and consulting service, an information service, and maintains a programme of experimental research covering all aspects of the production of iron castings.

The British National Committee on Materials

The BNCM (formerly Joint Committee on Materials & Their Testing) was founded in 1934 and consits of 27 constituent societies. It has a purely advisory function but aims to promote discussion, and disseminate knowledge gained on all aspects of materials science and technology. It encourages research into material problems, testing, fabrication, and use; and advises on education of materials science and technology.

British Ceramics Research Association (BCRA)

An amalgamation of the British Refractories Research Association and British Pottery Research Association. BCRA carries out research on the manufacture, properties and use of all types of ceramics. Some publications available to non-members.

British Non-Ferrous Metals Technology Centre

Promotes the interests of industry and carries out research to this end. Consultancy services available to non-members. Library, technical advice and information for members. Organises conferences. Publications include BNF abstract monthly.

British Plastic Federation

Represents the plastics industry. Promotes co-operation between manufacturers and sponsors research. Establishes standards for products; Publications available.

Building Research Advisory Service

Advice is available on problems associated with the design, construction or performance of buildings. Readily answered queries are dealt with free of charge. For other enquiries a fee is charged, based on the time spent. Site visits may be arranged, testing or laboratory work carried out and reports prepared. Quotations are given before work is put in hand. There are five sites in the UK:

Building Research Establishment

The scope of the establishment is broad. It includes work on the design and performance of structures, fire protection and prevention, building materials, construction techniques and the development of mechanical equipment. Some of the results of the work are incorporated in Codes of Practice and British Standards or published in appropriate journals. Addresses of establishments are the same as those above

Committee of Directors of Research Associations

Represents the Industrial Research Associations of the UK. Aims to achieve collaboration between them on matters of common interest and to provide a means of communication for information and ideas from one to another, and with similar organisations in the EEC and elsewhere.

Fulmer Research Institute

An independent organisation that carries out research in physical chemistry, corrosion, physical and process metallurgy, crystallography, electrodeposition, plastics, ceramics and enamelling, plastics and polymer organic chemistry, and pilot plant studies. Multi-client projects, technological market surveys and research management techniques available. General consulting work, failure investigation and trouble-shooting. Publications available. Information services normally confined to staff and to sponsors.

Institution of Metallurgists

Professional body for metallurgists that aims to promote the better education of metallurgists. Publications and handbooks available. Organises conferences and courses.

International R & D Co. Ltd.

Involved in many aspects of engineering including materials. Publications and information service available. Market and Techno-economic evaluation of projected activities and products available to clients. Prototype design, development and manufacture work undertaken.

Materials Science Club

A charitable organisation formed in 1963 after an Inst. of Chem. Eng'rs. working party on materials. MSC provides an informal forum for a variety of specialists. Three meetings held annually; quarterly bulletin distributed; and 2 awards made annually to outstanding materials experts.

Materials Technology Exchange Unit

A club for manufacturing concerns in the Midlands. Advice is available on problems associated with materials to members. Readily answered queries are dealt with free of charge. For other enquiries and long-term studies a fee is charged based on the time spent.

Midland Materials Engineering Club

An industrialists club formed in the mid 1960's to enable materials' engineers to discuss and trade information about materials. It was never put on a formal basis and now functions only irregularly.

National Physics Laboratory

The Materials Group has the responsibility for maintaining the national standards of measurement in chemistry, for providing definitive data on the engineering properties of substances and of materials and for advising on meaningful ways of specification of materials.

The Rubber and Plastics Institute

Provides a means for the exchange of ideas and knowledge on all aspects of plastics and aims to advance education in these fields. Organises lectures, discussions and meetings. Information service available.

Rubber and Plastics Research Association

Carries out research and publishes information on rubber, plastics and allied materials. Undertakes sponsored research. Library and information service mainly for members who are manufacturers, suppliers and users of materials.

Road and Building Materials Group

Professional body affiliated to the Society of Chemistry and Industry which provides means for the exchange of ideas and knowledge on all aspects of road and building materials. Organises lectures and conferences.

Special Steels User Advisory Centre

An advisory centre instituted by the British Steel Corporation's special steels division marketing department to give information on steel selection, properties and performance, fabrication and manipulation, sources of supply, applications and usage.

UKAEA, Materials Technology Bureau

Advises on the use of modern fabrication techniques for metals and ceramics, rubber plastics, adhesives, surface coatings, composites and foams, reactions between solids or between solids and gases at elevated temperatures, corrosion of ferrous and non-ferrous alloys in high pressure water and steam at elevated temperatures.

4.6 INNOVATION: MODELS AND CASE HISTORIES

The rationale for studying innovation models and related case histories was two-fold: firstly, it was examined because the experience of others can often help one along the learning curve more rapidly; and secondly, because any indication of the development process that innovations follow was thought to be useful, inasmuch that it might produce a model that Dunlop could use for the development of carbon/carbon.

It is important to understand what is meant by "innovation" because it is a word that has gained great publicity during recent years and is often confused with invention. There are numerous definitions of innovation. Six different groups were identifiied by Tinnesand in a study of 108 definitions: (1) new idea; (2) introduction of new idea; (3) invention; (4) introduction of invention; (5) an idea different from existing forms; (6) introduction of an idea disrupting prevailing behaviour.

Here, the word innovation will be used in a broad sense, as defined by Holt:
"Innovation is a process which covers the use of knowledge or relevant information for creation and introduction of something that is new and useful".

Innovations fall into two main categories, technological and administrative. These are generally subdivided still further, technological innovations include product innovations and process innovations; administrative innovations include social or organisational innovations, financial innovations and marketing innovations. None of these classifications really describe the type of innovation with which this study is concerned, that is material innovations. It does, however, have the benefit of being a commodity, like energy, that can stand cross-industry comparison, unlike other types of technological innovation.

4.6.1 THE INNOVATION PROCESS

Innovation can be a very complex process, requiring the use of knowledge in order to create and apply something that is new (Holt). The process has been studied widely by many people and a summary of nine models is given below:

A. The Jewkes et al. Model

This is basically an invention model following a linear sequence of events: Pure Science - Applied Science - Invention - Development - Prototype Construction - Production - Marketing - Sales - Profit.

Jewkes in particular has implied the entrepreneur outside R & D organisations has been responsible for the many great inventions and subsequent innovations in the earlier half of this century. But he does not take account of the many inventions which were complete failures commercially. Nevertheless, the model is valid and many innovations have followed this route but it is not recommended as being the best route to follow for industry today. Some of the smaller firms, private individuals and universities still follow this route and quite successfully.

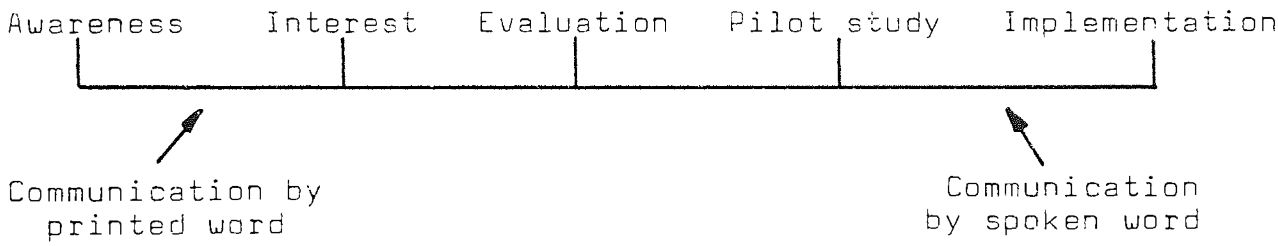
B. The Allen (J.A.) Model

A linear model similar to Jewkes is put forward by Allen. He suggests the most commonly stated model to be: Research - Development - Investment -Construction - Production - Distribution.

But he does state that "the linear scheme only very imperfectly represents or does not describe at all, the innovation effort in a firm or an industry." The model is not modified by Allen, he merely suggests that new product introduction or revolutionary new processes might be superseded to economic advantage by "devising new ways of doing things, of organising labour and utilising existing capital equipment, of improving material efficiency, or of promoting new, markets or designs, or generally by decreasing production costs by a combination of many practices of these kinds."

C. The Myers Model

Another linear model is put forward by J. M. Myers:



This suggests that an organisation is made aware of an innovation generally by means of written word communication, and that if this presentation is attractive enough it will lead to interest. Facts and figures are then used to evaluate it, which, if satisfactory, leads to the fourth stage, a pilot study. Personal communication plays an important role during the latter stages and providing the pilot study is satisfactory the innovator will perhaps innovate completely. The process can break down at any stage and the task of the implementing technologist is to progress the innovation through each stage. Like the previous models, the Myers model is descriptive rather than predictive and ignores external factors that may influence the progress of the innovation.

D. The Rogers and Shoemaker Model

Rogers and Shoemaker portray the innovation process as a four-stage sequential operation as shown in figure 4.10, and may be described as follows:

1. Knowledge. The innovation is brought to the individual's attention and gains some understanding of it.
2. Persuasion. Depending on the individual's perceived characteristics of the innovation he will form a favourable or unfavourable attitude towards it.
3. Decision. The individual engages in activities which lead to a choice to adopt or reject the innovation.
4. Confirmation. Provided the individual receives reinforcement to his decision to adopt he will continue to use the innovation, otherwise he may reverse his previous decision.

The Rogers and Shoemaker model is complex, inasmuch as it takes account of the external factors that can affect the progress of the innovation, and indicates the communication sources that influence each stage. However, it assumes the innovation is for internal use rather than being incorporated in the individual's own innovation.

E. The Nabseth and Ray Model

Nabseth and Ray's sequential model shown in figure 4.11 shows a similar pattern to that of Rogers and Shoemaker. It was developed after studying several industrial process innovations. The diagram does not indicate the variation in the

Figure 4.10 Paradigm of the Innovation Decision Process

(Source: Rogers and Shoemaker)

time taken between the awareness and the consideration phases that may occur in different organisation but the text of their work makes this clearer. It indicates that alert management teams will take a shorter time considering the innovation. The model fails to indicate external factors

Figure 4.11 The internal process of diffusion whithin a firm.

(Source: Nabseth & Ray)

affecting the process, and the text lists only suppliers, competitors, trade and research associations, and the company's own research and development work as being the sources of information about innovations.

F. The Langrish et al. Model

Langrish similarly expounds the linear-type models but in two forms:

- Discovery/push

  (i) "Science discovers, technology applies" and models A and B above fit this category.

  (ii) "Technological discovery" is the starting point of the model, not a science discovery.

- Need/pull

  (i) "Customer need" - the market place is recognised as the starting point.

  (ii) "Management by objective" - need is identified by management and not the customer.

The study done by Langrish et al. showed that the need/pull model was more prevalent than the discovery/push but that there was extreme difficulty in fitting a particular innovation to one of the four categories. The innovations generally fell into two of the categories. Neither of these models indicates the external factors that may influence the innovation process, or the explicit information sources that start and finish the process.

G. The Rothwell Model

Rothwell's simplified, schematic model of the innovation process is shown in figure 4.12. It recognises that innovations are started with needs generated in society or the market place and matched with technological capability.

Figure 4.12 Model for the Innovation Process

(Source: Rothwell)

The external factors affecting the process are illustrated but the information sources that instigate innovation are overlooked.

H. Bradbury et al. Model

The model proposed by Bradbury gets away from the linear-type model and shows that any one of six groups can start the innovation sequence. The model shown in figure 4.13 was developed from experience in the process chemical industry, and is the only model to deal explicitly with materials.

Essentially, ideas for new products may be generated by any of six groups, the end user, manufacturer, equipment manufacturer, manufacturer of intermediates, raw materials supplier and supplier of ideas.

Figure 4.13 Conceptual model of innovation

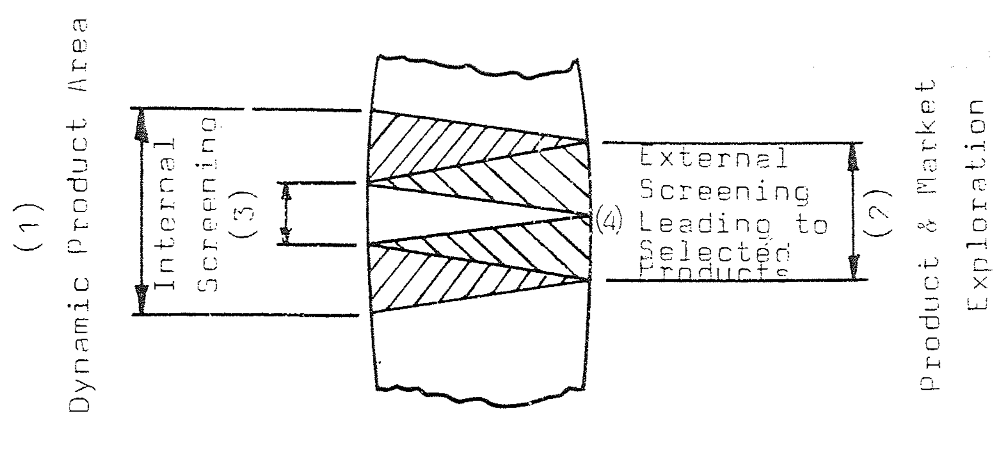
(Source: Bradbury et al.)

It may be the need from the consumer or the material supplier dreaming up a bright idea for his material. In any event, the idea generator has to convince the other groups in the chain and acquire materials and equipment to develop the idea. The emphasis is on the bringing together of new materials with the awareness of needs and demonstrates that invention is only one part of the innovative process.

I. The Ward Model

Although not stated by Ward as being a model of innovation his "successive focussing" technique must be classed as an innovation model. Figure 4.14 demonstrates the ideas.

Figure 4.14 Focussed Innovation



This is essentially a model in which the company is searching for new products to develop. It relies on four discrete elements:

1. Dynamic product area - the company recognises its own potential, its areas of experience, desire to expand, the streams of social and industrial change, etc.

2. Product and market exploration - this is an exploration to see what the needs of the "world" are and what other companies are doing.

3. Internal screening - to see if the found areas of development are really what the company wants to be in.

4. External screening - is basically a market research exercise leading to selected products.

This exercise of its very nature means that the company is on the look-out for potential product developments, but it is looking for the "need" areas and not trying to push its own inventions into the world.

4.6.2 CRITIQUE 1

Most of the models are of the sequential, descriptive type which are of little use for predicting the outcome of an innovation. As with the studies of Industrial Buyer Behaviour, the models proposed have extreme difficulty in predicting human behaviour, and therein lies a great dilemma.

The outright claims of the discovery/push type models expounded by Jewkes et al. and Allen have largely been superseded by others (Langrish et al. for instance), who recognised that innovations can often be of the need/pull variety. Langrish, Rothwell and Ward have recognised that "needs" are often the starting point of an innovation and although Bradbury recognised that innovations could be instigated by any one of six groups, he, and many of the others, have ignored the information sources that themselves trigger off ideas. This aspect is dealt with later.

Furthermore, several of the models fail to account for the external factors that can affect the tenuous innovation process. Another failing of many of the models is their unfamiliarity with the fact that the adoption of a particular innovation is, in many instances - and particularly for those organisations adopting material innovations - directly related to the output of another product innovation, which relies, in turn, on further users' adoption.

The models described herein all contain elements which are of importance when describing the innovation process, but individually they lack the cohesion that the sum of them gives. For organisations undertaking material innovation, it is therefore essential that they be aware of the individual models and examine their position in relation to the models.

4.6.3 THE USE OF CASE HISTORIES

Some may think that the problems facing material manufacturers in this advanced technology age in which we live are new. The scale and sophistication of the problem may have changed, but even in the eighteenth century there were difficulties in getting new metals accepted. For example, it took Dr. James Keir (1735-1820) many years to get his metal (54·05% Cu., 40·55% Zn., 5·4% Fe.) adopted by the navy for their men-of-war, according to Boulton's papers. That was for use as ship's bolts to hold the timbers together. After several years' trial, Keir's metal was chosen for the bolts, having competed with iron and copper. The problem had been to find a suitable material which would join the ships' timbers satisfactorily, and resist electrolytic corrosion caused by sheathing the hull exterior with a copper-based metal. The iron bolts used until the sheathing was put on corroded rapidly, and the copper bolts could not be driven through the timbers successfully. Keir's metal not only overcame the corrosion problem, they could also be driven home effectively. The barriers that were raised to his innovation were several, and similar to today's, and it took many more years before his metal found another use in window-frames.

Other historical innovations can be cited to illustrate the problems that entrepreneurs experience, but just one more example should be sufficient to illustrate the point. John Harrison (1693-1776) was the inventor and innovator of the timekeepers that "solved the famous problem of finding longitude at sea" (Gould). In 1714, the Government offered a £20,000 reward for any "generally practicable and useful" method of finding longitude at sea. This prize was won by Harrison some fifty years later for the fourth watch that he produced, which, incredibly, had an error of only fifteen seconds in five months when tested in 1764. In other words, the error was less than one tenth of a second per day.

This outstanding product innovation incorporated some notable material innovations. In particular, Harrsion's three large marine time-keepers - Nos. 1, 2 and 3 - required no oil at all. For, as Gould notes, "at practically every point where friction occurs, the surfaces in contact are self-lubricating; one being of lignum-vitae (a naturally greasy wood) and the other of solid brass." Such bearings ran themselves in and worked perfectly well unoiled, so long as their load was not excessive. A great advantage of such bearings was that the time-keepers never required to be stopped, cleaned, and re-oiled. The barriers that were raised to this innovation by the Royal Observatory and Board of Longitude make sombre reading; the more so when one realises that it took thirty years for his achievements to be recognised, and then not all of the prize money was paid! In particular, he met with economic, organisational, personal and perceptual barriers - although these are terms which have been described more recently by Bradbury, McCarthy and Suckling. Table 4.9 gives more detail of these and technological barriers.

Although innovations of the seventeenth and eighteenth centuries are far removed from the rapidly changing world of today, they at least hint at the problems which material producers have experienced in the past. Would it not be wise, therefore, for producers of new materials to study the path that other advanced technology materials have followed? Such a study should hope to focus on the reasons for the success or otherwise of a material's development. As Conant has said (quoted by Cahn):

> "Almost all that a trained scientist has to go on when he passes judgement on the prospects of a new venture far removed from his own speciality is his knowledge of the methods by which science has progressed in his own experience. To a considerable degree a non-scientist may come to have a similar base for his opinions. An intimate acquaintance with a relatively few historic cases should assist him in finding his way through the complexities of modern investigation as he listens to those who tell him what is being proposed."

Admittedly, as Cahn says, "Conant was concerned only with scientific and not technological events", but the parallel lessons are apparent to all. Unfortunately, the majority of case histories presented in the literature fail to deal with the "micro" aspects of the innovation, and instead concentrate on the "macro" aspects. Nabseth and Ray have

Table 4.9 Barriers to Innovation (Adapted from Bradbury et al.)

A. ECONOMIC BARRIERS

(i) Organisation will only undertake research if it believes it to be profitable.

(ii) Purchaser of a new process/product/material will only do so if the cost is lower or properties improved.

(iii) Organisation may have to invest in capital equipment to use research results.

B. TECHNOLOGICAL BARRIERS

(i) A scientific or technological target must be achieved - some studies show main cause of project failure due to poor manpower allocations by management rather than technical problems.

(ii) Some projects are dependent on other projects in the same or different organisation, e.g. new equipment for detecting aircraft required new communication system.

C. ORGANISATIONAL BARRIERS

(i) "Not invented here" syndrome - could equally be "Not interested here".

(ii) "Satisficing" rather than "optimising" type decision.

D. PERSONAL BARRIERS

Different Groups have different targets, motives, backgrounds.

E. PERCEPTUAL BARRIERS

Similar to C and D but there are two groups:

(i) different groups in the innovation chain may possess different criteria against which to judge new ideas, e.g. accountant and engineer.

(ii) new products are often judged against existing products.

suggested that this is a great loss, not only to students of the innovation process, but also industrialists actually involved with developing innovations. An overall picture of the development of the innovation can be seen from the macro studies, but too often they fail to give the all-important insight into how and why it developed as it did. An example of such a failing is that most material case histories deal with the technical aspects of the innovation and fail to deal with the essential steps of how uses were sought for the new material. Not all new materials are introduced because they are in a positive need situation, as will be shown later (see Chapter 5). The information channels that are used to link the material producer and potential user are all important, and should be subject to further investigation. The need for more studies of the micro type should therefore be manifest to all.

A large number of case histories are available in the literature, and Table 4.10 indicates those available on materials. There are many more dealing with product and process innovations. Investigation of these case studies reveals that the various authors have studied the innovation process from different standpoints. For instance, the Tanenbaum study was carried out for the Department of Defence in the USA, and many of the cases involved materials developed for military applications. This suggests that the lessons learnt might be awkward to transpose to the commercial world. The Langrish et al. study, on the other hand, was concerned with innovations that had won the Queen's Award to Industry and therefore all were regarded as successful innovations, and

Table 4.10 A list of published Material Case Histories and their source

(Note: the symbols ✕ • □ etc. indicate those material cases that have been presented by a variety of authors)

Material	Source
Cemented Titanium Carbide Cutting Tools "Lockalloy" - A beryllium-aluminium composite Polysulfide Polymers ✕ Silicones Polybenzimidazoles Antiozonants for SBR Rubber "Pyroceram" Brand Glass Ceramics Missile Grade Graphite "Lodex" Permanent Magnets Superconducting materials	Tanenbaum et al.
Reinforced Concrete 'Lytag', a lightweight aggregate used to make lightweight concrete Synthetic material (polypropylene) for cordage Rare earths	Langrish et al.
Bakelite • 'Cellophane' Δ 'Perspex', methyl methacrylate polymer ⊕ Neoprene □ Nylon ○ Polyethylene ✕ Silicones Stainless Steels + 'Terylene' polyester fibre ∇ Titanium Tungsten Carbide	Jewkes et al.
Super Plastic Aluminium	(J.A.F. Buchanan) The Institue of Metallurgists
■ Float Glass	Layton

/contd....

Table 4.10 (contd.)

Material	Source
■ Float Glass	Nabseth and Ray
Viscose Rayon • 'Cellophane' Acetate Rayon ⊕ Neoprene Cordura high-tenacity rayon Δ 'Lucite', methyl methacrylate polymer □ Nylon Polyvinyl acetate and alcohols Teflon ○ Polyethylene Orlon acrylic fibre ∇ Titanium + Dacron (USA trade name for terylene)	Nelson
○ Polyethylene + 'Terylene'	Allen, J. A.
'Corfam', synthetic leather	Robertson (1974,1977)
Magnetic ferrites	TRACES
Aluminium Fibre Glass Polyvinyl Chloride Polystyrene	Corey

the study by Nelson of Du Pont's successful material innovations was only superficial. The Jewkes et al. investigation of material and product innovations was a compilation of successful inventions/innovations describing the all-important role of the inventor but gave only a macroscopic viewpoint. It would be more useful if information about failed innovations was available, and although the paired study by SAPPHO did just that, it was not concerned with material innovations but rather with product innovations in the chemical and instrument industries.

The compilation and documentation of case histories is undoubtedly useful to students of innovation and industrialists involved in innovation alike. Unfortunately there is room for improvement in such documentation. For example, three case studies drawn from the reinforced plastics industry were presented at a one-day seminar on Product Innovation on 21st November, 1966 at the Central London Polytechnic. All trace of these proceedings have been misplaced, and as such must be considered a great loss in building up our knowledge of the innovation process.

4.6.4 CHARACTERISTICS OF TECHNOLOGICALLY INNOVATIVE FIRMS - EMPIRICAL EVIDENCE

There are many factors affecting the success of an innovation, be it with a new material or a product. The characteristics that make a firm technologically innovative are many and varied. Robertson, in comparing four major studies on innovation, suggested over twenty four characteristics that an innovative firm should have. Before examining these characteristics the basis of the four studies should be understood. Project SAPPHO, as has already been mentioned, was a paired study of successful and unsuccessful innovations in the UK - twenty two pairs from the chemical process industry and twenty one pairs from the scientific instrument industry. Carter and Williams examined two hundred successful product or process developments involving research and development departments in the UK. An American study by Myers and Marquis investigated 567 successful innovations in the housing, computer and railroad industries, whereas the Langrish study investigated eighty four successful innovations in Great Britain that had gained Queen's Awards to Industry.

The characteristics of a further two studies, by Tanenbaum and Layton have been added to Robertson's initial table for comparison purposes. The Tanenbaum study investigated ten material innovations in America and Layton investigated ten innovations, including product and material innovations, in the UK. The resulting characteristics can be seen in Table 4.11.

Although apparently adding weight to Robertson's initial findings, it is equally obvious that different characteristics have been found in the different studies; and this variability, or instability as Downs and Mohr term it, fails to give confidence for suggesting positive features which potential innovative organisations should try to emulate. For example, there are few common features between the different studies, only items 1 and 19 - namely good communication between innovator and the market place, and needs of the market understood and identified - are common to all six studies. Further, there are only two other features common to four of the studies: items 5 and 25 - a good communication and co-ordination between different management groups and a top person who promoted the innovation within the organisation.

TABLE 4.11 Characteristics of Technologically Innovative Firms

SAPPHO Equivalents	Carter & Williams	Marquis & Myers	Queen's Award	Tanenbaum	Layton
1. & 2. Successful innovations make more use of outside technology and scientific advice. They have better contacts with the scientific community, especially as regards their particular innovation.	1. Good information sources. 2. Seeking outside standards of performance	1- 4. Adopted innovations contribute significantly to commercial success. Ideas for innovations came from new information inputs. The main information inputs are general, widely diffused and easily accessible, (not in accordance with SAPPHO findings). Personal contacts and personal experience are best information sources for successful innovation.	1- 5. Good co-operation. Inter and intra-firm.	1. Individual with a well defined need who initiated communications.	1. Communication between development and market necessary.
3. No equivalent.	3. Not secretive.				
4. Collaborate with potential customers.	4. Readiness to co-operate.				
5. No equivalent.	5. Good co-ordination.	5. Innovation management is a corporate task, not R & D in isolation. Cannot be left to one functional department.		5. Close and frequent communications between organisationally independent groups necessary.	5. Transfer of information between development and production is important.
6. No exact equivalent but see 1 & 2.	6. Ideas surveyed.				
7. Successful innovators perform development work more efficiently and eliminate technical defects before launching an innovation.	7. Good consciousness in research.				
8. No equivalent. SAPPHO cases almost all exceeded estimated project costs.	8. Quantified investment decisions.				
9. No equivalent. Such techniques were used by successes and failures.	9. Good management techniques.				9. Technical leader able to guide management and influence strategy. Ability to move fast.
10. Good contacts with scientists.	10. High status of science.			10. Interaction with basic research findings or a basic researcher is important.	
11. Not a characteristic that discriminated success from failure.	11. Scientists on the Board.				
12. Did not emerge as a success characteristic. May be a necessary condition of innovation attempts.	12. Good chief executive.				

.. Contd..

TABLE 4.11 Characteristics of Technologically Innovative Firms (Contd.)

SAPPHO Equivalents	Carter & Williams	Marquis & Myers	Queen's Award	Tanenbaum	Layton
13 & 14 No equivalents. Supply of QSE not a limiting factor in success or failure.	13. Attractive to talent. 14. Good recruitment policy.			14. Individuals with formal post graduate training involved in the innovation.	
15. No equivalent.	15. Good training policy.				
16, 17 & 18. No specific equivalents. The key manager was the business innovator responsible for the project.	16 & 17. Enough and good intermediate managers. 18. Managers stimulated.				
19. Marketing was the most important SAPPHO discriminator in terms of user needs understood, good market research, adequate publicity, user education and anticipation of user problems.	19. Effective selling.	19. Recognising demand is more important than technical potential.	19. Clear identification of a need. Realisation of potential usefulness of a discovery.	19. An important need was identified.	19. Careful analysis of customers' future needs.
20. Avoidance of technical after-sales problems by good development work. User education.	20. Good technical service.				
21. No equivalent. Shortages did not emerge as a factor in failure.	21. Ingenuity with shortages.		21. Availability of resources. Not equivalent but related.	21. Flexibility of support was critical to the final success. No equivalent but related.	
22. No equivalent. Most firms claimed to do some kind of "forecasting".	22. Forward-looking tendency.				22. Large companies may establish a small strategic planning department.
23. No equivalent. Growth rate of firms did not appear as a factor in success or failure.	23. High expansion rate.				
24. No equivalent.	24. Rapid machine replacement.				
25. Business innovator as key figure (the "entrepreneur" in the innovating organisation).			25. Top person (presence of an outstanding person in authority). Other person (some other type of outstanding individual).	25. 'Champion' guided project.	25. Personal leadership by one or two people, whom all other key people know, respect and follow, particularly in small enterprises.

TABLE 4.11 Characteristics of Technologically Innovative Firms (contd.)

SAPPHO Equivalents	Carter & Williams	Marquis & Myers	Queen's Award	Tanenbaum	Layton
NOT LISTED BY C. & W., M. & M., QUEEN'S AWARD, TANENBAUM OR LAYTON		NOT LISTED BY SAPPHO, C. & W., QUEEN'S AWARD, TANENBAUM OR LAYTON	NOT LISTED BY SAPPHO, C. & W., M. & M., TANENBAUM OR LAYTON	NOT LISTED BY SAPPHO, C. & W., M. & M., QUEEN'S AWARD OR LATON	NOT LISTED BY SAPPHO, C. & W., M. & M., QUEEN'S AWARD OR TANENBAUM
1. Larger project teams.		1. Technical change is more usually by incremental rather than radical innovation.	1. Help from government sources.	1. One or two key individuals who through their efforts, bridged the geographical, organisational and functional gaps; actively stimulated communications and sometimes performed the technical work; generally known as couplers.	1. Fast lead times can be important in fast moving technologies, but otherwise successful innovation does not necessarily depend on fast lead time.
				2. In many cases, it was the act of timely recognition, bringing available knowledge to bear on the problem, that resulted in final solution.	2. Licensing can be a useful means of catching up with the latest technology.

(Inspired by Robertson)

Utterback's (1974) authoritative review of innovation has also recognised that market factors have a primary influence on innovation. His comparison of some of the major innovation studies (see Table 4.12) has shown that between sixty and ninety per cent of important innovations in a variety of fields were stimulated by market demands or needs (c.f. Robertson).

Table 4.12 A comparison of studies of the proportions of innovations stimulated by market needs and technological opportunities.

Author	Proportion from market mission or production needs (%)	Proportion from technical opportunities (%)	Sample size
Baker, N.R. et al.	77	23	303*
Carter and Williams	73	27	137
Goldhar	69	31	108
Sherwin and Isenson	61	34	710+
Langrish	66	34	84
Myers and Marquis	78	22	439
Tannenbaum et al.	90	10	10
Utterback (1969)	75	25	32

* Ideas for new products and processes.
+Research events used in 20 developments.

(Source: Utterback, 1974)

The identity and function of the top person who promotes innovation within an organisation has undergone considerable investigations, as indicated by the studies mentioned in Table 4.11. Schon introduced the concept of a "Product Champion" and suggested that such individuals played an important role in successful innovations. He defines this individual as an enthusiastic protagonist of an innovation in an organisation which is structurally unsuited to undertake such a project, or where there is opposition to it. Achilladelis found, when investigating the chemical industry for project SAPPHO, that two individuals could be identified as persons who promoted the innovation, the business innovator and the technical innovator. The business innovator was found to be often an older man with authority in the firm, able to manage scientists and engineers, with a good grasp of technical matters. On the other hand, the technical innovator was an individual in his early thirties who had joined the firm after completing postgraduate studies, and was given the chance to work on his own approximately five years after joining the firm. Jervis, who also worked on SAPPHO found Innovation Managers, i.e. the individual actually responsible within the management structure for the overall progress of the innovation project, to be far more important than product champions.

"Technological Gatekeepers" have been shown by T. J. Allen to be important individuals for introducing information into the research and development laboratories of American organisations. Frost and Whitley, however, suggest that while gatekeepers exist in English laboratories, their importance is not as great as suggested by American studies. Further, there appears to be no evidence to suggest that technological gatekeepers play important roles in engineering industries, in this country.

A study by Corey, which is seldom quoted, examined the development of markets for aluminium, fibre glass and the plastics, polyvinyl chloride and polystyrene, in the United States and really deserves more recognition. He concluded that a material producer who wished to introduce a new material should undertake extensive marketing programmes at two levels: (i) with the immediate customers, generally the end product fabricators and (ii) by using long range promotional programmes in the end product market, demand can be created among customers and industrial users. It is suggested that building the fabricator-customer group will be affected by two basic considerations: a) will the fabricator need to invest in considerable capital equipment to make the end product or can he utilise existing manufacturing facilities and b) will selling the new end product help to strengthen the fabricator's market position? Corey claims that the relationship between the material producer and the fabricator can be initiated and strengthened by the producer himself. For example, technical development of the new product by the material producer may make it possible to build a broad fabricator/customer group. By exercising such technical leadership the material producer may effectively maximise his own sales to the end-product manufacturers.

4.6.5 CRITIQUE 2

The variability between different innovation studies is possibly the greatest criticism that can be levelled, particularly when trying to suggest characteristics that firms intending to innovate should possess. This is probably even more serious when studies of product and process innovations are combined for comparison. It is doubtful whether much enlightenment can be gained from such cross-cultural analyses. A better understanding of the characteristics necessary for the technologically innovative material producing firm might be gained by comparing studies of material innovation where such cross-cultural barriers are removed. The reason for stating this is simply that all manufacturing firms are obliged to use material (and energy) for their products, whereas the choice of adopting product and process innovations is far more industry related.

It has been suggested that the majority of successful innovations are initiated by user organisations with a need. Unfortunately, little is said by the studies mentioned herein of how potential user organisations are identified. Further, the possibility of serendipity playing a part in matching material producer and potential user is totally ignored.

There are still more points at issue regarding the characteristics of innovative firms, and in particular, material producing firms, that are left undiscussed. For example, the question of whether a material producer should concentrate all his efforts in developing products with one user (or one type of industry) is not mentioned. There are advantages and disadvantages when pursuing one user, e.g. successful "bread and butter" type products help finance further product developments, but the material producer's success relies largely on the success of the user which will fluctuate over time.

The risk attached to innovation can either be high or low and the resulting commercial success is related to the characteristic of the development and the time available. Parker has illustrated this in Table 4.13. Whether material producers should aim for the relatively safe substitutional, or incremental innovation rather than the radically new product development is another neglected area, with only a few authors recognising technical change to be usually incremental i.e. Myers and Marquis, and Hollander.

The production of materials generally becomes more economic as the scale of production increases, which is, in turn, related to the number of actual material purchasers. Material producers are sometimes in the position of being able to see new markets opening up for their material, provided the cost can be reduced to acceptable levels to these new potential users. They consequently examine and sometimes introduce new or revised manufacturing methods which will reduce the price of the material and open up the foreseen market. On the other hand, there are material producers who often fail to examine the benefits and opportunities that economies of scale can give and never get the chance to introduce the material to new markets. This point is illustrated in figure 4.15.

Table 4.13 The likely rewards from Innovation

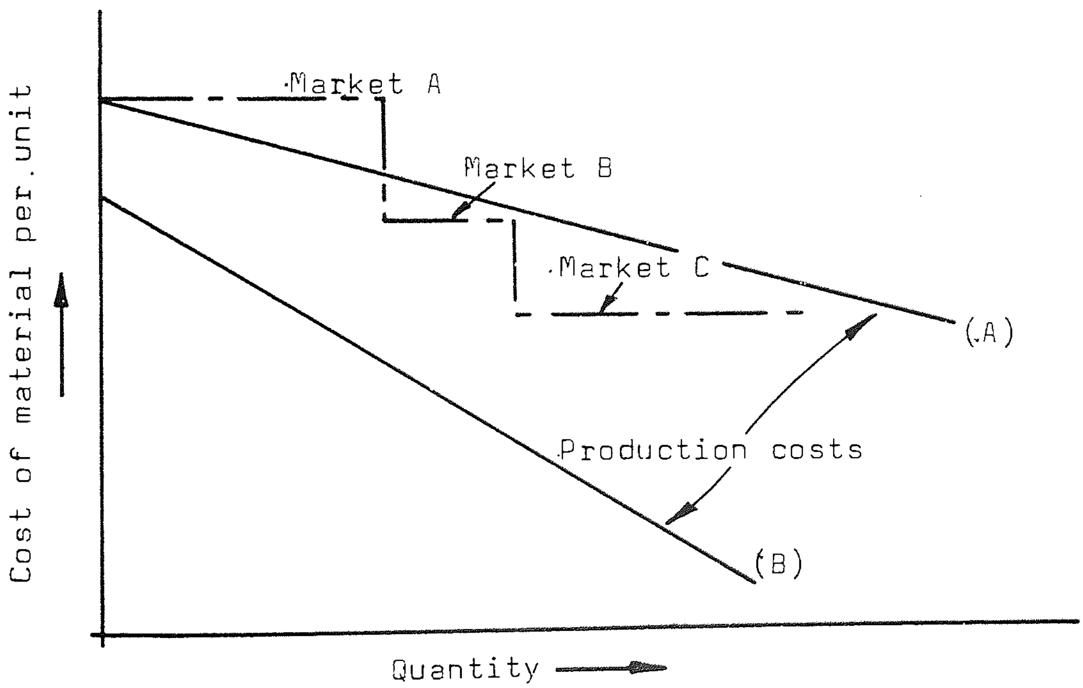
Available Time	Strategy	Characteristics of Development	Probability of Success	Main Decision Areas	Likely commercial success if targets met
SHORT	1	Innovative High Risk	Low	Allocation of significant resources	High
	2	Evolutionary Low Risk	Medium/High	Methods of combating competition	Low
LONG	3	Innovative High Risk	Medium/High	Degree of acceptable diversification	High
	4	Evolutionary Low Risk	High	Allocation of resources between fire fighting and new products/processes	Medium

(Source: Parker)

The question of whether technologically innovative material producing firms investigate economies of scale early on has not been examined by any of the studies mentioned herein.

Another area that is not investigated, and there are no doubt more, can be summarised quite quickly by the following question: are technologically innovative firms, particularly material producers, more likely to develop product ideas in-house, patent such products and then introduce the product (including the new material) to the world?

Figure 4.15 Illustrates the effect economies of scale can have on opening new markets to a material producer.



The cost of producing a material at the rate indicated by line A means that only Market A, which can afford that price, is available to the material producer. If economies of scale are introduced and the production costs can be reduced to, say, line B, then new markets, i.e. Markets B and C which can afford the lower priced material, become available for exploitation by the material producer.

4.7 PRE-REQUISITES FOR STIMULATING DEMAND

4.7.1 THE NATURE OF DEMAND

Distinguishing between the "demand" for a product and the "desire" for a product can pose awkward problems for the marketing executive who has to unravel the difference. According to Willsmer, "...demand exists only at the point where a transaction takes place." It is therefore very important to distinguish between demand and desire. Willsmer has illustrated the difference with the following straightforward example. You may have a very strong desire to own a Rolls Royce car, but unless you are among the fortunate few, it is unlikely that you will ever be able to buy one. A piece of consumer research by, say, test drives, would perhaps produce a highly favourable result with one hundred per cent saying they would like to own one. However, unless the result is analysed in terms of who can afford to buy and maintain one, it will give a very false picture of the likely market for Rolls Royce. Thus, although "demand springs obviously from utility", as Henderson has noted, "the only motive for buying anything is that it will serve some real or fancied use."

Marketing, then, is concerned with demand and not supply, but as the adage says, demand creates supply. The other side of the coin, i.e. supply creating demand, is, however, the position that many material producers find themselves in, unless the material has been developed for a particular user. Even then, the material producer can find himself in the position of having a supply and wanting to create a demand when he wants to expand his output, or reduce his reliance on one customer.

The three rules that have formed the cornerstone of economic theory have been known for a good many years:

1. When at the price ruling, demand exceeds supply, the price tends to rise, and vice versa.

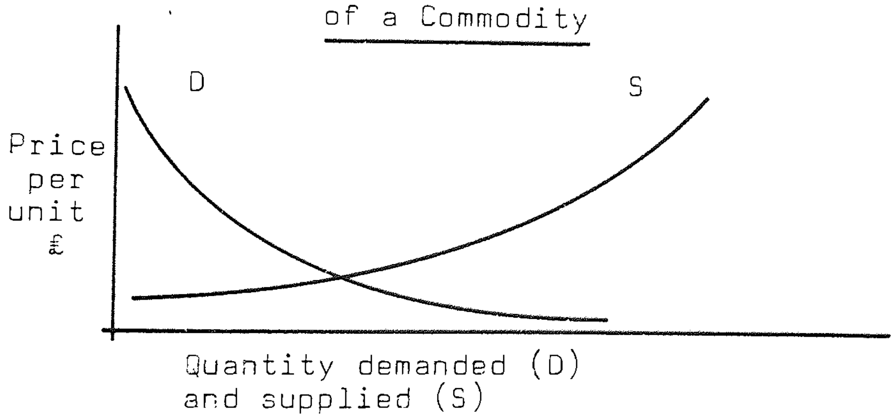
2. A rise in price, tends, sooner or later, to decrease demand and to increase supply, and vice versa.

3. Price tends to the level at which demand is equal to supply.

(Henderson)

These laws can be illustrated graphically in the well-known supply and demand graph shown in figure 4.16. Such a picture clearly shows when a material producer introduces a

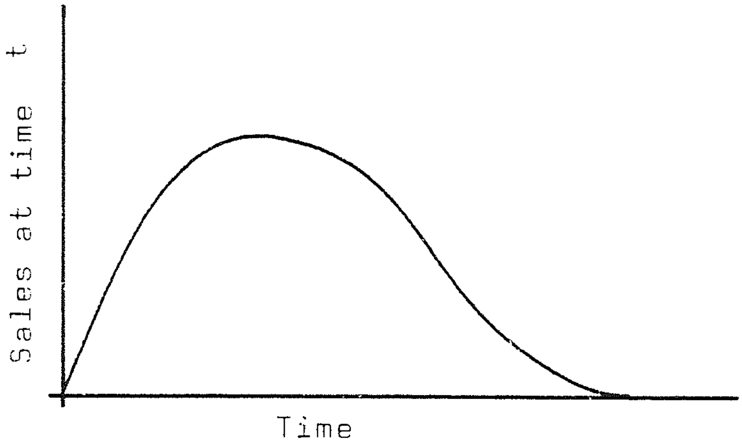
Figure 4.16 The effect of Supply and Demand on the price of a Commodity



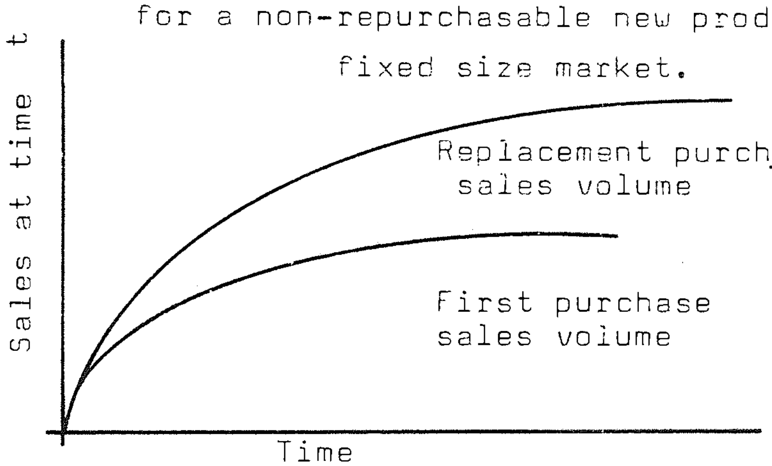
new material the price will naturally tend to be high when the demand is low. This being the case, what, then, is the demand pattern that a material producer is seeking to fulfill?

The pattern of sales life cycle varies according to the type of product that is being sold. For a product that is bought once only in a fixed size market, such as buildings, oil-rigs, and the like, the sales life cycle will look like that shown in figure 4.17(a). For a product that is purchased rather infrequently, such as a car, or a machine tool, the sales life cycle will be made up of new sales and replacement sales. Here, the buyer will be influenced by the wear of the product, the general state of the economy, and also the amount of product improvement since his last purchase. The sales life cycle of such a product will be similar to that shown in figure 4.17(b). Yet a different cycle will arise for new products that are frequently re-purchased (see figure 4.17(c)), such as consumer and industrial non-durables, of which materials is a good example. The number of persons buying the product for the first time increases and then decreases similar to the non-repurchaseable new product sales life cycle. But superimposed on the first purshase sales volume is another amount representing repeat purchase sales volume. Material producers would no doubt like to see the sales life cycle of their material looking like example (c) in figure 4.17, but to begin with, they have to concentrate on that first purchase which is common to all new product introductions.

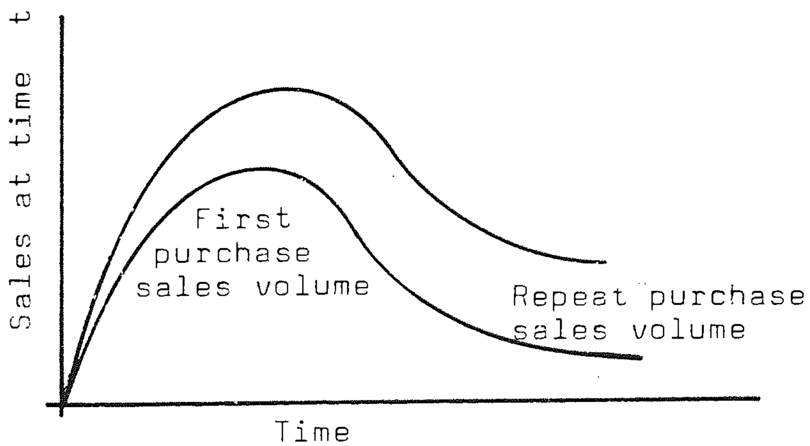
Figure 4.17 Pattern of Sales Life Cycle for Different Types of Product



(a) Sales volume, non-cumulative, sales life cycle for a non-repurchasable new product in a fixed size market.



(b) Sales life cycle for an infrequently purchased product.



(c) Sale life cycle for a repurchasable new product.

4.7.2 DEVELOPMENT OF DEMAND FOR MATERIALS

There is sufficient empirical evidence to suggest that the usage of materials develops over time and follows an approximately sequential pattern. From his study of the Bronze Age, V. Gordon Childe observed that the progress of metals followed a set pattern, (see Table 4.14).

Table 4.14 Materials Utilisation Sequence

(derived from V. Gordon Childe and Gregory)

Stage 1.	Discovery or introduction
Stage 2.	Ornamentation, leisure or military use
Stage 3.	Technical exploitation
Stage 4.	Every-day practical application
Stage 5.	Throwaway outlets

Examples of such a sequence are rampant and Table 4.15 illustrates this for four different materials, aluminium, iron, polyethylene and titanium. The field of application for new materials is generally restricted by its high initial cost per kilogramme, and the high cost of research. This generally implies military and aircraft uses where the advantages of such materials are appreciated and can be afforded. J. E. Gordon has quoted the ironic example of a water pump gland for cars which his firm developed and which they were prepared to guarantee for 100,000 miles. He states that "the cost was only fractionally more than the usual sort but none of the motor manufacturers were interested". Perhaps this indicates the extreme difficulty material producers will have, should they try to jump over various stages.

Table 4.15 Examples of Sequential Development of Material Usage

(Each stage refers to that described in Table 4.14)

Aluminium

Stage 1. Introduction early 19th. century

Stage 2. Jewellery, cutlery, works of art, cavalry helmets

Stage 3. Aircraft frames and engines

Stage 4. Roofing, consumer products, electric cables

Stage 5. Packaging - "easy open" cans

Iron

Stage 1. Discovery between 3,000 and 1,400 B.C.

Stage 2. Weapons - spears, knives, etc.

Stage 3. Tools - ploughs

Stage 4. Cooking pots

Stage 5. Packaging - cans

Polyethylene

Stage 1. Discovery 1937

Stage 2. Radar and submarine cables developed during Second World War

Stage 3. Atlantic submarine telephone cables, other electrical cables, and film and sheet for agricultural and building applications

Stage 4. Household equipment such as kitchen-ware

Stage 5. Packaging - film wrapping for food

Titanium

Stage 1. Discovery and introduction 1940's

Stage 2. Military aircraft engines and airframes, yacht masts and fittings

Stage 3. Developments in chemical, medical, nuclear and engineering industries

Stage 4.)
) Has not yet reached this stage of development
Stage 5.)

4.7.3 METHODS OF FORECASTING DEMAND

Liversey has claimed that the two most important general determinants of demand for consumer products are income and price. Robert Leduc however, suggests that social factors as well as economic factors will affect demand for products. He claims that demographic trends, sociological trends (e.g. urbanisation, decentralisation of industry, amount of leisure time and the way it is spent, influence of television, etc.), economic trends (both long- and short-term), and market trends (e.g. growth of self-service and larger selling areas, appearance of new distribution channels, extension of shop hours, and so forth), are the principal factors affecting the demand for new products in the community. Such factors no doubt affect material producers who are supplying the materials used in consumer products, but when they are one, two or even three steps removed from the consumer, the task of analysing such trends becomes more awesome.

Kotler has identified six major methods for forecasting demand, although there are actually only three bases for building a forecast, that is (a) by what people say, (b) by what people do, or (c) by what people have done.

The first of these - what people say - encompasses three methods: (1) survey of buyer intentions, (2) composites of sales force opinion, and (3) expert opinion. These methods entail a close scrutiny of the opinions of buyers or others close to them, such as salesment or outside experts. The third of these methods - expert opinion - may also allude to controlled experiments of consumer attitudes and for details of such methods you should refer to Liversey, or Sowter, Gabor and Granger for instance. Building a forecast on what people do involves another method: (4) putting the product into a test market area, possibly using a limited geographical area. The last two methods, (5) classical time series analysis, and (6) statistical demand analysis are used to predict demand from what people have done. Essentially, they involve analysing historical records of buying behaviour.

The aforementioned methods of forecasting demand have mainly been developed for predicting demand of consumer products. Whether or not such methods can be used for predicting demand of industrial products and in particular predicting demand for new materials is another matter. The first three methods, which revolve around what people say, can be used for predicting the demand for a new material if the potential user knows exactly the product in which it will be incorporated. But, and it is a big but, such methods cannot be used until the potential user(s) have formalised their own product ideas. This means material producers will be left wondering how to forecast demand for their material when product ideas have not been conceptualised. The fourth method, using market test methods has the same basic failing of the first three methods when the product has yet to be conceived. And the final two methods, using historical data of customers' previous behaviour with new materials can give no guarantee of them doing the same with another new material. When the current or future conditions can be so different from those pertaining to the period in which data was collected, historical data renders the past a poor guide to the future.

4.7.4 CREATING DEMAND

There is scant evidence of how industrialists, including material producers, forecast the demand for their products, and what there is tends to be subjective.

Nabseth and Ray, who examined eight industrial product and process innovations, found (i) that an increase in demand for a firm's particular product led to a call for investment in new productive capacity, and hence led to an increased demand for product innovation, and to a lesser extent they found (ii) that for a given demand, new processes will be introduced more rapidly in firms with old equipment rather than those with new capital equipment, simply because replacement of equipment is more urgent for the former.

Corey has suggested that material producers have three promotional assets which his customers (in most cases the fabricators) may not possess in equal measure: technical skill and reputation, promotional strength, and strategic position. As such, the material producer, with possibly the strongest motive, is in the best position for creating the initial demand. Depending on the type of material, the material producer can try to create demand for consumer end products or industrial products:

Creating Material Primary Demand for New Consumer End Products

Primary demand has been defined by Corey as "the demand for a product which may be made by one or more manufacturers".

Such demand for new materials can best be stimulated by the materials producer's brand promotion, the effectiveness of which depends on: (i) the nature of the end product i.e. the characteristics which differentiate the materials from others and (ii) the overall promotional programme, i.e. ensuring that the aggressive promotion which may at first include some educational content, is backed by an adequate distribution network.

This can best be illustrated by one of Corey's cases. Owens-Corning introduced fibreglass marquisette curtains just after World War Two. The characteristics which distinguished these curtains from others were the fact that they would not burn, rot or mildew, they required no ironing, and also their attractive translucent quality. Owens-Cornings overall promotional package included: technical service to the weavers to ensure the production of a high quality fabric; promotion of the product using television, magazine and direct mail advertising; and also included working with the sales people in the retail outlets on the display and demonstration of the product.

4.7.5 CREATING PRIMARY DEMAND FOR NEW MATERIALS IN INDUSTRIAL PRODUCTS

Corey has again assumed that the material producer has established an end product in principle for the new material, and works at creating demand from that point. He suggests there are two broad objectives of any market introduction, (a) to overcome any resistance to the new product and to create demand for it quickly and (b) to prevent misapplication and improper use of the new product thus assuring initial satisfactory experience.

Such an introductory marketing programme can often involve working closely with a limited group of potential users. The material producer can direct his efforts at three groups - (i) the potential manufacturers of the new product, (ii) the potential end user of the new product or (iii) some intermediate. In many instances, working with potential manufacturers can be very speculative unless they are very strongly motivated. On the other hand, working with the potential end user can have its advantages once the benefits of the new product are realised, by pressurising the manufacturers, both old and new. There are three factors to be considered before working with the potential end users:

(i) the end user is unlikely to co-operate unless he will benefit considerably by adopting the new product instead of an existing product.

(ii) the strength of the end user's relationship with existing suppliers may be a problem.

(iii) unless the potential end users are few in number and easily reached, it could be difficult to persuade them to adopt the new product.

It has been demonstrated in the past that working with potential manufacturers can prove very difficult if the introduction of new materials and processes alters the whole technology of a firm or industry (see also Section 4.2.2) and this should also be borne in mind when deciding to approach potential manufacturers or end users.

4.7.6 CRITIQUE

Although it is commonly recognised that demand creates supply, the position in which material producers find themselves, is apparently less evident, that is, having a supply and wanting to created demand. Methods of forecasting demand have, to date, concentrated on consumer end products, although it seems equally feasible that some of these techniques could be transposed to forecasting demand for industrial products. Unfortunately, all the techniques except those using historical records assume that the end product is known to the manufacturer which, alas, is not always the case for the material producers. The historical analysis methods are also of little use for predicting demand of new materials.

The methods used to help stimulate demand for materials have been examined empirically by Corey, but even he has assumed that the material producer knows what the end product will be. In conclusion, it is all too evident that there is a distinct lack of understanding of the prerequisites necessary to stimulate demand for new materials.

4.8 SEARCH METHODS FOR FINDING USERS

A search operation is a complicated business, whether it be for users of a new material, an exploration for mineral deposits (coal, oil, etc.), an audit (i.e. searching for errors - accounting for instance), a military search for enemy aircraft or ships, or even a child searching for a lost ball in a field. This review is essentially concerned with the way in which an organisation can instigate a search operation for material users. Very little has been written about such a task and this account relies to a large extent on studies of operations research, organisational behaviour and even child psychology. Although concerned with material producers searching for actual users of their material, the study also encompasses to some extent the way in which customer organsiations search for products, as the problem is a complex search and match exercise.

The material producer generally instigates a search process for new material users when he wishes to expand his output to other users, and/or reduce his reliance on too few customers. Material producers should understand that customer organisations usually need a high level of dissatisfaction before they will undertake a search for new suppliers, according to Cunningham and White. There are however, other factors which may stimulate a search operation, for example: changes in the ultimate customers requirements; changes in other suppliers' products; technical improvements in production processes; the possibility of financial savings; wooing from other suppliers of improved services; and changes in product requirements.

4.8.1 SEARCH THEORIES

Most problems are concerned with making decisions when all the information that is necessary is available. Ackoff and Sasieni have recognised that these conditions are reversed in a search situation, i.e. we know what we ought to do if we had certain required information. They describe two types of search situation:

(i) qualitative-quantitative, which refers to the "relevant characteristic of the individual elements of the population from which the sample is taken". For example the qualitative situation may be regarded as assigning an individual to observe a particular class (e.g. defectives or acceptables, correct or incorrect), the quantitative situation consists of observing some measurement along a scale (e.g. income per household, weight of an element, etc.).

(ii) distributive-collective, which refers to the "use that is to be made of the results of sampling". For example the distributive situation can be considered as the action taken by an individual rather than collective basis (e.g. a defective part is sent back for repair whilst the acceptable part is sent on, or a high income family is placed on a certain mailing list), the collective situation refers to action taken on a collective basis (e.g. the entire lot from which the sample is taken is either sent back or sent on, the entire neighbourhood is placed on the mailing list).

These static type of search situations can in no way be associated with the dynamic search situation where we are looking for new material users.

The theorists studying organisational behaviour have examined search operations from two standpoints. First, they have considered search activities as a function that copes with uncertainty by identifying alternative solutions to problems. Second, and stemming from the first search process, is the concept of searching for the <u>consequences</u> of particular alternatives (Mumford and Pettigrew p.53).

March and Simon (1966) have shown that investigators do not search out all the alternatives available to them but seek a satisfying rather than optimising solution. The "optimising" and "satisficing" approach to decision making theory was pointed out by Cyert, Dill and March (1967), and they form the basis of two search types. The optimising approach was derived by economists, and treats business behaviour as a rational attempt to maximise profits, with businesses knowing exactly what they have to do to achieve this aim. Business is thus viewed as a very logical activity where optimum solutions are always sought, and assumes that the decision maker knows all the alternatives open to him. Cyert, March, and Simon, on the other hand, all believe decision making has a more behavioural stance. They are the main advocates of the satisficing approach, which sees human decision making behaviour as encompassing various acts in an organisation - searching, choosing, and problem solving (Cyert et al. 1956; March (ed) 1965; March and Simon 1966; Simon 1961, 1965). Because of man's shortcomings (e.g. man can only handle a limited amount of information, and he has a limited ability to perform only a few things at any one time) he seeks a satisfactory solution rather than the optimum, and this can act as a barrier to innovation as indicated in Table 4.9.

Etzioni (1968) believed both theories could be improved because of their lack of consideration of external forces (psychological and political pressures for instance) acting on the decision makers. He put forward his own theory which has been termed as the art of "muddling through". In effect this says that large scale decisions to change are not taken, but rather that small reforms in an incremental manner are undertaken. It is a "mixed scanning" technique, which combines the rational and incremental approaches that seperate the basic decisions from the small decisions. The basic, or fundamental decisions are treated to a broad search process concentrating on the alternatives at the expense of the detail. Minor decisions relating to subunits of the problem are given less coverage of the alternatives but are much higher on the detail. Such a technique does not solve the problems but merely attacks them, and only 'improves' rather than finding some specific goal. It also suffers from two problems: (i) the strong can be over represented at the expense of the weak in decisions taken this way and (ii) it may not be appropriate for new forms of technology.

Now consider the second concept, searching for the consequences of particular alternatives. Knight (1967) has found that uncertainty can be reduced or controlled by groups searching within their cognitive limits when seeking a viable solution. Mumford and Pettigrew believe that the viability of alternative solutions cannot be established unless the consequences of implementing such alternatives are known i.e. the consequences to the organisation, subgroups and individuals. Simon (1961) suggested that search for consequences was carried out after the alternatives had been identified, but Mumford and Pettigrew, who investigated the decisions taken by an organisation introducing a computer system disagreed. They found that many alternatives were screened out almost immediately on the basis of undesirable consequences, and those few alternatives that remained were subject to a closer scrutiny of their consequences at a later date. Furthermore, they suggest that the search of the consequence of introducing the alternatives is mainly limited to technical or economic effects, and that little thought is given to the human consequences, a point which is also borne out by McKinsey Associates. They found that the operational feasibility of a new application was often neglected until after it had been implemented and found wanting, which in their words was "the costliest kind of feasibility test".

Such search techniques and the accompanying conclusions are of use to the material producers, in as much that they show how many organisations seek out new products. At the same time they suggest some problem areas that they should try to overcome when undertaking their own search operation.

The work described by Cohen and Christensen who investigated the search patterns shown by children of varying ages, offers some interesting parallels for the material producer and his search operation. Not only did they show that the child's search strategy improved with age by reducing the uncertainty at each step and actually structuring the search (a move from an element-type to a set-type strategy in Cohen and Christensen's terminology), they also showed that the older child was more aware of influences on the situation which were outside his control. An analogy of the "sweep width" in a search and rescue operation was made, and to a degree is applicable to the search for new material users. For example, the factors affecting the sweep width are the same, only in a different guise:

(i) type of target: in both cases the identity of the target may be unknown. The target (i.e. potential customer) is there but has to be excited before the searcher can see it.

(ii) speed at which search unit is moving: in the case of the search and rescue operation, a slow, lighter than air machine could be available for a very thorough search of a chosen area and any targets within that area would almost certainly be found. If however an aircraft is available and a very much wider search over a far larger area is undertaken there is the likelihood of seeing targets that are not there but missing those that are. Similarly in a search for new customers, there is the possibility of missing the prime customer and finding the second best, or worse none at all if the search is moving either too fast in the right area or too slow in the wrong area. A happy medium must be found and that is not easy. Whilst patience may be regarded as a virtue when developing advanced technology business, it is as well to be aware of external developments and modify the search speed accordingly.

(iii) visibility: both types of searcher are dependant on visibility to identify the target. For the material producer, visibility can be of his own making - if he can make the target shout loud and clear, identification is fairly easy. Thus, visibility is in some manner related to the degree of provocation produced by the material producer.

The selection of the correct communication channels plays an important role here - see Section 4.9 and Chapter 7.

An unstructured search (e.g. looking for a lost ball in one corner of a field, when it is just as likely to be in the middle, opposite or anywhere else) is quite fruitless for the material producer and child alike. However, a structured search can also have its pitfalls: Bartlett has suggested that a searcher following a structured search routine is likely to continue along his chosen route regardless of evidence proving that a different course would be better. This could be akin to a material producer being convinced that his material is ideal for making candles and not restructuring the search when it is shown to be an excellent dielectric, as happened with polyethylene initially (see Appendix B).

The ideal search, particularly for material producers would be done by choosing the search areas so as to get the maximum possible information but this is not easily done. None of the above authors provide definitive answers to such a problem but rather serve to make one aware of the nature of search operations and higlight some of the traps to be aware of.

A more explicit search process, giving actual practical guidelines is given by Ward, and forms the backbone of his 'successive focussing' innovation model described in section 4.6. Ward has described six stages which an organisation planning a product search and introduction study should be aware of: this is reproduced in Table 4.16.

Table 4.16 Table showing stages for a single product-planning study summarizing the action to be taken in sequence or parallel.

Stage	Description
1. Pilot Study (Review or Planning)	Define say 10 functional dynamic areas, consistent with the company's resources and experience, embracing but not limited to their existing business, plus basic screening criteria.
2. Search	Conduct a carefully defined and systematic worldwide search within the agreed dynamic areas for self-contained proprietary product opportunities which might be introduced under licence or some other acceptable manufacturing and sales agreement.
3. Exploration	Explore corresponding sectors of the market in order to identify emerging or unsatisfied requirements and to check the probable demand for products discovered; also ascertain possible parallel requirements of present customers and diversification lines successfully adopted by competitors, at home and overseas.
4. Acquisition (Audit)	Investigate prospects for acquiring companies or agencies, serving to extend or complement the company's product range, or to provide additional manufacturing or marketing resources necessary to exploit the products recommended.
5. Evaluation	Evaluate the products brought to light, technically and commercially, and particularly with reference to competitive activity, through a procedure ranging from coarse screening to market research in depth.
6. Action	Recommend a positive course of action and introduce proposed associates, with a detailed programme for implementation, showing cash flows and prospects for further innovation; also advising generally on the negotiation of agreements and indicating possible lines of longer-term development; resolve identity.

Although this is essentially for the firm that wishes to manufacture new products, the principle behind the operation are just as applicable for material producers searching for potential users. Ward has suggested several information sources that should be cultivated over the years when carrying out such a search; sources such as engineers, consultants, patent and licence agencies, research foundations, development bodies and government establishments throughout the world who are prepared to forward product information. The effectiveness of such sources was not indicated by Ward but it is the subject of a detailed investigation in a later section and Chapter 6.

4.8.2 SOME EMPIRICAL EVIDENCE OF SEARCH HABITS BY BUYING ORGANISATIONS

White has provided evidence to show that there is a tendency for both humans and animals to search for information even when their needs are satisfied, and that such a search behaviour is not accounted for as a means of anxiety reduction. Simon (1956) has also noted such tendencies to prolong a search and suggests the cause arises when the investigator is dissatisfied with the available solutions. Moreover, as the searcher progresses along the learning curve he becomes more adept at recognising clues which suggest avenues of investigation that are fruitfull to pursue further. Mumford and Pettigrew found from their research that the search process was often prolonged by the innovator group and top management reformulating goals.

Conversely, if the alternatives being pursued are seen to be leading to quite a different goal from that originally sought the search is likely to be limited or even halted (Simon 1956). It is clear that to search out all the alternatives in a constantly changing area of technology would be a never ending task, and that there must be some factors which draw the search to a close. Morris (1964) has pointed out that in a technological society, information costs are escalating all the time, and that a theory relating the cost and value of information is needed. The search process itself has a major cost attached to it and the allocation of resources for securing information is really an investment decision (Koopman). Following an investigation of the information that a firm required for investment decisions on computer systems, Hawgood and Mumford believe that the search for information should form part of the total cost of the project.

The high cost of searching for information is obviously a limiting factor but there are other causes which can limit the search. A lack of perceivable benefits and the need for standardisation were two other reasons given by Cunningham and White who investigated the number of quotes requested by various firms in the machine tool industry. Of the fifty one companies they contacted, one third requested only one quote. Such findings are in broad agreement with those of Kettlewood who found that fifty per cent of the forty three freight transport companies he contacted in Scotland had not invited competitive quotations during the previous ten years. Cunningham and White found the average number of quotes to be requested by each company to be three; with companies tending to search more alternatives as the machines increased in value, innovation and technical sophistication, and also as the machines fulfilled replacement rather than expansion requirements.

Cardozo, who studied the methods of obtaining quotations, found that customers tended to adopt either a sequential evaluation (i.e. telephoning suppliers one after the other) or a simultaneous scanning approach (i.e. examining returned tenders at the same time). Those companies using the sequential evaluation tended to have shorter lists of potential suppliers and were less likely to change their suppliers than those using the latter technique.

Mumford and Pettigrew's investigation of the computer system selection procedures showed how personal interactions can affect the search. If several systems are under investigation by different members of a search team, the individuals tend to push their own work forward for selection because they are closely identified with that unit. The decision makers, say the Board, then have to unravel the personal arguments from the technical as best they can when deciding upon a particular system.

4.8.3 CRITIQUE

Material producers face an extremely difficult search and match problem when looking for users of new materials; it is a problem that has received scant attention by researchers.

The search situations described by Ackoff and Sasieni give no help to material producers who face a dynamic search problem. It is useful to know that the behaviouralists have shown most searchers aim for a satisfactory solution - both to themselves and the organisation - rather than the optimum. That they "muddle through" to a solution which has been affected by political and social pressures is of interest, but their theories fail to indicate viable search techniques that a material producer could emmulate. It is perhaps of more interest to note that the "mixed scanning" technique advocated by Etzioni is probably a fair representation of the search technique employed by many firms seeking a new material for a new product. That is, many materials are scanned and evaluated rapidly on technical and economic considerations, leaving say one or two candidate materials. These two materials are then subject to a more intensive evaluation which examines the consequences of implementation. Failure to examine such consequences can in turn lead to commercial disaster as McKinsey et al. and also Pick (1972) - see Section 4.2.2 - have hinted.

The search methods discussed by the psychologists serve to show some of the problems that can pre-empt a search of any kind, including the search for material users e.g. searchers who insist on going along wrong routes for too long at the expense of either unexplored or too quickly scanned areas.

Of the different search methods discussed, the most practical for material producers and the most easily understood is that put forward by Ward. Nevertheless, it is too simplistic to say do this, this and this and the search will be completed. It gives guidelines as to how best to get information during the search but it lacks evidence of their effectiveness.

The empirical evidence provided by organisations of their search habits, indicates: the factors that can prolong or limit searches; some of the search techniques used by buying organisations; and the personal interactions that can affect decisions. However, it fails to indicate how a material producer should search for new material users. It seems feasible that a material producer could search either actively or passively for potential users as indicated in figure 4.18. All applications for materials arise from either a passive or active interaction between supplier and end user but this type of interaction has gone unexamined.

Figure 4.18 Four models of Supplier/End-user Searches.

	SUPPLIER				END-USER
(a)	Passive	←————	S	————→	Active
			E		
(b)	Active	←————	A	————→	Passive
			R		
(c)	Active	←————	C	————→	Active
			H		
(d)	Passive	←————		————→	Passive

To understand the models it is necessary to have active and passive defined. The Concise Oxford Disctionary states:
Active - Given to outward action; working effective; energetic, diligent, acting of one's own accord, acting upon others.
Passive - Suffering action, acted upon; not active, inert.

4.9 EFFECTIVE COMMUNICATION STRATEGY

Material producers, or for that matter, any selling organisation, that fails to communicate their wares to potential customers will naturally fail to sell. This is particularly true for new innovations, as Nabseth and Ray have recognised: "For the individual firm, information about a new technique is a pre-condition to adoption." It would therefore seem prudent to study the diffusion of information as well as the actual adoption.

It has already been shown that the composition of the Decision-Making Unit (DMU) varies between firms, industries and even from one decision to the next (Section 4.4.). Failure to recognise this can have profound consequences for suppliers. Individual members of the DMU have different needs and will naturally try to minimise the risk element of decision-making by seeking information (Bauer). An astute supplier will realise this, identify the key individuals, and then determine his own profile that he wishes to present, as Hill and Hillier have discerned. They suggest a successful marketing strategy will incorporate a supplier profile and communication (message/media) matrix. Suppliers and customers are thus linked by a communication network when various fundamental questions have been answered (figure 4.19). This can only be done if the supplier has a real understanding of organisational buyer behaviour. When a supplier has this understanding it can help to "Optimise the effectiveness of communications", as Hill and Hillier point out.

Figure 4.19 The Communication link between Supplier and Customers (Source : Hill & Hillier)

4.9.1 INFORMATION SOURCES USED IN THE ADOPTION PROCESS

Most students of innovation are convinced that effective communication is vital for the success of an innovation (e.g. Carter and Williams, Langrish et al., Burns and Stalker, Myers and Marquis, Rothwell et al. (1974), Freeman et al. (1971), and Utterback (1971)), and several studies of communication patterns within organisations have been made. Research and development laboratories have been scrutinised in particular. Notable studies in this area are those done by Allen and Sloan in the USA, Frost and Whiteley, Walsh and Baker, and Hall and Ritchie in the UK. Such studies have investigated the role of communication, as used by scientists mainly in research and development environments. All, to varying degrees, put forward the idea of a "technological gatekeeper" coupling with the outside world. It is argued by Allen and Sloan that "...new information is brought into the organisation through the gatekeeper". Much of this information is gained by reading, particularly the harder type literature. However, the evidence presented by the British authors suggest that the role of the technological gatekeeper is not so important in the UK as it is in USA.

Whilst technological gatekeepers have been identified as important individuals who feed information into American scientific establishments, there is little evidence to suggest that the same is true for engineering organisations in either the USA or UK. Both Allen and Sloan, and Rothwell (1975b) who did a comparative study of five innovative works (Langrish et al., Myers and Marquis, Rothwell et al. 1974, Freeman et al. 1971, and Utterback 1971) concluded that the information habits of scientists differed significantly from those of technologists. It is suggested that scientists couple more regularly with extra-organisational sources and rely on primary source literature (i.e. scientific journals, university laboratories); whereas technologists use mainly in-house sources and secondary source literature, (i.e. trade journals and textbooks). This is in common with engineers selecting materials (Section 4.2.1.), where it was stated that information sources included handbooks, British Standards, and literature from research associations, and manufacturers' and suppliers' catalogues.

Studies of the information sources used during (a) idea generation and (b) problem solving processes have highlighted a reliance on personal contact. For example, Myers and Marquis, and Utterback (1971), say that for idea generation,

personal contact accounted for 34% and 44% of the ideas respectively; whereas literature accounted for only 10% and 15·3% of the ideas respectively. For problem solving, personal contact accounted for 22% and 21·7% of the ideas and the literature for 9% and 8·4% of the ideas respectively. Other authors have also suggested that the literature is of secondary importance to personal contact for generation of new product ideas. Holt (1974), Owen, and Parkinson have all added weight to the argument that literature is a poor medium for generating ideas. Indeed, Owen, who made a study of mechanical engineering projects said:
"Mechanical engineers make small use of published information, that in acquiring information they prefer informal contact to a formal system, and oral communication to reading. They usually consult only easily accessible sources and are quickly deterred if the information found is not readily comprehensible to them."

The above references indicate that written sources have a low value when it comes to generating product ideas. However, students of the innovation process believe that papers and trade journals should not be dismissed so quickly. For example, Gibbons suggests that:
"It could be that transfer via people is easier to spot.... perhaps because it is more dramatic. Typically, scientists and engineers do not keep records of their reading habits and frequently they do not remember when or where they picked up the ideas which figure later in technical problem solving".

Robertson (1976) has proposed a study of the written word and its effect on technological innovation, the aim of which is to test whether "the written word plays a more significant part in technological innovation and particularly successful innovation than has hitherto been recognised". This study in particular was brought about because of the popular belief that "a person to person transfer" is more usual than the written word in technology transfer.

Indeed, it is difficult to understand how some people can suggest that the literature plays only an insignificant role in developing innovations. For example, it is commonly recognised that the development of printing was largely responsible for "accelerating the diffusion of information and ideas in the Renaissance and Reformation". Burns and Stalker believe that the appearance of scientific journalism in the nineteenth century played a similar role in developing technologies where personal communication was replaced by mass communication. The books and journals that appeared rapidly from the 1850's onwards "spread the new learning to the utmost limits of literacy in industrial Britain" with the help of clubs and institutions. Thus "knowledge of existing or presumptive demand for goods and services.... was spread at random among a very large proportion of the literate population. The fact that it was so spread meant that innovations might appear anywhere, might be lighted upon by almost anyone". (Burns and Stalker).

Many surveys (particularly by technical journals themselves) have already shown that technical journals are the most widely used basic source of information. Independent studies, such as that by Robertson, will make these other surveys more plausible if it can be shown that the written word has an important role in the innovation process.

Various authors, Rogers and Shoemaker, and Beattie and Reader, for instance, have already highlighted a major difference between the mass media and personal channels for communicating information. Whilst the personal communication channels are "excellent for communicating something really well to an individual", (Beattie and Reader), the mass media information sources, be they reports, magazines, radio and so forth are more useful for presenting selected information to a wide audience. Rogers and Shoemaker, as has already been indicated, have suggested that the innovation decision has four steps:
(1) Knowledge (2) Persuasion (3) Decision (4) Confirmation.
They go on to suggest that to influence the knowledge function, the mass media information sources are relatively more important. On the other hand, to influence the persuasion function, the interpersonal channels are relatively more important. The advantages of the mass media and interpersonal channels are shown in Table 4.17.

Table 4.17 Advantages of (a) Mass Media and (b) Interpersonal Channels

Mass Media can:		Interpersonal Channels can:	
(i)	reach a large audience rapidly;	(i)	allow a 2-way exchange of ideas
(ii)	create knowledge and spread information;	(ii)	can persuade receiving individuals to form or change strongly-held attitudes;
(iii)	lead to changes in weakly-held attitudes.		

(Source: Rogers and Shoemaker)

However, there seems to be some disagreement between researchers as to which are the more important information sources for early adopters*. Rogers and Shoemaker believe that mass media sources are relatively more important than interpersonal channels for the early adopter rather than late adopter. But, Bower has provided some evidence to suggest that personal influences are more important than impersonal influences for early adopters rather than late adopters. There is obviously room for further research in this area.

Nevertheless, putting this ambiguity aside, it is believed that as the adoption process proceeds the number and variety of sources consulted increases, with the speed of adoption being greatly influenced by the amount and quality of the information (Ozanne and Churchill, Webster 1969).

As far as personal sources are concerned, industrial salesmen appear to be a key element in generating interest. For industrial marketers, their credibility can be regarded as being a function of the company's reputation and the salesman's presentation. According to Webster (1968), both of these factors influence what a customer is willing to believe about a product. Although the evidence that individuals act as opinion leaders in industrial markets is inconclusive (Webster 1968), there is some evidence to suggest that members of the DMU do consult competitors, other organsiations and members of professional institutes (Weigan, Hillier).

* Adopter categories such as early and late adopters are described in detail in Section 4.10.4.

It seems likely that the diffusion of information about a new technique is a time-consuming process, a fact which has been confirmed by Carter and Williams, and Nabseth and Ray. Carter and Williams concluded in their study that "the backward firm may not hear of an idea for several years after it has been made". Nabseth and Ray suggested that the time lag between the first and last firm's awareness of a new process could be as much as ten years, although for the majority of firms this is shortened to five years. Furthermore, they have provided some evidence to show that the big firms get information about new processes earlier than small firms. This was most apparent with information about numerically controlled machine tools in America, Germany and Sweden, and special presses in Germany and Sweden. Most firms with more than one thousand employees got the information before those with less than one thousand employees (Table 4.18).

Table 4.18 Size of Firm and Date of First Information

	First information obtained		
	Before 1960	1960 or later	Total
NC machine tools			
Employing less than 1000	22	21	43
Employing 1000 or more	30	8	38
Total	52	29	81
Special presses			
Employing less than 1000	10	69	79
Employing 1000 or more	7	28	35
Total	17	97	114
Special presses excluding US firms			
Employing less than 1000	10	69	79
Employing 1000 or more	7	11	18
Total	17	80	97

(Source: Nabseth and Ray)

4.9.2 COMMUNICATING WITH DECISION-MAKERS

It is commonly recognised that the sellers' main problems are (i) to design the best possible message and (ii) to ensure it is received by the intended receivers in the intended manner (Kotler, Hill and Hillier). The first of these requires an understanding of the target buyer(s) whilst the second entails knowledge of the weak points in the communication process e.g. encoding, the message, the message channels, decoding and timing. For the communication to be effective, it must meet four considerations as summarised by Wilbur Schramm:

1. The message must be so designed and delivered as to gain the attention of the intended destination.
2. The message must employ signs which are common to the experience of source and destination, so as to "get the meaning across".
3. The message must arouse personality needs in the receiver and suggest some ways to meet those needs.
4. The message must suggest a way to meet those needs which is appropriate to the group situation in which the receiver finds himself at the time when he is moved to make the desired response.

Hill and Hillier, who believe that an effective communication strategy revolves around the target, timing, media and the message, examined each in turn:

Target: Once the supplier has decided which products to offer to which industries and market segments, he has then to concentrate on the company level for communication.

Essentially this entails identifying key members of the DMU - either the recommenders, or approvers of recommendations - and communicating in the right fashion with the target individuals. They suggest the target can be identified by (i) field research (using either inter or extra-organisational research bodies) which describes them in terms of "demographic factors" or by (ii) a deductive approach, wherein the supplier with some knowledge of the market, can deduce that because items are bought for specific reasons and usage, then certain types of individuals are involved in the purchasing.

Timing: Buying in industrial organisations can take months or even years depending on the complexity of: the technical problem, commercial negotiations, human interactions; and whether the product is buyer or supplier specified. The information requirements will change as the purchasing activity proceeds; and it is therefore necessary for the supplier to know when the different decision stages take place, i.e. precipitation, product, supplier and commitment decisions, and the composition of the DMU at each stage.

Media: Communicating with industrial buyers can be by a variety of methods - salesmen, and direct or indirect advertising media. The expenditure level will be determined by the nature of the task and therefore by the information sources used by individuals in the buying process.

Salesmen: Personal selling usually plays a major role in any industrial marketing communication, but it is costly and reaches only a limited audience in a limited time.

There is some evidence to sugest that sales prospects are greater if the salesmen are compatible with the buyers (Davis and Silk). Salesmen should therefore be selected accordingly.

Advertising Media: It has already been shown that there is evidence of impersonal methods (trade journals, newspapers and so forth) being a useful means of communication, particularly for new purchases. If it is accepted that the advertising media can act as a useful means of communication with the DMU, the next problem is to link the appropriate media with the target individuals. These sources are discussed in detail a little later.

Message: Any supplier wishing to sell his products must be able to show that his products will meet the needs of the customer with the minimum of risk. The supplier is put in the difficult position of having to know which characteristics of his product to stress in the message. This is made even harder because the profile devised has to appeal to all members of the decision-making unit and not just one member of it. For example, the recommenders will want detailed technical, delivery and handling information, whilst the approvers may only want brief technical and commercial details. Price is often stressed by customers as the most important factor of the suppliers profile but in fact this is not always so. It is more realistic to consider the total cost of procurement, i.e. the sum total of price quoted, cost of buying (includes searching for information, testing, etc.), and costs of the consequential adjustment (sorting out the problems of an unsatisfactory purchase). Although such a total cost is all too frequently ignored by both supplier and customer alike, it is likely that there will be a trend towards such costing in the future. Several studies which have examined supplier profile variables are of help to the supplier in designing his profile. For example, Pingry showed that product reliability, reliability of manufacture and of delivery were all more important than price for hydraulic components in America (Table 4.19). Hammet found that price was the most important factor in deciding supplier for a particular grade of oil in Sweden with quality and delivery ranked equal second (Table 4.20).

Table 4.19 Ranked importance of Supplier-profile Variables for Hydraulic components in United States

	Mean rank score	Standard deviation	Median rank score
(1) Product reliability	4·70	·524	5
(2) Reliability of manufacture	4·57	·789	5
(3) Reliability of delivery	4·50	·809	5
(4) Speed of delivery	4·22	·859	4
(5) Price	4·22	·636	4
(6) System capability	3·91	1·033	4
(7) Innovativeness	3·76	1·103	4
(8) Previous experience	3·71	1·035	4
(9) Discount policy	3·38	1.101	4
(10) Depth of product line	3·16	1·122	4
(11) Breadth of product line	2·90	1·121	3

N.B. (Rank score based on 5 point scale where very important = 5 to very unimportant = 1) (Source: Pingry)

Table 4.20 Ranking of criteria used in deciding supplier for a particular grade of oil in Sweden

	Rank 1st	2nd	3rd	4th	5th	6th	Overall rank
Price	149	38	31	7	2	5	1
Quality	43	77	42	26	12	9	2-3
Technical service	1	10	33	48	52	23	4
Delivery	33	67	73	28	9	6	2-3
Payment terms	1	12	12	26	13	18	7
Salesman	3	5	4	6	13	22	8-9
Technical capability	2	5	9	33	33	31	6
Facilities and equipment	0	4	6	8	17	16	8-9
Previous experience	2	9	18	36	49	46	5
Documentation procedures	0	0	0	3	2	8	13
Product range	0	4	3	3	11	22	10
Financial assistance	1	1	0	0	1	2	14
Location	2	1	3	3	4	2	11
Security of supply	0	0	0	0	1	0	16
Ease of communication	0	0	0	1	1	1	15
Reputation	0	0	0	0	0	0	17
Other	1	3	1	2	1	1	12

(Source: Hammet)

4.9.3 INFORMATION SOURCES USED BY DECISION-MAKERS

A wide variety of information sources are available to decision-makers, and the sources used depend to a large extent on the decision-maker and his function. If the design function - which represents one of the main bodies of decision-makers for materials (see Section 4.4) - is examined, one finds a vast pool of information sources available to designers (figure 4.20). Such a diagram of the information flows affecting design (proposed by Gregory, 1977) illustrates the complex nature of the information patterns that designers and draftsmen handle during their working days. It shows the interrelation of many different information sources from education and experience to recorded (written and unwritten) and unrecorded sources; and indicates what a time-consuming business actually gathering information for design can be - fifty per cent of a designer's time is spent gathering information.

Sharpe recently described the benefits of various information sources available to the engineering industries for both buying and designing. Included in his review were computer services, technical journals, directories, research association, exhibitions, conferences and libraries. While most of the sources that Sharpe cites appear to be useful at first glance, he makes no real mention of which ones are effective for particular functions. One of his most apt comments about conferences and exhibitions is that while they may provide the best forum to see what competitors are doing, they can be very wasteful of time.

If, however, there was some means of finding out which sources were (a) best suited for particular information dissemination and (b) regarded as effective by the potential users of the information, then the communicator could judge which sources were best suited to his needs. As it is, much information appears to be put through the wrong

Figure 4.20 Information Flows Affecting Design
(Source : Gregory 1977)

Aston University

sources and in some cases is not understandable by the potential users - as Rothwell (1975b) has pointed out. Only a few studies appear to identify the most useful information sources for particular functions. To illustrate the diverse range of information sources and their effectiveness in different situations, a few examples are given.

Briggs and Rees, who examined the effectiveness of communication channels used by the Department of Health and Social Security for communicating availability of supplementary benefit to the nation, found posters to be the most efficient; the supplementary benefit offices themselves were ranked quite low (see Table 4.21). This provides further evidence of the utility of the written word at the awareness stage.

Table 4.21 Claimants' most useful sources

	No. of mentions	% of all mentions
Posters	317	18·1
Post Office	243	13·8
TV	208	11·8
Radio	35	2·0
Press	134	7·6
Information sent from SB Office	108	6·2
Information from visit to SB Office	101	9·2
Friends, relatives	210	12·0
Social Services	40	2·3
Medical Servies	43	2·5
Advice centres	21	1·2
Pension book notes	100	5·7
Unemployment benefit office	134	7·6
Total	1754	100·0

(Source: Briggs and Rees)

Beattie and Reader showed the value of examining the reading habits of senior technical managers in the British Steel industry over a decade ago. Their results showed that even though there were many journals peculiar to the engineering industry available, the Financial Times was regarded most highly by managers. A similar study carried out by the Financial Times itself in 1967 showed it to be the most important source for keeping managing directors in touch with business trends and developments.

Following an investigation of information requirements of polymer chemists at thirty nine establishments, Menzel concluded that the literature - articles, reprints, handbooks, other books and unspecified literature - was the most important source for "findings" information, i.e. information about facts, data, findings or constants, and that personal communication was the most important source for "procedural" information, i.e. information about proceduers, techniques, materials and apparatus. Table 4.22 shows the result of his study on the incidence of different forms of information channel.

Another study carried out by Parkinson investigated the information sources used in the earth-moving industry. This showed that the potential users of new machinery relied heavily on the local dealer, whilst trade journals were hardly used at all. Table 4.23 illustrates the forty nine respondents' rating of the usefulness of the range of information sources available.

Table 4.22 Incidence of different forms of information channel

Articles and reprints (including pre-prints, etc.)	107 encounters	(25%)
Handbooks	29	(7%)
Other books	46	(11%)
Literature - unspecified	26	(6%)
Total - published primary literature	208	(49%)
Total - semi-published literature	33	(8%)
Secondary publications	5	(1%)
Library and information services	2	(0%)
Total from the literature	248 encounters	(58%)
Total personal communication	176	(41%)
Total from presentations, conferences and seminars	4	(1%)
Total (all channels)	428 encounters	(100%)

(Source: Menzel)

Table 4.23 Effectiveness of information sources in the earth-moving industry

(All percentages calculated on a base of 49 firms)

Sources of information	Highly useful	Middle point	Not at all useful	Not used	Total
Leaflets and brochures	45%*	24%	12%	18%	100%
Trades shows/exhibitions	35%	20%	14%	31%	100%
Trades journals	18%	10%	20%	51%	100%
Demonstrating	65%	6%	0%	28%	100%
Local distributor	61%	12%	10%	16%	100%
Members of own organisation	37%	4%	8%	51%	100%
Other sources of information	16%	4%	0%	79%	100%

* To be read: 45% of the respondents to the postal survey said they felt that leaflets and brochures were a highly useful source of information when they began to evaluate the various types of (machine) available.

(Source: Parkinson)

The media have also investigated the readership habits of businessmen, mainly in an attempt to promote the sales of their sponsors' medium. However, the definitions of "businessman" used in media research on readership behaviour are often incompatible with those used to describe members of the decision-making unit.

One of the most recent and broadly-based surveys was the Business Media Research Committee and Research Services (BMRC) "Businessman Readership Survey 1977", which was carried out in the UK. The BMRC defined a businessman as "A man or woman whose occupation implies the exercise of significant managerial, executive, technical or advisory functions, and who works in an organsiation eligible on grounds of size." They examined the readership habits of businessmen in terms of national and provincial newspapers, and general interest and business magazines. Over five hundred usable replies were received from businessmen in engineering and technical services, and Table 4.24 gives an indication of the reading habits of design and production people.

Hill and Hillier criticised an earlier survey of BMRC (1973) on the grounds that classification of the personnel was incompatible with that of studies of buyer behaviour. As an example, purchasing was cited as an area of primary responsibility in the BMRC survey, which it is not, according to buyer behaviour studies, particularly for the new buy situation (see Section 4.4). There is no indication that BMRC have improved their categorisation and the criticism still

Table 4.24 Businessman Readership of Selected Media in Engineering and Technical Services.

	% Reading Design	% Reading Production
Daily Newspapers		
Daily Telegraph	32	21
Financial Times	2	13
Guardian	14	9
Times	9	3
Sunday Newspapers		
Observer	14	10
Sunday Times	35	27
Sunday Telegraph	13	13
Weekly Magazines		
The Engineer	23	26
The Economist	7	7
New Scientist	15	7
Monthly Magazines		
Factory Equipment News	8	14
Production Equipment Digest	6	16
What's New	4	12
Mechanical Engineering	22	24
Chartered Mechanical Engineer	17	8
Engineering	26	29
Engineer's Digest	9	11
The Director	3	6
Industrial Management	3	14
Industrial Purchasing News	3	7
Management Today	12	21
Modern Purchasing	1	4
Procurement	1	1

stands. Further, although the survey examined readership habits in various industries and in different sized firms, there is no way of judging whether the respondents included decision-makers for materials or any other product for that matter.

An earlier survey by the New Scientist (1974) asked for information on occupation, type of manufacturing industry, mangement status, functional area and involvement in purchasing. A questionnaire approach was adopted and distributed to all overseas readers. The results gave little guidance to suppliers as to which journals to use because of the difficulty in answering the questions. For example, many respondents indicated their involvement in purchasing as "specifying", "consultation" or "approval". Another problem could well have been that the copies of the New Scientist reached only the immediate readers, who might not have been those best qualified to reply.

4.9.4 CRITIQUE

From the evidence presented it seems doubtful that technological gatekeepers play as important a role in feeding information into engineering organisations in this country as they do in scientific establishments in America. No-one has identified technoligical gatekeepers as important beings in the decision-making unit and they do not appear to warrant as much attention as the psychologists maintain.

Considerable disagreement reigns over the worth of the written and unwritten word as a cue for idea generation. In recent years several researchers have come to believe that the written word has been far under-rated for idea generation, and this also is the author's contention. Material producers have got to get information about new materials across to the majority of potential users, to create an initial awareness before any product ideas can be generated. The written word appears to be a far more efficient means of creating this awareness than the unwritten word. However, nearly all of the studies examined failed to investigate the worth of other information sources, e.g. company representatives, conferences, exhibitions, government information services, internal company channels and patents. This failing has to be rectified if material producers are to know the best medium for promoting their materials.

4.10 ORGANISATIONAL ADOPTION HABITS

It is possible that the failure of many new products in the industrial market place is due to lack of understanding of the adoption and diffusion process by industrialists. Hill and Hillier believe this is not only because of inaccurate forecasting but also because the marketing strategies are inappropriate. If this is indeed the case, it is more than an adequate reason for examining the literature to investigate the adoption process in general, and the characteristics of an innovation which affect the adoption and diffusion rate, the categories of adopter, and the characteristics of early adopters in particular. However, unless the innovatory effort by the manufacturers is complimented by similar innovatory effort by the consumers and possibly the distributors, the manufacturers activity is all for naught

(Hayhurst). It is therefore essential that manufacturers contemplating the introduction of an innovation to others should understand as much as possible of the potential user's adoption habits.

4.10.1 ADOPTION AND DIFFUSION EXPLAINED

No innovation, of whatever sort, can be regarded as a success until it has been adopted by a user. Rogers and Shoemaker's definition of adoption can be broadly interpreted to be the decision to make full use of an innovation as the best course of action available. Even then, an innovation can be discontinued by the user at a later date when he finds it does not meet all his requirements, technical and financial for instance. Rejection, according to Rogers and Shoemaker is "a decision not to adopt an innovation," whilst discontinuance is "a decision to cease use of an innovation after previously adopting it." Should the innovation be successful with one user, the chances are that it will diffuse to others by a process of communication and usage. Diffusion and adoption are two separate and distinct phases - "the diffusion takes place between companies and industries, the adoption process takes place within companies" (Hill and Hillier). Both are important to the material producer but of the two, adoption is the more important, for without that initial adopter, the innovation can never diffuse to other users.

4.10.2 THE ADOPTION PROCESS AND ITS PLACE IN THE INNOVATION PROCESS

The aftermath of an innovation, i.e. adoption, rejection, discontinuance or diffusion, can be viewed as a means of judging the success or otherwise of an innovation; and research into the adoption and diffusion process has been going on for over thirty years. One of the classics, and probably the first study of the diffusion of an innovation was that of the hybrid seed corn adopted by Iowa farmers in USA. The study was carried out by Brice Ryan and Neal Gross, two rural sociologists, in the early 1940's. Other studies of the diffusion process followed rapidly in many and varied fields. According to Rogers and Eveland there were more than 2400 publications on diffusion studies by 1975. Hardly any of these have dealt with the innovation process in organisations but have dealt with the individual or organisation-to-organisation diffusion, and Rogers and Eveland have challenged the classical diffusion model, i.e. "(1) an innovation (2) communicated via certain channels (3) to members of a social system (4) who adopted it over a period of time." For example they have questioned whether (a) an innovation is advantageous for all adopters, (b) cross-sectional data gathering at a point in time is sufficient for study of a process like diffusion and (c) whether a study of organisations would show different results from past studies of individuals. Many of the studies have dealt with the diffusion of ideas in varied audiences, mostly alien to the manufacturing industry with which this study is interested. For instance, there is a wealth of information about how ideas are diffused through agricultural innovations, education, anthropology, communication, marketing, economics and medical sociology, as Rogers and Eveland have pointed out.

Before discussing the adoption process in detail it is important to understand where it stands in relation to the whole innovation decision process. The number of stages leading to adoption has varied among researchers and figure 4.21 summarises three of the major attempts to analyse the process. Strong's four-stage model arose from studies of effects of advertising and personal selling calls. The model proposed by Lavidge and Steiner in their investigation of advertising effects propcses six stages, and Rogers summarised the five-stage model formulated by various rural sociologists. All three models can be split into basically three levels - a cognotive level, an effective level and an action level. Where more than one term is present at a particular level, the first is a weaker response than the second, or, put another way, desire is stronger than interest in Strong's model.

Figure 4.21 Adoption Models

		Authors		
		Strong Model	Lavidge & Steiner Model	Rogers Model
Levels	Cognitive level	Attention	Awareness → Knowledge	Awareness
	Affective level	Interest → Desire	Liking → Preferences → Conviction	Interest → Evaluation
	Action level	Action	Purchase	Trial → Adoption

A later model of the innovation decision was suggested by Rogers and Shoemaker (see p.90) and indicates some important factors that may influence the overall process. For example, the communication channels (mass media or interpersonal) that are used to influence the potential user's decision to adopt or reject the innovation can be important (see Section 4.9 and Chapter 7).

It is of interest to note that following research into the automatic machine tool industry in the American Mid-West, Ozanne and Churchill were able to identify four of the five stages proposed by Rogers. From the fifty two companies studied, they found that with expensive innovations, the trial stage of the process was missing.

4.10.3 CHARACTERISTICS OF AN INNOVATION WHICH AFFECT THE ADOPTION RATE

The inherent characteristics of an innovation can have a marked effect on the rate with which it is accepted by users. Rogers and Shoemaker have recognised that it is the attributes of the innovation as seen by the users that is important, and not as seen by the manufacturer. They suggest that for a product to succeed it must have a relative advantage (measured in economic, social prestige, convenience and satisfaction terms), be compatible (with existing values, past experiences and needs ofthe user), have a low degree of complexity (i.e. easily understood by the users), be open to trial (i.e. allow the user to experiment with the innovation on a limited basis), and be observable to others (the easier it is for potential users to see the results of an innovation the more likely they are to adopt).

For an industrialist, the relative advantage described by Rogers and Shoemaker must be a measure of the net worth of the innovation to the customer, expressed in economic terms. Webster (1971) has pointed out that it must represent an incremental profit relative to available alternatives. In his view, relative advantage may be considered by the user as a higher market share or improved profit performance. Webster (1969), and Fliegel and Kivlin (1966) suggest that such a relative advantage may be provided by an innovation that:

1. Offers reduction in average total cost per unit
2. Increases the total sales revenue due to greater sales because of improved product quality or differentiation
3. Permits an increase of the average revenue per unit because adoption of the innovation allows prices to be raised
4. Offers a saving in time and hence labour costs.

Such findings have been broadly backed up by Parkinson who investigated the diffusion of earth-moving machinery by forty nine companies. One of his hypotheses was that:

"The rate of adoption of industrial innovation depends, ceteris paribus, on the individual organisation's perception (mainly individual managers) of the relative economic advantage perceived, the quicker the rate of adoption". His work supported the hypothesis and he also concluded that "the net perceived advantage of the new machine was greater for early adopters* of the machine than for the majority of late adopters."

* Adopter categories, i.e. early and late adopters, are discussed in the next section.

Although financial advantage will be a prime consideration by industrialists investing in new innovations, emotional factors can also be imprtant, as Ozanne and Churchill discovered. Baker also found that when the economic advantage was marginal, then emotional factors could be particularly important.

In accordance with Rogers and Shoemaker's advice, Fliegal and Kivlin found that those processes which are compatible with a firm's practices and technology, and are not complex, are likely to be adopted most rapidly. Another of their findings showed that high cost practices were adopted at least as quickly as low cost practices.

The suggestion that trial usage of an innovation is a factor in its adoption appears to be under some disagreement between various researchers. Kotler has indicated that trial-use can help convince a consumer to buy if he is frozen at the interest stage and unable to make the transition to adoption. However, Fliegal and Kivlin discovered that small scale trials did little to encourage rapid adoption. Such trials may be relatively inexpensive for consumer products compared to similar trials for industrial products.

There is, however, no disagreement regarding the results of an innovation being observable to others. According to Webster (1969), diffusion of the innovation will occur more rapidly as the amount of information available to prospective adopters increases over time, due to additional firms using the innovation and word spreading. Mansfield also believes that as the proportion of firms already using the innovation increases, a given firm is more likely to adopt the new product or process. Also, the likelihood of an innovation being adopted by a firm is, in Mansfield's opinion greater as (i) the profitability of the innovation increases, and (ii) the size of investment decreases.

Besides the perceived attributes, there are other factors that affect the rate of adoption of an innovation, according to Rogers and Shoemaker. These are:

1. "The type of innovation-decision." If the innovation-decision is relatively simple, for example an innovation that is needed, simple in concept, readily understood and adopted by one individual with no external effect on the rest of the population, then adoption may be quite rapid. However, if the conditions in the example above were reversed, it is likely that the adoption rate would be much slower.

2. "The nature of the communication channels used to diffuse the innovation at various functions in the innovation-decision process." This has been dealt with in detail in Section 4.9 and Chapter 7, and readers should refer to the appropriate section for further information.

3. "The nature of the social system". A prime example to illustrate this point for the adoption of material innovations is provided by the tragic Summerlands fire disaster of 1973. The introduction of new materials into the building trade has suffered tremendously since that date. Modifications and restrictions imposed on building regulations as a result of the official enquiry and

report (see the Royal Institute of British Architects Journal, July 1974), have virtually meant that architects can only design with proven materials such as brick and slate. J. Napper made the following comment, some two years after the Summerlands fire disaster and it drives home the effect the social system can have on an innovation:

"As legislation and accompanying regulations multiply and become impossibly complex, more and more decison-makers, the builders and professionals, have to rely on "permissions" from statutory authorities and government agencies before they can even begin to make decisions - a kind of chicken-and-egg situation. This is causing all except a few to adopt a passive role rather than a dynamic, creative one. The result is reflected in the buildings and environments which are produced. The arguments in favour of this system are powerful for they are concerned with public safety and health and the effects of laissez-faire, but it is a negative system in that is succeeds in preventing "the worst happening". It also reduces the chances of inadequate people making gross errors of judgement".

The nature of the social system will therefore have to be judged by individual innovating firms prior to the time of launch to ensure that the social system is in a favourable mood.

4. "The extent of change agents' promotion efforts in diffusing the innovation". A change agent is a person whose function is to promote an innovation to the best of his ability. Webster (1969) has concluded that the

earliness of adoption depends on certain characteristics of both the adopting firm and the innovation. Different innovations produce different adoption rates; and earliness of adoption is related to the type of innovation in the following manner:

1. For innovations involving some net capital outlay or investment with the risk of some negative outcome, earliness of adoption is positively related to the firm size, liquidity, profit trends, sales growth and market share of the buying firm.
2. For innovations involving little or no investment of resources, with only a slight risk of a negative outcome, earliness of adoption is positively related to profit trends, sales growth and market share of the buying firm.
3. Earliness of adoption is positively related to the relative advantage (profitability) of the innovation for the buying firm.
4. Where the selling firm provides valuable information (e.g. technical or marketing) the earliness and speed of adoption is negatively related to the size of the buying firm (see also Baker).

Material innovations are perhaps in a unique position compared with product or process innovations, and as such, their adoption and diffusion can be slower than other types of innovation. Besides the factors that affect material selection (see Section 4.2) and the sequence of usage that history apparently dictates (see Section 4.7.2), materials are also prone to the "sailing ship" effect. This phenomenon was first recognised by S. C. Gilfillan in his work "Sociology of Invention" and relates the story of the best and fastest sailing ships coming into service after the arrival of the steamship. In a similar fashion, when a new material threatens to displace a traditional material from a particular product the manufacturer's of the traditional material may well "fight back": they may improve the properties and characteristics of their material to combat the newcomer. Such was the case with "Corfam" (a synthetic leather) when the leather industries improved the scuff-resistance, toughness and durability of leather (see Chapter 5); and it seems likely the same could be happening with silicon nitride and nimonic alloys (see Chapter 5).

4.10.4 CATEGORIES OF ADOPTERS

Innovative firms who wish to see their innovations adopted rapidly by other industrial users need to know the likely adopters. Some users will obviously adopt an innovation quickly, some very slowly, and some not at all. Different names have been given to adopters by various authors, according to the category they fall in. For instance:

Name of Adopter Category	Function/Description	Author
Innovators) Progressives)	Innovators are venturesome, like to try new ideas and take risks and are cosmopolitan in outlook	Danhoff, and Rogers and Shoemaker, Carter and Williams
Initiators) Early Adopters)	They accept new ideas with some care and thought and are regarded as opinion leaders	Rogers and Shoemaker Danhoff

Name of Adopter Category	Function/Description	Author
Early Majority	Are those who are very deliberate in their actions	Rogers and Shoemaker
Fabians) Late Majority)	Are sceptical users, and adopt the ideas only after utility has been widely acknowledged	Rogers and Shoemaker Danhoff
Drones) Laggards) Parochial)	The last to adopt an innovation, and very suspicious of change	Danhoff Rogers and Shoemaker Carter and Williams

Holt (1977) has provided a clearer picture of the adopter categories in terms of the number of users one can expect at any of the stages with the distribution curve shown, figure 4.22.

Figure 4.22 Theoretical diffusion curve and user distribution

(Source: Holt (1977))

Such adopter categories, though readily accepted, are not so readily identified. A would-be innovator with a new product, process or, as in the present study, a new material, would like to identify fellow innovators who will adopt the innovation rapidly.

On an individual basis, Rogers and Shoemaker suggest from their research findings that earliness of adoption is related to socio-economic status, personality variables, and communication behaviour (see Table 4.25). In an industrial context, innovators and early adopters are likely to be those with both a broad-minded outlook and advanced technical outlook (Hill and Hillier). Webster (1966) has given a little more detail of the characteristics of those firms that adopt innovations first. For example:

1. They recognise the innovation offers a large relative advantage (incremental profit).
2. They are best able to tolerate the risk of adoption, in terms of the amount of investment required and the loss they could sustain. The ability to tolerate risk is a function of the firm's size, liquidity and management's self-confidence.
3. They have the highest level of aspiration as shown by recent profit trends, market share and gross sales.
4. They recognise that the information relating to the innovation, and provided by the seller, has great value as measured by:
   a) its influence on the adopters relative advantage from innovating
   b) its ability to enable the adopter to reduce perceived risk.

Table 4.25 Distinguishing Characteristics between Early Adopters and Late Adopters as seen by Rogers and Shoemaker

Socio-economic findings

Early Adopters: are not different in age from late adopters
: are better educated
: have a higher social status
: are likely to be commercially oriented, rather than have a subsistence orientation
: have larger sized unite (farms and so on)
: are more inclined to credit (borrow money)
: specialise more

Personality variables

Early Adopters: have greater empathy
: are less dogmatic
: are better able to deal with abstract concepts
: are more rational
: have a more favouralbe attitude to change
: are less fatalistic
: are more achievement motivated
: have greater aspirations

Communication behaviour

Early Adopters: have more social participation
: are more highly integrated with the social system
: are more cosmopolitan
: have more contact with change agents
: are more exposed to mass media communication channels
: are more exposed to interpersonal communication channels
: are more likely to seek information about innovations
: are more knowledgeable about innovations
: are likely to be opinion leaders
: are more likely to belong to modern systems rather than those with traditional norms
: are more likely to belong to well-integrated systems.

Baker, who believed there was too great a concentration on the economic factors (e.g. size and profitability) when trying to identify early adopters, investigated the relationship between managerial attitudes (related to organisation structures and methods of operation) and adoption. His research revolved around the question "can one predict the likely reaction of potential users to a new industrial project offered to them, and if so, can we utilise the information to accelerate the diffusion of that new product?"

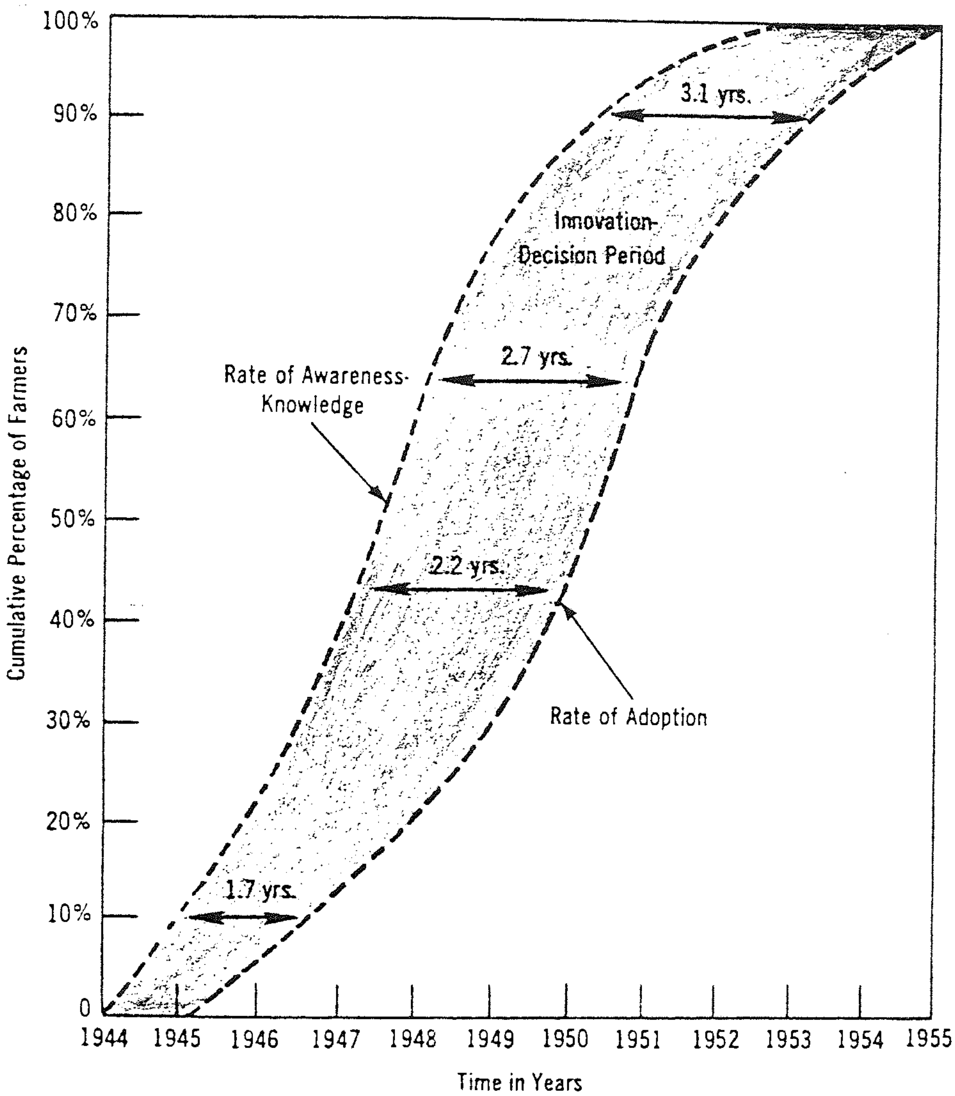
He examined the relationship between a firm's adoption habits and behavioural and economic factors, and concluded that:

1. the economic variable (i.e. firm size) had the greatest effect on the time of adoption. Size, he surmises, is important because it allows more resources to be committed for collection and checking of information, and searching for new and better ways of exploiting a firm's resources, and it also leads to formalised procedures and practices;
2. there is a relationship between the management-attitude variable and time of adoption;
3. small firms are likely to adopt first provided that the investment is not too great, but for a major investment, large firms adopt first.

4.10.5 ADOPTION TIME

It can be seen from the preceding work that the rate of adoption depends on the perceived attributes of the innovation and also on the characteristics and attitude of the adopting firm. However, such results give no indication of time delay that can be expected between a potential user's awareness and his actual adoption of the innovation. Studies of the process by which new products are adopted into their potential markets follow a similar pattern for many different products and techniques. Namely, when the cumulative number of adopters is plotted against time, an "S" shaped curve emerges similar to that shown in figure 4.23. Such a pattern transpires both for the rate of awareness and the rate of adoption characteristics, with the latter curve generally lagging by a few years (see figure 4.23). Although the diffusion of an innovation will lag that of its preceding information, Nabseth and Ray have found no evidence to support Rogers and Shoemaker's hypothesis that information diffused more rapidly than adoption. They found that the later a process was introduced to a country, the more rapid was its diffusion, possibly due, in their opinion, to further process improvements leading to a more rapid spread. Many authors, Enos, Sherwin et al., Lynn, and Gregory, for example, have proposed various lengths of adoption periods for a variety of products in different fields, ranging from three to seventy nine years (with a standard deviation of sixteen years in those time lags in the innovation studies by Enos). Seventy nine years might seem excessive, but there is no doubt that the time delay can be lengthy. Gregory (1972), for instance, suggests that (i) major innovations requiring basic research will take over twenty years; (ii) innovations requiring applied research will take over ten years and (iii) innovations based on available technological knowledge will take approximately five years. The distinction between different types of innovation and the diffusion period

Figure 4.23 Rate of awareness-knowledge, rate of adoption, and length of the innovation-decision period for Iowa farmers adopting 2, 4-D weed spray by year.

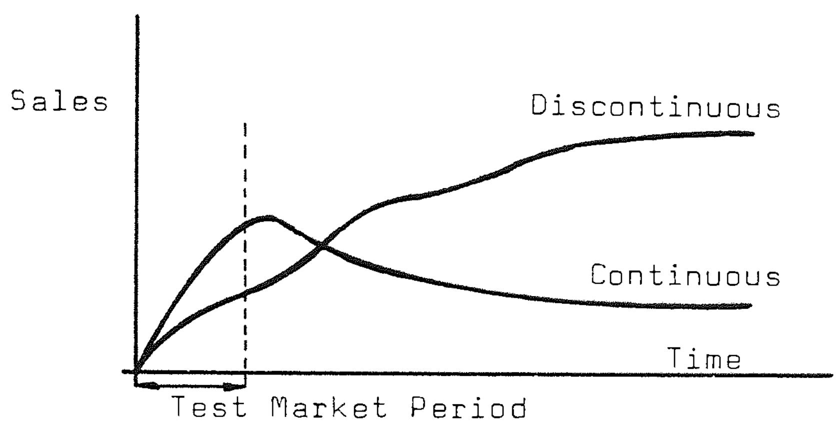


The shaded area in this figure illustrates the aggregate innovation-decision period between awareness-knowledge and adoption of 2,4-D weed spray. Knowledge proceeds at a more rapid rate than does adoption. This suggests that relatively later adopters have a longer average innovation-decision period than do earlier adopters. For example, there are 1·7 years between 10% awareness and 10% adoption, but 3·1 years between 92% awareness and 92% adoption.

Source: A re-analysis of data originally gathered by Beal and Rogers (1960, p.8), and quoted by Rogers and Shoemaker.

has also been highlighted by Tauber who put it in a slightly different way: "Continuous (incremental) innovations diffuse more quickly than discontinuous (radical) ones. Major innovations which are not immediately compatible with cultural values or consumption habits take longer to win approval from the general public". Although no figures are quoted, he suggests the picture of adoption for incremental and radical innovations might be similar to that shown in figure 4.24.

Figure 4.24 A suggested picture of the Diffusion of Continuous and Discontinuous Innovations.



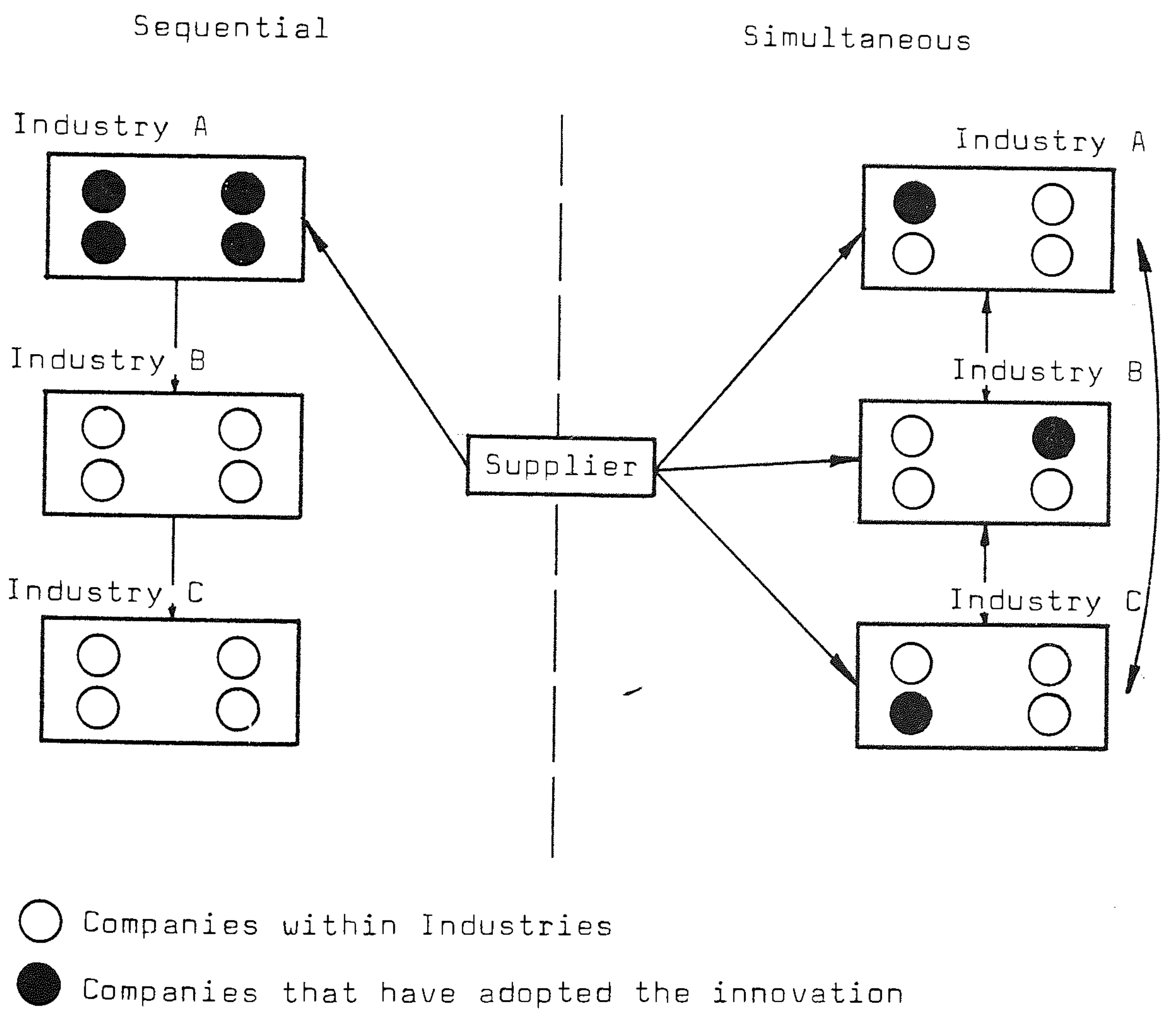
(Source: Tauber)

A distinction has also been drawn between the consumer and industrial type product by Lynn. Consumer products taking less time for adoption than industrial goods. Different industrial sectors apparently adopt products at different rates as well. Enos concluded that "mechanical innovations appear to require the shortest time interval with chemical and pharmaceutical innovations next. Electronic innovations took the most time".

It can be seen that the time for adoption of individual innovations varies among individual firms and industrial sectors according to the type of product. For the innovation to diffuse to more than just one user, the supplier can tackle the problem in two ways. He can either promote the innovation simultaneously among appropriate industries or he can attempt to spread the innovation to the whole of one industry and then move on to the next industry in a sequential fashion (see figure 4.25).

Figure 4.25 Diffusion Patterns for an Industrial Innovation

(Inspired by Hill & Hillier)



Hill and Hillier suggest that for those innovations where the adoption and diffusion process is short, then the supplier might be advised to opt for a sequential strategy; whilst the simultaneous strategy would be better for long adoption and diffusion times. Such recommendations should be of particular importance for material producers, where firms may have to redesign for the new material if all its benefits are to be realised. This implies a simultaneous marketing strategy.

4.10.6 CRITIQUE

Rogers and Shoemaker, the proponents of the awareness, interest, evaluation, trial and adoption hypothesis have been challenged by other authors when it comes to suggesting an adoption model in the industrial environment. In particular, the trial sequence seems to be in some doubt; and this could be of paramount importance to material producers who regularly supply samples for trial purposes.

Many researchers have examined those characteristics of an innovation which makes for succes, and their findings are broadly agreed upon by one and all. However, none of the research has dealt with the characteristics that a material innovation should possess. It seems likely that a material innovation should evoke the same characteristics of other types of innovation, although there is little evidence to this effect. But what is worrying is that there may be other characteristics peculiar to material innovations which are as yet not documented. For example the "factors affecting material selection" (Section 4.2) and the "sailing ship effect" illustrate that material innovations are exceptional. Unfortunately, such a criticism stems from the fact that the vast majority of research into the adoption and diffusion process has been aimed at the individual, and organisation-to-organisation process, and not with the industrial adoption process. There is, therefore, a distinct shortage of work concerned with the adoption of materials.

Following directly from this, is the fact that identification of rapid adopters of material innovations has been impossible from the literature. The characteristics of the innovators and early adopters will be of much use to a material producer to check out those firms who have become interested in adopting their new material. But they are of little practical use when it comes to identifying the innovators beforehand.

The evidence presented on the adoption times that can be expected by the supplying innovator have not, unfortunately, dealt with material adoption. It may therefore be slightly misleading to accept such figures particularly as adoption times are likely to depend on the type of industry end-user, besides the factors already mentioned.

4.11 SUMMARY

There are many facets associated with the introduction of a new material into the industrial and consumer market place. This review has attempted to illustrate to those material producers contemplating the introduction of a new material some of the problems they are likely to encounter. A knowledge of others' experiences should at least help to guide them along the innovation route.

However, it should be realised from the preceding sections that there are gaps in our knowledge of the innovation process as it affects materials. The rest of this thesis attempts to fill in some of the gaps.

Although most of the innovation models reviewed are of little use for prediction purposes because of their sequential and descriptive nature, they do at least act as guidelines for forthcoming innovators. The variability between various innovation studies has been a major criticism, for it does not help would-be innovators to formulate their own contingency plans. Chapter 5, which examines the innovation of ten materials, hopes to remove the variability due to cross cultural differences. Materials, like energy, are used by all manufacturing firms and as such transcend the cross cultural barriers otherwise experienced by product and process innovations. The methods used to identify potential users with a "need" has been given scant attention in the literature, but this search and match problem is studied in Chapter 5.

The studies of buyer behaviour have failed to examine the introduction of a new material as a "new-buy" situation. Furthermore, the current literature gives a false indication of who material producers should see when introducting new materials to a firm, i.e. the purchasing staff. Chapter 6 examines this problem and identifies the material decision-makers (MDM) and their roles in various industries. The size and nature of material decision teams and the relative importance of material innovations are also investigated.

Although several studies have investigated various information sources for their worth as a means of idea generation and general awareness, few have examined all the information sources available to users. Firms that use materials have access to at least ten different information sources for awareness of materials, - colleagues, company representatives, conferences, exhibitions, government information services, internal company channels, journals, newspapers, patents and television - these have been investigated in Chapter 7. The effective information sources and channels for MDM's have been identified for different industries and actually put to the test (Chapter 9).

Chapter 8 examines the adoption process of materials in some detail for several reasons. First, it was not possible to identify the potential early adopters of new materials from the literature; secondly, the expected adoption times suggested in the literature were not for materials and could therefore give a false picture to material producers; and thirdly, the trial stage in the adoption process seemed in dispute by several authors. This chapter investigates the knowledge phase of new materials by MDM's, the relationship between awareness and adoption, and also the adoption times that can be expected of new materials in different industries.

There are at least three other areas which need further investigation to aid material producers as they introduce new materials. Whilst this thesis identifies those areas it does not attempt an analysis, due to a lack of resources.

Cost per unit function analysis has been identified as a new and upcoming area which is likely to affect the choice of materials by user firms in the future. Material producers should be aware of this area, for if they fail to become involved with any systems that are introduced, either on a local or national scale, their material may equally fail to go on the computer records.

The benefit that economies of scale can bring to producer firms have long been known. Unfortunately, there is little evidence of material producers actually examining such economies when they are introducing the material. For many it is forced upon them at a later date when they want to diversify. It can, however, be a useful exercise for examining potential markets at the introduction stage, and should not be overlooked by material producers.

Finally, there appears to be a general lack of understanding of the pre-requisites necessary for stimulating demand of materials in the market place. Any research that can examine this problem will no doubt help material producers in the future.

5

HIGH TECHNOLOGY MATERIALS - THEIR INNOVATION

Page

5.1 CHAPTER PREVIEW

The innovation of advanced technology materials is a complicated process, and because many companies have experienced the problems of getting new materials adopted into successful products, a case history approach has been used to try and discover the path to success whilst avoiding some of the pitfalls.

Ten case histories have been examined - four of which are documented in Appendices A to D: carbon/carbon, polyethylene, silicon nitride and titanium; the remainder have been taken from published literature: Silicones, Titanium Carbide and Lockalloy from Tanenbaum et al; Super Plastic Aluminium by Buchanan; the Rare Earths from Langrish et al; and Corfam by Robertson (1974 and 1977).

Case histories of innovations can often benefit those amongst us who have not actually experienced the innovation process. Although the problems facing material innovators may seem new to them, the likelihood is that they have been faced by others previously. This chapter in particular deals with the effect that different need applications may have on the way an innovation develops, giving examples of material innovations that have developed from different needs. Material producers will probably have to search for users of new materials unless they have developed the material for one positive need customer alone. The question, "is it necessary to search for users?" is answered, as is the question of whether the material producer should aim initially at substituting the new material into existing products or aiming it at new products alone. The search techniques that are available to material producers in their quest for product users are many and varied, and a contrast between those which are thought to be used and those that are actually used is highlighted. Those search techniques that are actually used meet with varying degrees of success and these again have been highlighted by reference to the cases.

5.2 DEVELOPMENT OF CASE HISTORIES

It has been clearly shown that case histories of material developments - even those dating back to the eighteenth century - offer a pertinent means of studying the material innovation process (see Chapter 4.6.3). Many studies have been carried out (see Table 4.10) but few provide a microscopic insight into the firm's efforts of finding new uses for the material. Those studies that offer micro details, although few in number, should be highly regarded for they allow a close inspection of the material producer's efforts in introducing his material.

The compilation of detailed case histories is a time consuming business and, if, as has been found whilst compiling some of the older cases, the people directly concerned with the innovation during the early days are not available then there is another problem, and this is to actually find a source of information. The information sources for the authors' case histories are described in a prefix to each case, and may be found in Appendices A to D. It is rare to find a company that has kept records of its actions. This is probably because it requires a person being employed to document such things as enquiries, sales, contracts, policy decisions, people active in the innovation, information channels used, development work undertaken and so forth. Generally this is not done; the information may be available with some key persons for a while, but it is eventually destroyed either because the information was regarded as classified or simply to clear the filing cabinets. This naturally poses the question of whether a company introducing subsequent new materials will recall its experiences from previous new material launches. For those companies introducing materials on a regular basis this may not matter, but for those that introduce new materials only intermittently it might be a sad loss. Case histories, for all their faults, are the only documented source of information concerning innovations, and such histories should be regarded as "primary source material" (as Cahn points out) to benefit those with less experience of innovations.

5.3 THE PROBLEMS FACING MANUFACTURERS OF NEW MATERIALS

Unless a material has been developed with a specific application in mind - and there is evidence to suggest that few materials have the benefit of such an application - then there is automatically a problem for the material producer. That, as has been suggested by the author elsewhere* (1978a) is the identification of potential users. For the material manufacturer who is in this position, the problem is a very real one, being "faced with a complex search and match exercise" (see also Chapter 4.8). The material manufacturer does not know which properties of the material he should

* See Appendix F for copies of these references.

investigate in detail and may even be reticent to publish such information anyway. For the potential users part, he probably will not know of the materials existence, and in many cases will not know where to go for information regarding his material selection problem. This though, is a problem that industry in general has faced for many years - how should it keep up-to-date with material developments? The answers to this seemingly simple question have been hinted at by the author* (1978b) and treated in far greater detail by C. H. Starr during the late 1950's. Industry though, does not seem to have progressed very far between Starr's work and that of the author over the past twenty years. This again raises the problem that the material producer has - how to search out potential users for his new material.

The factors affecting the success of a new material are many and varied (see Chapter4.2). Sambell and Davidge, for instance, have suggested that a material will meet with success providing it is able to meet four different requirements:

- it must have adequate properties for a particular application
- the fabrication techniques must be acceptable
- it must be economically competitive
- political and social pressures of the day have to be met, i.e. a number of indirect factors should be considered:

* See Appendix F

(a) existing and future material resources

(b) effects on the environment

(c) energy inventory

Such factors will indeed play a part in the success or otherwise of a new material, but Sambell and Davidge have assumed that potential uses for the material have been found. Their study is based on the substitution of silicon nitride for a metallic super alloy (nickel/chromium/cobalt) for a high temperature engineering duty. It precludes the fact that at the outset, the material producer may not have a potential use for his material and that a search operation will have to be mounted to try and find such potential users.

Another problem, which is not always recognised by the material producer is of his own making, and that is, should he be a raw material producer or a finished product manufacturer? It is brought about mainly in those organisations not normally regarded as material producers. The larger organisations, specializing in material production - ICI (polyethylene), IMI (titanium) for instance - have remained firmly as the raw material producer (fabricator of wrought products in the case of IMI's titanium). This, despite the fact that they have frequently stimulated end uses by actually designing, manufacturing and field testing various products. Other companies - for example, Lockheed Missiles & Space Co. (Lockalloy), Ford Motor Co. (titanium carbide) - recognised they were basically finished product manufacturers. Consequently, as soon as they had developed the material to the point where they had proved its use in their own products, they handed over the commercial manufacture of the material to a raw material producer on a licensing basis. Presumably then, the search for alternative uses for the material is up to the licensed raw material producer. Still other companies - Advanced Materials Engineering (silicon nitride), Dunlop Ltd., (carbon/carbon) for instance - have run the middle route, being both suppliers of raw material and finished products. In the case of Dunlop though, there has been some confusion over the years on exactly what their policy should be on this point. There is argument for them to remain as finished product manufacturers on the basis that a greater contribution will be earned. But on the other hand there are those products and industrial sectors of which they have no experience, where other specialized organisations could turn the raw material into a finished product benefiting itself as well as Dunlop. This point has not been settled yet.

In mentioning the problem of raw material producer/finished product manufacturer it is as well to remember that there are six different product idea sources from which new materials might be employed (see Bradbury et al. model of innovation, Section 4.6.1).

Bradbury's innovation model (see figure 4.13) suggests that the product idea may occur in any of the following groups: end user, manufacturer, equipment manufacturer, manufacturer of intermediates, raw material supplier and supplier of ideas. It is worth noting that it is only the end user who can innovate without involving more than one organisation, whilst the raw material supplier has to involve at least three organisations. His communication problems to stimulate product innovations are therefore likely to be that much more difficult.

Whilst the characteristics of technologically innovative firms have been discussed previously (see Chapter 4.6.4), the four cases presented in this thesis (Appendices A, B, C, and D) have also shown some interesting facets of the innovation process. Some of these facets have helped the material producer along the innovative route, others have hindered, whilst still others merely provide interesting comment on the innovation. Table 5.1 summarises these points, and serves to indicate that all companies have something to learn when it comes to innovation.

5.4 HOW IMPORTANT IS THE NEED APPLICATION FOR MATERIAL INNOVATION

With material innovations at least - and probably with other types of innovation - it appears to be too simple to state that for success there should be a need. Two types of innovation - radical and incremental - have different bases. Most of the basic or radical innovations, which represent major technological breakthroughs are initiated by the discovery of an opportunity. This view is held by Globe et al, Langrish et al, Myers and Marquis and Tauber. Tauber sums it up like this:

"When large numbers of consumers can perceive a need for a product, it is usually a simple product improvement. Major innovations and the need for them are beyond the foresight of masses of people".

Table 5.1 Summary of Interesting Features noted in the Case Histories - Helps

Carbon/Carbon	Polyethylene	Silicon Nitride	Titanium
1. 'Chance' played a part in starting the development of the material at Super Temp. 2. Dunlop's brake technology exploited characteristics of material. 3. Promoter at director level pushed the development along. 4. Dunlop developed 3 interchangeable brake units for Concorde which helped to sell brake. 5. Dunlop concentrated resources on brake project and developed a successful unit. 6. Expertise brought into the company for developing the material and process. 7. External experts investigated market for other uses.	1. 'Chance' played a part in discovering polyethylene. 2. Inter-disciplinary search approach adopted for searching for uses and investigating properties. 10. Patents on processes and products were taken out as the manufacturing methods developed. 4. Submarine cable application came about by 'chance'. 8. ICI worked with go-ahead firms (TC & M) after experiencing very slow developments with initial organisations (CMA). 9. Development of uses took place by working in close co-operation with users during World War II. 7. Concentration on one product - cables - led to further uses downstream of market i.e. television and radio cables. 5. First use was substitutional i.e. polyethylene for gutta percha in submarine cables. 6. External experts were used to research the material. 3. Polyethylene was promoted at a high managerial level; P.C. Allen - the business innovator - and at the technical level - J.C. Swallow. 11. Polyethylene technology was licensed to other manufacturers.	1. External experts investigated the properties of the material. 2. Expertise of many organisations brought together in a consortium. 3. Some manufacturers employed external experts to research the market. 4. Publicity was given to silicon nitride by AME through selected journals, exhibitions and via technical salesmen.	1. Numerous enquiries for titanium from aircraft frame and engine manufacturers played an important part in ICI's initial interest in titanium. 2. Development of sponge and fabrication techniques split between divisions of ICI. 3. The Government placed a 4 year contract for titanium which convinced ICI to develop the material. 4. ICI concentrated on one user - the aircraft industry - that was able to justify high costs. 5. First uses were substitutional - titanium for stainless steel in non-structural aircraft parts - a policy which was also carried through to non-aersopace uses. 6. Organised publicity with titanium which included technical sales people, technical literature, exhibitions, abstracting service and in-house conferences. 7. In-house uses developed for titanium. 8. Successful in-house developments were patented. 9. Aircraft industry formed backbone of titanium development on which other uses grew. 10. A team of specialists was appointed to investigate potential uses in particular industries other than aerospace.

Table 5.1 (Contd) Summary of Interesting Features noted in the Case Histories - Hindrances

Carbon/Carbon	Polyethylene	Silicon Nitride	Titanium
1. Competitor industry in foreign country closed ranks on Dunlop to prevent Dunlop establishing technological lead with aircraft brakes. 2. Development of such a major product is politically sensitive internally and may cause friction between people (e.g. when technical staff were not invited to brake demonstration for customers). 3. Dunlop relied heavily on one customer -the aviation industry. 4. Dunlop suffered from a lack of marketing experience, not only with a new material, but for any product outside the aerospace industry. 5. Variability of properties in product slowed developments. 6. Failure to examine and implement economies of scale led to lost products. 7. Not invented (interested) here syndrome precluded product ideas being considered. 8. No inter-disciplinary team available to investigate products, instead there was a reliance on metallurgists. 9. Lack of project management and commitment to product ideas led to a failure to investigate product ideas fully -no promoters for non-aerospace products. 10. Communication barrier between laboratory and design staff. 11. There was considerable indecision within Dunlop as to whether they should be finished product manufacturers or raw material producers.	1. ICI had extreme difficulty identifying first use. 2. There was considerable indecision within ICI as to who should be responsible for the development of polyethylene and its sale. 3. The not invented (interested) here syndrome slowed the development of the submarine cable idea. 4. There was considerable indecision within ICI as to whether they should be finished product manufacturers or raw material producers. 5. ICI did not look at the benefit of economies of scale until after World War II, by which time the Americans were producing more polyethylene than ICI. 6. Du Pont (who had technical agreements with ICI) delayed publication about polyethylene to the world.	1. The inductility problem associated with silicon nitride has been insurmountable for many applications. 2. Claims of successful products often preceded the actual tests which unfortunately often failed. 3. A great deal of emphasis was placed on developments with gas turbines, when other uses may have been more easily attained (e.g. internal combustion engine components). 4. Engineers are very cautious when designing with brittle materials and little attempt was made to educate engineers in new design techniques. 5. Trials that were arranged for silicon nitride were only slowly followed up by the manufacturers. 6. The AME consortium suffered many management changes since its inception. 7. British Leyland pulled out of the consortium and left AME without one of its best potential outlets.	1. Titanium suffered with low creep strength but this only slightly deterred engineers from using it. They used it where temperatures were lower. 2. IMI relied on one customer - the aircraft industry - although this became unacceptable as defence policies were changed by the Government. 3. Even with the introduction of economies of scale in manufacture, titanium still remained very expensive, necessitating very cost effective applications. 4. IMI (as with most titanium manufacturers) ignored the possible use of commercially pure titanium for many years. 5. The fortunes of the UK industry have followed very closely those of the American industry, who closed ranks on British developments.

Table 5.1 (Contd) Summary of Interesting Features Noted in the Case Histories - Comments

Carbon/Carbon	Polyethylene	Silicon Nitride	Titanium
1. It took Dunlop 7 years between their initial search for a more efficient brake material and their actually manufacturing the material. 2. Dunlop were first to successfully develop the technology for aircraft brakes but others have reaped the benefit since. 3. Carbon/carbon was developed for use on a civil airliner (Concorde) before military applications. 4. The introduction of a new material such as carbon/carbon to the medical world as a possible prosthetic material can be very slow, not just because of lengthy trials, but also because many surgeons have their own prosthetic designs and are reticent towards others. 5. 'Chance' conversations in public houses were noted as a source for product idea generation.	1. ICI fixed a high price initially to prevent too keen an interest in the material early on.	1. It was a formal search by the Admiralty for suitable gas turbine materials that led them to study silicon nitride in depth. 2. A government body - the NRDC - played an important role in silicon nitride's development by licensing the technology to industry. 3. Although many of silicon nitride's properties were known during its early development, they were often presented in too casual a manner to engineers.	1. Titanium was first exploited by Rolls Royce who at that time were more renowned for civil aero-engines than military developments. 2. Although the Soviet Union market has been closed to the Western World, the USSR has been free to export titanium to the West (approx. 20% of free world's consumption in 1974).

However, the majority of innovations in industrial companies are of the incremental (improvement) innovation type, and they are the ones started by receiving information, which leads to a need recognition and this maybe triggers off the technological solution. It has been suggested, again by Tauber that the incremental type innovation diffuses more rapidly through society than the radical type. It appears to be safer, therefore, for industrial firms to go for the incremental type innovation even though the long term rewards may not be as great as for a radical innovation when it succeeds.

5.4.1 DEFINING NEED APPLICATIONS

For those innovations that are started by a need recognition be they incremental or even possibly radical - there appears to be a wide variety of need classifications. This fact does not seem to have been recognised by many students of the innovation process. Knut Holt (1974) may be an exception to this for he does admit that little has been done to investigate methods of assessing 'needs'.

As far as material innovations go, the material producer tends to seek those applications that will give a quick return whenever possible. This is borne out by many of the first "bread and butter" type uses being fairly straightforward product improvements - using more efficient materials. This study has at least shown that a material producer generally manufactures his material because there is a recognized need for it. It is the author's contention that there are at least two different need categories which make a material producer start making a new material - (i) a positive need and (ii) a projected need. However, a manufacturer can start producing a new material for other reasons, i.e. when he conceives there is a need. Still others produce materials when there is no need - some may say both of these fit the technology push situation. When the material is in production, as often as not the producer is looking for unforeseen needs. These five different need classifications have been defined below - Table 5.3.

Table 5.3 Suggested need classifications that an innovation may meet during its life cycle.

Need Classification	Definition
Positive Need	Occurs when a users product is either failing or cannot be made from any other material and needs the situation correcting rapidly.
Projected Need	Occurs when the innovator or some respected establishment (government or other institutional body) predicts there is a general (projected) need after examining the market, which will have to be fulfilled in the near future.
Conceived Need	Occurs when the innovator believes there is a need for his product, without ever examining the market.
No Need	The innovator produces his innovation regardless of the fact there is no need for it.
Unforeseen Need	This situation arises after an innovation has been developed and further, unforeseen applications come in its wake.

5.4.2 EXAMPLES OF INNOVATION THAT AROSE FROM DIFFERENT NEEDS

It has been suggested that material innovations come about for a variety of different need reasons. To illustrate the differences, the ten case histories examined in this thesis have been compared. Table 5.4 illustrates the different product ideas that led the material producer to believe there was a need for his particular material. Where possible, the first (1) and subsequent (2) major uses have been classified under the different need headings.

By way of explaining this table in more detail a summary of the materials first few applications is given:

Carbon/Carbon: (Source Appendix A)

From Dunlop's point of view - in common with other aircraft brake manufacturers - they had set themselves the target of developing a lighter, more efficient brake for the aircraft of the 1970's and 1980's. Such an objective led to a search for new materials. After several years development the company's projected need of the 1960's led to a positive need as they competed for Concorde brake contract with other manufacturers. Other manufacturers were developing carbon/carbon brake assemblies and to remain a viable supplier they had to do the same. The Dunlop carbon/carbon brake was successfully introduced on Concorde in the mid 1970's. Dunlop in the process of developing the carbon/carbon brake became manufacturers of the material and whilst developing brakes for other aircraft they have also been searching for other uses of the material. To date, none of major consequence have arisen - any that do are likely to be from unforeseen needs.

Table 5.4 Materials that were introduced for different need reasons and their success or otherwise.

(1) - First major product idea brought to fruition because of this need.
(2) - Subsequent major product idea brought to fruition mainly because of this need.

Material	Need Classification: Positive	Need Classification: Projected (a) by an external organisation	Need Classification: Projected (b) by the firm	Need Classification: Conceived	Need Classification: No	Need Classification: Unforeseen	First need came to fruition?	Subsequent need application came to fruition
Carbon/Carbon	1		1			2?	Y	N
Polyethylene			2		1	2	N	Y
Silicon Nitride		1	2	2			N	Y
Titanium	1	1	2				Y	Y
Silicones	1					2	Y	Y
Super Plastic Aluminium+			1				Y	
Rare Earths*				2?		2		Y
Titanium Carbide			1			2	N	Y
Lockalloy	1	1					Y	
Corfam				1	2		N	N

+ It is not clear from case history if subsequent uses have been found for super plastic aluminium.

* It is not clear from case history how the first application for the rare earths came about.

Polyethylene: (Source Appendix B)

Polyethylene was discovered by some ICI staff by chance. Although there was no obvious need for the material at that time, development work continued with it. Whilst ICI examined the market and projected there to be a general need for polyethylene in its waxy phase, the first major uses (submarine cables and then radar cables) were completely unforeseen by ICI. In both instances, it was an outsider who recognised polyethylene's potential as a dialectric for these applications. The users identified polyethylene - ICI did not identify the users.

Silicon Nitride: (Source Appendix C)

The Admiralty projected a general need for a suitable material for stator blades to withstand temperatures of 1200°C in gas turbines. The search for this material was carried out by staff at the Admiralty Materials Laboratory. Silicon nitride was chosen as the material offering the best potential. Other minor uses were conceived - thermocouple sheaths, crucibles and so forth - by AML, but the commercial development of the material passed out of their hands to the National Research Development Corporation. The NRDC licensed several manufacturers; unfortunately no major uses were forthcoming. A consortium - Advanced Materials Engineering Ltd., - was formed from the licensed companies and whilst some uses have been projected by the company, few have been successful.

Titanium: (Source Appendix D)

Whilst a projected need for high strength/weight ratio materials had been decreed by the Ministry of Defence for aero turbine engines, it could also be claimed that Rolls Royce Ltd. had a positive need for such a material to develop their engines. Indeed it was largely at their instigation that many of the titanium alloys were developed by IMI (then ICI Metals Division) for particular applications. Subsequent uses for titanium - outside the aerospace industry - were largely projected by IMI, by examining the market in the nuclear, chemical and medical industries.

Silicones: (Source Tanenbaum)

One of the first uses for silicones - heat resistant resins - came from a positive need of Corning Glass Works. They had just developed glass fibres and believed one outlet to be as a woven tape for electrical insulation to replace a similar cotton product. The cotton product had a tendency to char and glass fibres, it was felt, would overcome this problem. Unfortunately the resin which was used to bind the cotton and subsequently the glass tape charred at only a marginally higher temperature than the cotton - thus negating the benefit of the glass. Dr. J. E. Hyde who had just started work with Corning suggested a silicone compound that he had previously been working on. The resulting product from his studies was shown to General Electric Company, who in turn, started a study of organosilicone insulating resins. Of the other uses developed for silicones by Dow Corning -

high temperature lubricants and dielectrics, high strength and radiation resistant elastomers and biomedical applications - none can be classified in the positive need bracket. If anything they all fell in the category of unforeseen needs.

Although Corning Glass Works realised the potential of organosilicone products after developing the resin, the development work they undertook was of a very general nature - "do anything that looks interesting and which seems likely significant", was the brief given to the research staff. They first developed ethyl silicate for gluing glass blocks and then worked on many of its derivatives. From their investigations with aliphatic silicates they noticed that many of the reaction products were high viscosity fluids with odd temperature/viscosity relations (unlike most oils the viscosity did not drop as temperature increased) and they were inert to oxygen. It is claimed that Dr. McGregor (one of the researchers) realised the potential and mentioned his work to a friend at the Pittsburgh Chemists' Club Meeting. The friend was an employee of the Mine Safety Appliences Company and as chance would have it they were looking for a suitable fluid for oxygen pumping systems - an unforeseen need. The subsequent trial work that was done showed organosilicone materials served extremely well.

During the ensuing work with pilot plants and some fundamental work on the oxygen stability of organosilicones, they noticed that many of the fluids became resinous and

and rubbery. Investigations into these materials revealed that they had excellent dielectric properties. Now Corning Glass did not have the resources to explore the potential of these materials fully and approached Dow Chemical Company to pursue the research jointly. Whilst Dow Corning Corporation was being formed in 1943, Admiral Rickover learnt of the silicone dielectrics. Stemming from his recommendations Dow Corning were able to build a complete plant and provide silicone dielectrics as an insulating material in submarines and aircraft during World War II - an unforeseen need?

The silicone elastomers were not quite so unforeseen. Dr. Warwick - another of the researchers - continued investigations into the properties of methyl silicone polymers, many of which had properties similar to natural gums and rubbers. After talking with fellow workers at the Mellon Institute (where much of the research was done) he reacted silicone compounds with benzoyl peroxide, on their suggestion - not expecting anything startling. However, after many trial and error experiments the silicone material did gain rubber-like characteristics including improved strength. This work eventually led to patent US 2,460,795 for the vulcanization of liquid silicone polymers in 1944. It was not until a Dr. G. C. Akerlof - a fellow member of the Mellon Institute - asked for a silicone resin membrane for separating oxygen from air that the more remarkable properties of silicone were discovered. He was given some material that had been on the shelf for some time which contained a finely divided silica filler. Upon vaulcanization under high pressure this mixture gave a rubber with remarkable properties - including exceptional strength. As a result of this, more work proceeded on filters in silicones at Dow Corning, until the high strength silicone elastomers were developed to compete with polyester rubbers. This is perhaps the only class of silicone that can be regarded as being projected by Dow Corning (at least from this case history), though the final solution was pointed to by an outside source.

The radiation resistant rubber development, perhaps follows more directly the unforeseen need criterion. It was not until a Professor from Pittsburgh University visited Mellon with a request for various compounds for some irradiation studies that this property was discovered. He was given some vulcanized and unvulcanized material, and found that on completing his studies the unvulcanized silicone had become vulcanized. This led to further studies by the Dow Corning researchers themselves, eventually giving radiation resistant rubbers - yet another example of a fortuitous need arising which could not be foreseen.

To complete the story, the biomedical applications for silicones arose after surgeons began requesting samples of the material moulded to specific shapes. The high strength rubbers had by this time been commercialised - late 1950's. As a result of the work by many of these surgeons it became apparent that silicones were biocompatible. Even though sales were not expected to be large Dow Corning decided practical benefit would come of this research and in 1958 they set up the centre for Aid To Medical Research to help develop these unforeseen uses for silicones.

Super Plastic Aluminium: (Source Buchanan, J. A. F.)

In 1966 physicists and metallurgists at Tube Investments' Research Laboratories, Hinxton Hall, recognised from the literature that super plastic forming of complex components was now possible, and that there might be some benefit in it for TI. Although a small research project was started - with the aim of understanding the metallurgical micro-structure which gave super plastic properties - it was not until a competitor, Pressed Steel Fisher, announced 'Prestal' (a zinc aluminium eutectoid alloy) for car bodies, that TI first realised the potential developments. Their research was then directed towards more practical ends, and whilst developing sheet metal for formability trials, they also carried out their own marketing study. This study enabled them to project a need for super plastic aluminium and encouraged them with their technical develop-ments. The development programme was for forming machinery - as there was nothing suitable available - and for the material itself. By September, 1973 the decision to build a plant had been taken and by July of 1974 the first plant of Superform Metals Ltd. was operational. The case history given by Buchanan does not give enough detail to say what applications were first developed, or indeed how subsequent applications have been found. It is clear, however, that the material developed by them was brought to commercial production because they projected a need for it through their marketing study.

Rare Earths: (Source Langrish et al)

When thorium oxide* was first used for gas mantles in 1891 the so called rare earth metals became more widely known since they were found in the raw materials used in the gas mantle industry. The development of this industry provoked a search for applications for the rare earth by-products of the thorium extraction process. One of the first uses found was for Mischmetall - a German coined phrase - which is a mixture of rare earths, purified, compounded and alloyed with iron. It was (and still is) used as the 'flint' for gas lighters and later cigarette lighters. Langrish's history does not make clear how these first uses came into being from the need point of view.

Nothing spectacular happened on the application front for rare earths for many years. It was not until the 1940's - when work on the atom bomb in the United States led to the discovery that n-tributyl phosphate (TBP) was useful for metal extraction and could be used for rare earths - that other potential applications came to be thought of. Further Atomic Energy research in this country led to a solvent extraction process for the purification of uranium in 1941. Again on the nuclear front, it was suggested that neutron bombardment of thorium would give the fissile isotope, uranium 233. It was thought that after a reactor containing thorium had been started with uranium, it might produce enough U233 for the reaction to sustain itself with the

* It was actually a mixture of thorium oxide with 1% cerium oxide.

addition of thorium alone. Thorium was therefore classified as a strategic material. The atomic energy agencies were later to give contracts to people looking for rare earth applications but it would appear that little success was achieved.

Another war time effect was the projected need for high strength/weight ratio materials. This led to mischmetall being used in magnesium alloys for some of the early development work with the jet engine. The demand for applications in the war changed the rare earth industry from an impoverished state to one with promise.

However, the unforeseen need applications that were to profit Thorium Ltd. were still many years away. Thorium Ltd. had been in existence since 1914 and was owned 50/50 by ICI and Howard & Sons of Ilford. Following the war time developments a very large research effort was devoted to thorium and the rare earths. This was particularly to develop an industrial scale thorium extraction process for nuclear fuel. In the event thorium nuclear reactors were never developed and the research team did not find any new uses for the materials. Following the sale of Thorium Ltd. to Rio Tinto Corporation and Dow Chemi International, the research department (with a new research team) moved to Widnes. A new extraction process was soon developed using versatic acid. However, apart from some research into polishing powders for telescope glasses no application research was carried out during the 1950's. Instead they relied on making samples of compounds available to anyone in the hope that new unpredictable markets would develop. The Government even stepped in and sponsored some research but still no application was developed.

It was not until the 1960's that outside researchers began investigating rare earths for novel effects, that any major developments occurred. Their studies led to a substance, yttrium orthovanadate being developed which was activated by europium and gave a superior red phosphor for colour television. The publicity surrounding this led to other devices being developed e.g. microwave devices and lasers. Surely these were unforeseen needs.

Throughout Thorium Ltd.'s history the company has kept faith with thorium and the rare earths believing (conceiving) a future need would someday arise. Their faith eventually paid off but it is probably as well to be aware that they had had as a mainstay market the specialised glass and ceramic glasses where these materials were used as additives.

Titanium Carbide: (Source Tanenbaum)

Following World War II, the Ford Motor Company in the United States re-organised the company and formed a corporate R & D activity as an adjunct to corporate engineering. The organisation structure was based on field oriented departments - physics, chemistry, engineering mechanics, metallurgy and so forth; plus a department devoted to the development of gas turbine engines.

The company had projected a need for developing ceramic materials for gas turbine development and set up a research team under Dr. Mr. Humenik - who had done previous post-graduate research with ceramics - on a long term research project. This was in the early 1950's.

They investigated TiC-Ni systems and TiC-Ni-Mo systems, but by 1954/55 "the gas turbine project had progressed to a state of development where the possibility of introducing a new cermet material was minimal". However, Humenik and his co-workers recognised that the titanium carbide material was showing a hardness far greater than the tungsten carbide-cobalt systems, and suggested it might be useful as a cutting material.

In 1955 a TiC-Ni-Mo material was submitted for evaluation on machinability tests. Initially the material showed plastic deformation but with greatly reduced flank wear. Within three months a suitable, modified composition showed improvement - even over existing commercial materials. A three year development programme followed, which led to Ford's decision to exploit the cemented titanium carbide commercially. The first operation was the immediate introduction of TiC tools in the company's manufacturing operations. Ford also decided that the tools would be manufactured within the company until licenses could be arranged with outside organisations.

The research staff were given the task of developing the necessary production facilities, which became operational in 1959. Humenik undertook the task of introducing the material into the manufacturing operations at Ford direct from the laboratory. The introduction of TiC was regarded as a successful innovation and by 1961 a patent on TiC had been issued. Following this, outside firms were contacted and granted licenses to manufacture the material both to Ford and the general market.

So whilst the first projected need for a new material in gas turbines came to nought, the unforeseen need of cutting tools proved to be successful.

Lockalloy: (Source Tanenbaum)

Lockalloy is a beryllium-aluminium composite alloy developed by the Lockheed Missiles & Space Company by 1962. The history of the metal started during World War II. It was a Department of Defence objective that low density, high stiffness, high strength alloys should be developed for military aircraft and aerospace system. (i.e. a projected need).

Between 1946 and 1949 the American Bureau of Aeronautics (Navy Dept.) sponsored research to increase the stiffness (modulus) of aluminium alloys by the addition of beryllium. The first alloys developed were very stiff ($E = 20 \times 10^6$ psi.) but they had low ductility and their strength was less than commercial aluminium alloys. Because of this, and also because of problems of getting beryllium due to its use by the AEC as a moderator in nuclear reactors the research ceased.

However, the AEC instigated research for the production of beryllium in massive form and also an investigation into the properties of beryllium and its alloys. Beryllium became commercially important by the 1950's in the atomic programme, but it was precluded from non-nuclear applications because of (i) the AEC requirements (ii) its extreme brittleness (iii) its toxicity and (iv) its high cost.

In 1954 the American Society of Metals and the AEC sponsored a beryllium conference, the proceedings of which were published in 1955 making much information about beryllium available to the public.

As handling techniques for beryllium became safer and the AEC's needs for it reduced, other organisations again took an interest in it. Micks and Hoffman of the Rand Corporation issued a report to the Air Force emphasising the advantage of beryllium for use in aircraft and missiles, for structural and nose cone applications. The Department of Defence consequently sponsored further research and as a result beryllium became a contender for nose cone applications due to its high temperature thermal properties. Another organisation - AVCO - was investigating methods of brazing beryllium with silver. This was successfully demonstrated and patented by J. B. Cohen in 1958. His results were published in the Transcripts of the AIME in February 1960 and showed that ductile beryllium-silver alloys could be produced.

Unfortunately, the fortunes of beryllium then went into decline as:-

: beryllium was phased out of nose cone applications as ablative materials came to the fore.

: the Air Force showed no interest in the beryllium-silver results.

: AVCO stopped the funds in favour of other programmes.

: strong materials for aircraft frames were recognised to be of secondary importance in comparison to nose cones.

: Cohen left AVCO.

Nevertheless, whilst work had been proceeding at AVCO, so also the Armour Research Foundation had been investigating the development of ductile beryllium alloys - supported by the Bureau of Naval Weapons. Their work was reported at a NASA research advisory meeting in 1960. Lockheed was represented at that group - and forms the background to their involvement.

In 1960, Lockheed had positive need of materials that had a high modulus. One of their internal studies had shown that a weight saving of one pound in missiles was worth investing $20,000 in R and D. The current literature pointed to a possible solution in ductile beryllium alloys and the decision to back a research programme to investigate the material was made. Note, no DOD funds were used. By 1962 they were capable of producing beryllium sheet for space craft skins, having invested in both in-house research and subcontracted some research with an outside laboratory who was a leader in beryllium technology. The feasibility of a large scale laboratory process had been demonstrated by the end of 1962. Lockheed, who did not regard themselves as basic material producers then decided to look for licensees to make the Be-Al alloys. In September 1963 an agreement was reached with Dow Metal Co., though they are not now making the alloy and the Beryllium Corporation.

So, whilst the DOD had initially projected a need for high stiffness, high strength/weight ratio materials, it was Lockheed with a positive need who turned the initial studies with beryllium into the reality of Be-Al alloys, enabling them to win space craft contracts. The case history does not indicate whether either Lockheed or Beryllium Corporation have been successful in looking for other applications, so subsequent need classifications are unknown.

Corfam: (Source Robertson)

The Corfam case is a story where the manufacturer, Du Pont, appears to have done everything right at first glance - they carried out a market appraisal, developed a material with good properties, encouraged trials with both manufacturers and end users - and yet Corfam is now held up as a prime example to illustrate how a company should not innovate.

Corfam was the name given to a synthetic leather - a permeable polymer sheet - which it was thought would replace leather for shoe uppers in the footwear industry. Corfam began life at Du Pont's Central Research Department in the 1930's, when they developed a method for making mircroporous polymer films. This was apparently directed at the packaging and textile industry. Nothing happened on the Corfam front though until the 1950's when Du Pont's economists forecast there would be a need for a leather substitute for shoe uppers. This was based on the population growth and the increase in the proportion of people wearing shoes. Perhaps added to this was the forecast of synthetic foods becoming available and therefore a likely decrease in the number of cow hides available. Their forecast was based on leather being the main rival to a micro-porous synthetic substitute, quite wrongly as it turned out; it was the non-porous synthetic vinyl coated fabrics made by Du Pont themselves which rivalled Corfam.

During the early 1950's much research and development work went on to develop a suitable substitute very similar in properties to leather. During 1956 and 1957 the materials were field tested and by 1960 Du Pont were ready to commit themselves to production. They were encouraged no doubt by the fact that leather had hit an all-time high price.

In response to this onslaught the American tanning industry responded rapidly, developing scuff-resistant, tough, durable leathers - all properties that Corfam had. Du Pont though went to great lengths to convince footwear manufacturers that Corfam was going to succeed. Two hundred shoemakers were encouraged to make 16,000 test pair of shoes and these were given to a wide cross section of the population to test. Although the user tests proved satisfactory there were technical problems with the makers, because their machinery could not handle a tough unyielding Corfam like it could soft leather. And the retailers were not inclined to push Corfam - they were after rapid turnover, generating big profits, and they found it extremely hard selling Corfam because of customer resistance.

Some problems did not come to light until after Du Pont had launched Corfam in 1963. For instance, the material did not have the natural 'stress decay' of leather which meant they would not 'break in'. However, sales were rising rapidly in 1964 and Du Pont was able to over-ride this problem. Areas that they could not over-ride however, soon became apparent for example styles changed and women's shoes became 'open'. No longer was there a need for a permeable porous material. Shoes in Europe were repaired when heels or soles needed replacing - unlike those in America. And when the cobbler came to repair Corfam shoes all sorts of problems arose, which more often than not led to the shoe being ruined.

Even though many other companies entered the field with synthetic leathers none have succeeded, and Du Pont themselves eventually pulled out. The reasons were probably that costs remained too high, leather fought back, the properties of the material were too good for the intended market segment, the market did not expand and finally Du Pont's own vinyl coated fabric maintained its share of the market.

For Du Pont then, they would probably claim they conceived a need for a substitute leather. Their conception unfortunately was wrong and Corfam has not gone on to find any other uses.

It can be seen from the forementioned cases that the first applications that succeeded were due in the main to a positive need on the part of the user, e.g. carbon/carbon - brakes by Dunlop, titanium - aero engine components by Rolls Royce, Lockalloy - space craft skins by Lockheed. In these instances the applications had been projected by an organisation external to the material manufacturer i.e. Dunlop, who at that time were not producing carbon/carbon, foresaw its use in brakes; Rolls Royce projected titanium's usage in aero engines; and the American Department of Defence projected a general need for high stiffness, high strength/weight ratio materials, which resulted in Lockalloy.

The first applications that were projected either by the material producer or some other organisation were generally not so successful e.g. polyethylene in its waxy phase, silicon nitride in gas turbines, and titanium carbide in gas turbines. Super plastic aluminium is an exception here with Tube Investment projecting its successful usage.

Those materials for which there was no initial need (i.e. polyethylene) or for which the producer conceived there to be a need (i.e. Corfam) met no success in developing successful first applications.

Whilst some of the subsequent uses for the materials were projected by the manufacturers, many of the successful applications arose from unforeseen needs introduced to the material producer by potential users and came about in many instances by chance. For example, submarine and radar cables were both uses thought of for polyethylene by external organisations; silicone usage in oxygen pumping systems, as an insulating material, as a radiation resistant rubber, and in biomedical applications were all thought of by external users; similarly for the rare earths being used as a red phosphor in colour televisions. Titanium carbide on the other hand provides an example of an unforeseen need being generated within the producing organisation, when cutting tools were developed after Ford workers recognised the material's superior hardness to other cermets.

Such examples serve to indicate that many of the major uses for a material are developed not by the material producer, but by an external organisation with a positive need of some characteristic of the new material. Many of these product ideas are completely unforeseen by the material producer and are brought to his knowledge by chance in many instances. This suggests that information about the new material should be made as widely known as possible rather than restricting product idea generation to in-house people.

5.5 THE SEARCH FOR USERS OF A NEW MATERIAL

5.5.1 IS IT NECESSARY TO SEARCH FOR USES?

As has been shown in an earlier section, some of the companies that have developed a new material have not actually had the responsibility of searching for other users. For them - Ford with Titanium Carbide and Lockheed with Lockalloy for example - it had been sufficient to produce a material that fulfilled a function for one of their products or processes. Then because they did not regard raw material manufacture as any part of their business they have licensed their technology and know-how to other companies who are in the business of producing materials.

Other companies which have developed a material because of a positive need from an outside user, or because there was a projected need have had to search for new users. IMI for instance mounted a quite intensive search for titanium users outside of the aerospace industry, mainly because of the problems that reliance on one particular customer (or industry) brought, i.e. demand fluctuating depending on the fortunes of the user. Most companies who are in the business of producing raw materials have found themselves in the position of having to search for users of their material at one stage or another, if not continuously. Another example, not cited in the cases here, was that of International Nickel. They were supplying nickel during the First World War and going from strength to strength with the demand for armaments. With the arrival of peace however, their sales dropped dramatically to a quarter of the war time level. It was then that the company set up one of the very first industrial marketing teams "to foster the development of new nickel-consuming markets such as electroplating, manufacture of stainless steel, etc." (Weston).

So in answer of the question "is it necessary to search for users?" it must be said that for material producers the answer is almost certainly 'yes'; whilst for those companies whose business is other than material production the answer is probably 'no - try to license the manufacture to others more able'.

5.5.2 DO NEW MATERIAL PRODUCERS AIM TO SUBSTITUTE THEIR MATERIAL OR FIND NEW PRODUCT USES?

Rothwell (1977) has shown that the radical type of innovation in the textile machinery industry has offered the most dramatic increases to productivity, whereas in the fork lift trucks and portable power tool industries innovations tend to be of the incremental nature. And from the evidence gathered in these cases it would appear that though a new material might in itself be a radical innovation for the producing company, seldom is it used in a radical innovation by the early users. Does this mean that the adopters of new materials do not use them in new products? The answer in most cases must be that the new material is generally substituted for another less efficient material, be it for mechanical or financial reasons - or both. Examples of this abound from the cases:

(i) carbon/carbon was substituted for cermets in aircraft brake linings.

(ii) polyethylene was substituted for gutta percha as the insulating material in submarine cables.

(iii) silicon nitride was substituted for alumina in welding nozzles.

(iv) titanium was substituted for: light alloy and stainless steel skins in the Bristol Britannia, stainless steel springs, valves and nozzles in nitrogen and oxygen compressors, and for cupro nickel tubes in heat exchangers for power stations.

(v) Silicone resins were substituted for other resins in glass tape electrical insulations.

(vi) titanium carbide was substituted for tungsten-cobalt systems in machine tools.

(vii) Lockalloy was substituted for light alloys in missile applications.

There are of course instances where new materials have been used for radical innovations that have been successful:

- polyethylene for radar cables
- silicone elastomers in biomedical applications.

Others have been unsuccessful, notably, carbon fibres in the Rolls Royce RB.211 engine - the first three shaft high by-pass ratio turbo fan developed by an aero engine manufacturer. Not so well known, is the disaster that Pressed Steel suffered when they demonstrated their superplastic zinc alloy Mini: its creep strength was poor and the body work sagged (The Financial Times, Carbon Fibres: The Tale of a "Wonder Material", 12th October, 1977).

Most manufacturers of new materials admit to looking for those uses where they can substitute their new material. Beginning in a small way and building up the users' confidence until the material has gained some sort of support, and then going on to build more adventurous products with it. In actually developing these substitution uses, the material manufacturer often has to be prepared to analyse the material's properties in great detail. IMI did exactly this with titanium when entering chemical, paper pulp and bleaching, metal finishing, power generation, medical and automotive industries. To influence the potential user, IMI had to know how the material would handle in various corrosive environments, and foresee its fatigue resistance for instance.

On the basis of limited evidence the author would propose the hypothesis that most new material innovations are used in incremental type product innovations until they have gained social acceptance (in the engineering sense).

5.5.3 A CONTRAST BETWEEN THE REAL AND IMAGINED SEARCH TECHNIQUES USED IN INDUSTRY.

For a material producer making a new material, ideas for new products have to be generated. Whilst "we must be rid of the (platonic) concept that the idea is all that counts, because it is the way in which the idea is used that transforms society" as Gaudin has stated, a material producer who agreed in principle would no doubt also counter that identification of product ideas for a new material can be very difficult, and is for him a very important part of survival.

Although "the origin of good ideas appears to be fairly random" (Finniston, quoted by The Institute of Metallurgists), there is considerable evidence to suggest that most ideas that are successfully developed come from outside the firm*. Utterback (1971) found that thirty two of the fifty nine pieces of information incorporated in new scientific and measuring instruments came from outside the firm that developed the idea. Of the 157 cases studied by Myers and Marquis, ninety eight of the ideas were instigated by information from sources external to the firm. Of the twenty five major product and process innovations studied by Mueller, fourteen originated wholly from outside the firm. Similarly, Langrish et al's study has shown that over sixty per cent of ideas for innovation come from outside the firm, and Table 5.5 below (reproduced from Langrish et al) indicates the method of transfer of ideas from outside the firm.

Table 5.5 Method of transfer of 102 important ideas from outside the Award-winning firm

From Langrish et al., 1972, p.79.

* See also chapter 4.9.1 and Chapter 7.2 for details of the information sources used by innovative firms.

It is immediately apparent from this table that the first three methods are not generally available for a material producer with a new material. B. J. Habgood who joined ICI from the cable industry and suggested polyethylene should be used to replace gutta percha in submarine cables, provides a good example of the first method, but it did not appear to be a common method with material producers. And common knowledge of a new material is something that takes several years to establish before an outside organisation can suggest potential products. Consequently only the last nine methods are available to a material producer if Langrish's study can be considered common to material innovation. If a material producer is to make the most of these external sources for generating product ideas it would be wise for him to understand the rules governing the circulation and adoption of ideas and know how to improve the flow, as Ferrari suggests.

In recent years much has been written about the methods that are available for generating ideas and Holt (1977) has compiled many of them in his book, referenced. He has suggested a number of tools that can be used in the idea generating process: intelligence-need related, intelligence-technology related, forecasting, development of creativity, preliminary study and project formulation methods. Only the first four of these can be used for actually developing new product ideas, the last two being screening processes for new ideas. Within these four categories, a total of twenty six methods are put forward by Holt as means of generating ideas. Most of the methods sound very theoretical and one wonders whether industry does indeed use any of the methods. Holt admits that only two are in general use by most companies and those are the employee suggestion system and work simplification methods. Table 5.6 summarises the methods available and the source of reference for further information on them.

One of the few companies that has published information on how new product ideas were generated is Climatrol Industries Incorporated. Climatrol's business is the development, manufacture and selling of heating, ventilating, air conditioning and refrigeration equipment. Yousoufian reported that Climatrol used a product versus market search matrix to search for new product ideas within the companies' objectives, and identify those areas where the company was lacking in its product range. Having identified potential new products, they then used a brainstorming technique to suggest possible solutions to the product ideas.

However for material manufacturers with new materials the search procedure for new product ideas seems to be very different. From the limited evidence gained from the case studies, the methods used to generate new product ideas - or more precisely the sources of new product ideas - are likely to be far less sophisticated than suggested by most of the literature. Table 5.7 shows the source of some of the product ideas for eight different new materials*. Not all of the sources listed have led to new products and

* Some of the product idea sources have previously been mentioned by D. W. Karger.

Table 5.6 Twenty-six methods that can be used to generate ideas.

The methods are summrise by Holt in his book - Production Innovation - but a more detailed account of the methods can be gained by reference to the authors listed in Bibliography.

Intelligence Need-related	Source	Intelligence Technology-related	Source	Forecasting	Source	Development of Creativity	Source
1. Need Confrontation	Holt 1975	1. Surveillance of Technology		1. Scenario	Kahn 1966 Durand 1972 Rhyme 1974 Gregory 1972 Twiss 1974 Jantsch 1967	1. Creativity Tests	Taylor and Barron 1963
2. User Observation	Holt 1975 Hake 1971	2. Development of Technological Competence		2. Delphi Technique	Helmer 1966 Claude and Morize 1972 Gregory 1972 Twiss 1974 Jantsch 1967	2. Climate Measurements	Tagiuri 1968 General Electric 1969 Holt 1971, 1973 and 1972a
3. User Contacts	Kelly 1968 Holt 1975	3. Surveillance of Resources	Kelly 1968	3. Trend Extrapolation Technique	Cheaney 1966 Ayres 1968 Martino 1972 Gregory 1972 Twiss 1974 Jantsch 1967 Gorle and Long 1973	3. Morphological Technique	Ayres 1969 Zwicky 1969 Geschka 1973 Gregory 1972 Twiss 1974 Jantsch 1967 Holt 1973
4. Surveillance of Competitors	Kelly 1968 Holt 1975	4. Industrial Espionage	Hamilton 1967 Kelly 1968 Wade 1966	4. Relevance Tree Technique	Esch 1965 Cetron 1969 Gregory 1972 Twiss 1974 Jantsch 1967 Gorle and Long 1973	4. Brainstorming	Parnes and Harding 1962 Parnes 1967 Hake 1971 Gregory 1972 Holt 1973 Twiss 1974 Jantsch 1967
5. Surveillance of Government Regulations				5. Systems Dynamics	Forrester 1961 Derviniotis 1973 Gregory 1972 Jantsch 1967	5. Forced Relationship Technique	Parnes and Harding 1962 Parnes 1967 Holt 1973
6. Surveillance of Market Sectors	Kelly 1968			6. Structural Models	Wonnacott and Wonnacott 1970	6. Synthetics	Gordon 1961 Prince 1970 Gregory 1972 Geschka 1973 Twiss 1974
				7. Cross Impact Analysis	Enzer 1969 Helmer 1972 Gregory 1972 Twiss 1974	7. Eclectric Approach for Creative Thinking	Holt 1973
						8. Work Simplification	Maynard 1963
						9. Suggestion System	Maynard 1963 Ekvall 1971

TABLE 5.7 Source of Product Ideas for New Materials.

+1 source led to successful product. -1 source did not lead to a successful product.
0 not known whether successful products have been derived from these sources.

NEW IDEA SOURCES:	Carbon/ Carbon	Polye-thy-lene	Silicon Nitride	Tit-anium	Sili-cones	Super Plastic Aluminium	Rare Earths	Tit-anium Carbide
WITHIN THE COMPANY Research Team - responsible for invention /development.		-1	-1		0		-1	+1
Inter-disciplinary R & D Team.				0	+1	0		
Inform other divisions of Company - Do they have any ideas for uses?	-1	0		0				
Designate certain divisions within the company to develop material characteristics, i.e. moulding, extruding, machining, etc.		+1		0		0		
Marketing Groups		0	0			+1		
Company Salesmen		0		0				
Professional Associates								
Plant Personnel								
Design Personnel	-1							
Search area designated to various individuals and made responsible for product developments.				+1		+1		
OUTSIDE THE COMPANY Professional Associatas	+1							
Consultant Inter-disciplinary team.								
Information given to a well respected representative who is in frequent contact with potential user firms.		+1						
Present Papers : At Technical Meetings	0	0	0	0				
: In well read, general technical journals.	0	0	0	0				
Articles in professional and trade journals.	0	0	0	0			+1	
Material manufacturer produces an abstracting service - available to interested parties.				0				
Produce Handbooks and guides for material user.				0				
Invite technical journalists to a symposium at which the material's characteristics and potential are put forward.			0	0				
Tour all likely exhibitions, seminars, lectures, etc. to discover current thinking.				0				
Show material at relevant exhibitions - where it is thought material will have potential.	0		0	0				
Present material on T.V.								

TABLE 5.7 Source of Product Ideas for New Materials (Contd.)

NEW IDEA SOURCES:	Carbon/ Carbon	Polye-thy-lene	Silicon Nitride	Tit-anium	Sili-cones	Super Plastic Aluminium	Rare Earths	Tit-anium Carbide
OUTSIDE THE COMPANY (Contd.)								
Discover what other companies in the world have introduced or are developing.	+1	-1		0		+1		
Enquire of chief engineers and buyers what features of present equipment are unsatisfactory or what new features could usefully be introduced.	-1							
Customers	-1		+1		0			
Distribution Channels		0						
Inventors	-1	+1						
Friends					+1			
Research Centres, Professional R & D Companies.	-1	+1,-1	-1		+1		+1	
Sales Representatives from other companies.								
Advertising agency Personnel.								
Government Personnel	0	+1	0		+1			
Equipment Manufacturers								
Professional Marketing Firms.	-1		-1					
New Product Announcements	0	+1		0				
Public utility companies interested in area of commercial development.								
City, County and State industrial development commissions/Government agencies.							-1	
Trade Associations interested in specific areas of industrial activities.								
Organisations and individuals available to search plant records for developing areas.								
Commercial Bankers directing new product financing activities.								
Company Acquisition.			0					
Licensee or Licensor.		+1	0					
Fabricator/Customer Group - for a material producer there might be a third party (fabricator) who converts the raw material to a finished product and then sells to customer.		+1		0				
Companies with whom technical agreements are in force.		+1	0	0	+1			
Samples provided to interested parties allowing them to investigate material and suggest use.	0	+1	0	0	+1		0	

of those that have been used, some have led to successful products for a particular material whilst for another material they have been unsuccessful sources. Of the ten sources listed within the company eight have been used by one material or another, and of the thirty six sources outside the company, twenty six have been used.

5.5.4 A CONTRAST BETWEEN THE SUCCESS AND FAILURE OF THE REAL SEARCH TECHNIQUES USED BY MATERIAL MANUFACTURERS

As can be seen from Table 5.7 some of the idea sources have led to successful products for some materials but not for others. To illustrate the difference some of the sources are compared below:

- Research team responsible for invention/development.

Polyethylene: The five team members responsible for the invention of polyethylene at ICI - Swallow, Perrin, Manning, Williams and Paton - all thought of the material only in terms of its waxy phase, i.e. as a superior paraffin wax. As such the uses would have been in candles, waxed paper, polishes, etc. None of the major uses stemmed from the suggestions of the invention team.

Titanium Carbide: Dr. M. Humenik led the team responsible for the development of titanium carbide at Fords. Almost certainly Humenik was aware of developments with cermets in general, and in particular with the fact that tungsten carbide-cobalt systems were being used for cutting tools. In realising that TiC had a greater hardness than WC-Co, it must have been apparent to Humenik that TiC could be of use as a cutting material.

- Discover what other companies in the world have introduced or are developing.

Polyethylene: At one stage ICI were prepared to exchange information with I. G. Farben Industries of Germany for information on some new resins that IGF had developed. IGF were at the forefront of resin technology at this time (early 1930's) whereas ICI were lacking in this area. However, ICI eventually decided that polyethylene was far too important to trade information like this and pulled out of the discussions.

This cannot truly be classified as a search for new product ideas for polyethylene, rather it was a search by ICI for a new material product line for themselves. It did not, however, lead to new product ideas for polyethylene or indeed to a new resin product.

Carbon/Carbon: After Dunlop had heard that a new structural carbon had been developed in the USA they sent a representative to America to visit all the carbon manufacturers. As a result of this Dunlop ended up with sample discs of carbon/carbon from several manufacturers which allowed them to investigate the potential of the material for aircraft brake discs. After analysis and some trial work carbon/carbon (manufactured by the CVD route rather than the resin route) was chosen, and it went on to replace the beryllium brakes that had only recently been developed for Concorde.

Super Plastic Aluminium: As a result of Tube Investment learning that Pressed Steel Fisher were introducing a zinc-aluminium eutectoid alloy 'Prestal' for motor car bodies, they themselves directed their own research work on super plastic aluminium towards more practical ends.

- Customers

Carbon/Carbon: Even though Rolls Royce (1971) Ltd. are one of Dunlop's main customers for aero engine control equipment, no use for carbon/carbon has yet been developed with them. That, despite the fact that Rolls Royce have shown interest in the material and have suggested possible uses. Rolls Royce never pushed the potential uses very hard and Dunlop did no development work on the uses, since they were considered to be too long term in nature and would not represent major products to the manufacturing unit.

Titanium: Close co-operation between Rolls Royce and ICI Metals Division (now IMI), led to the development and introduction of several titanium alloys for use in Rolls Royce engines. Rolls Royce specified the properties they required for a particular application and IMI began preparing suitable alloys that would do the job for them.

- Inventors

Carbon/Carbon: Dr. MacLeod, inventor of a heart valve tried to interest Dunlop in making the valve from carbon/carbon. Although the idea seemed sound enough, no valves were ever made by Dunlop and very little development work was done.

This was probably due to management's unfamiliarity with the medical world - an area that Aviation Division had no experience of.

Polyethylene: Sir Robert Watson Watt, inventor of radar handed the transmitting details of RDF* to Metropolitan Vickers Ltd., who were already investigating polyethylene's electrical properties for ICI. They were able to link the product idea with the new material and radar cables were developed. Without polyethylene it is possible that radar would have been delayed for several years.

- Research Centres, Professional R & D Companies

Polyethylene: This was a case of a successful product stemming from one research centre, whilst nothing came from another. For while Metropolitan Vickers investigated polyethylene and developed the radar cables, the Cable Makers Association, who had asked ICI for the sole rights to develop electrical uses for polyethylene achieved nothing. ICI eventually broke off all contact with them and worked with more dynamic organisations.

Silicones: The development of radiation resistant rubbers did not come about until samples of vulcanized and unvulcanized rubbers were given to a visiting Professor from Pittsburgh University. Whilst carrying out his radiation studies he noticed that the unvulcanized samples became vulcanized. Further development work by Dow Corning led to the development of radiation resistant rubbers.

* Radio Direction Finding

Rare Earths: It was not until researchers outside Thorium Ltd. began to investigate the rare earths for novel effects that yttrium orthovanadate was developed. This provided a superior red phosphor for colour televisions and eventually led to other devices being developed - microwave and laser devices for example.

Such examples lead to a picture of some idea sources working for one company with one material whilst not working for others. There were also examples of similar idea sources working successfully and unsuccessfully within one company at one and the same time, and from the evidence gathered it is difficult to say which types of idea source are most effective. This is reflected not only in Table 5.7 but also in the fact that many of the companies associated with the cases had no record of where their product ideas originated. None of the companies apparently kept records of the effectiveness of their search operation. Most would have records of orders, but not of the source that led to the order. To judge the effectiveness of a product idea source is therefore not easy. The only logical thing to say is, "it all depends" - on whether people are in the right place at the right time; on bringing information about the material to those that are in need of it at the right time; on the potential user being prepared to adopt a new, unknown material, and so on, and that is not to mention its price, properties, fabrication techniques, etc. It all depends!

It cannot be predicted where a major product idea will come from. ICI's first major user of polyethylene, Telegraph Construction and Maintenance Company came about after J. N. Dean (owner of T.C.& M) read about polyethylene's development in ICI's Annual Report. Thus was born the submarine cable use.

There is no one source of ideas on which you can generalise. The only recommendation that can be made to a company producing a new material is that it should use all possible product idea sources that are open to it. Even when product ideas have been accepted as economically beneficial it does not automatically mean they will be accepted by the firm. Before that happens the product must face the whole organisation and the associated behavioural problems - see Chapter 4.3 for instance.

5.6 CHAPTER REVIEW

Because the innovation process experienced by material producers is not new, a case history approach was adopted to investigate particular facets of the process. The fact that companies have experienced many of the problems before, and that case histories of these can help the less experienced material producing innovator, was felt to be ample justification for pursuing the case histories. In all, ten cases were used to provide information about the innovation process.

The major problems facing a material producer with a new material were identified as knowing (a) how to find users for his material, and (b) which properties should be investigated. For those producers new to material production a problem could sometimes arise in actually deciding the implications of being a raw material producer or finished product manufacturer.

The 'need' application mentioned by so many authors as being a prerequisite for the success of an innovation has been discussed. Too little is known about the different types of need that can prompt an innovation, but at least five classifications have been identified with these cases: positive, projected, conceived, unforeseen and no need. An assessment of these different needs has been made. Those material innovations that are developed because of a projected need by an external organisation alone cannot be guaranteed, whereas those that are developed because of a positive need associated with a projected need are far more likely to meet success for the first application. Although materials might be developed successfully because of positive and projected need (by the firm) applications, the subsequent applications that are developed successfully are split fairly evenly between projected (by the firm) and unforeseen need applications.

For those companies whose business cannot generally be regarded as material manufacture, but who have nevertheless developed a new material, it is sensible to consider licensing the technology to a material manufacturer. If, however, the company wishes to remain as a material manufacturer some basic guidelines to consider would be as follows. Beware of reliance on one customer and search for new users. Most of the successful products that have used new materials have been substituted for older, less efficient materials. This appears to apply particularly when the material innovation was getting under way. A hypothesis has been proposed - but unfortunately not proven by this work that: most new material innovations are used in incremental type product innovations until they have gained social acceptance (in the engineering sense). Although recommended methods of generating new product ideas are well documented, it appears that very few material producers actually use the theoretical methods; preferring instead to stick to relatively unsophisticated but user oriented sources. However, even those sources are not always reliable; they have been shown to vary from material to material. In recommending a material producer to consider all of the idea generation sources that are available it is as well to be aware of the effects of the many different variables on the success of individual techniques, and of the difficulties in defining the most effective approach.

6

THE MATERIAL DECISION MAKER - HIS FUNCTION (ANALYSED BY INDUSTRIAL SECTOR AND COMPANY SIZE) - AND INTEREST IN INNOVATION

6.1 CHAPTER PREVIEW

It was assumed - before the survey, 'decisions on materials' - that there were individuals in industry, who had the task of deciding which materials were to be used in their company's products or process equipment. At the very least, the response to the survey has indicated that there are indeed people who recognise the title 'material decision maker'*, as one of their roles.

The function of this 'material decision maker' is, in many cases, much wider than just material selection. The function of such individuals appears to vary not only from industry to industry, but also according to the size of the company - as will be shown in this section.

Is there just one 'material decision maker' per company? - or is there a team of individuals from various roles who group together to make material selection decisions? Such questions, about the size of material decision teams will be answered. There are indications that in some industries, one individual - a material specialist, keeps track of material developments, and makes the decisions: whilst in other industries a group is formed to take these decisions. And the size of this group is not always constant - it may vary from product to product.

Innovation in the field of materials is important - but how does it compare with say, product or process innovations in terms of importance. The 'material decisions makers' from this survey have indicated that material innovations are indeed important - probably more so than is generally realised.

This chapter then, looks at (i) the function of material decision makers, (ii) the size of and nature of material decision teams and (iii) the relative importance of material innovations as indicated by the same 'material decision makers'.

---

* A material decision maker is defined as a person with the responsibility of making a conscious choice among alternative courses of action, in this case about materials; adapted from Kotler, see also 2.1.2.

6.2 THE FUNCTION OF MATERIAL DECISION MAKERS

A 'material decision maker' is that person with the responsibility of deciding which materials his company's products (or process equipment) are to be made from. He may well be the sole person responsible for such decisions - or equally, he may be one of a team who have the collective responsibility of material selection. This section will show that material decisions play an important part in product design and manufacture - and that the individuals taking these decisions have many different functions. It was anticipated (prior to the survey) that material decision makers would have responsibilities in engineering, design and buying roles (see Chapter 4.4). Whilst this has been vindicated, (more or less) material decision makers do come from more diverse areas of the company.

The results have been analysed from the replies of 224 material decision makers. To indicate the size of the organisations that these material decision makers came from figure 6.1 has been included to show the distribution.

6.2.1 FUNCTION OF MATERIAL DECISION MAKER BY INDUSTRIAL SECTOR

An overall picture of what function material decision makers have can be found by viewing table 6.1.

The heading 'design' has been taken to include those respondents whose function included mechanical engineering and stress analysis - as well as those with the title chief engineer, technical manager, and obvious designer. Not surpris-

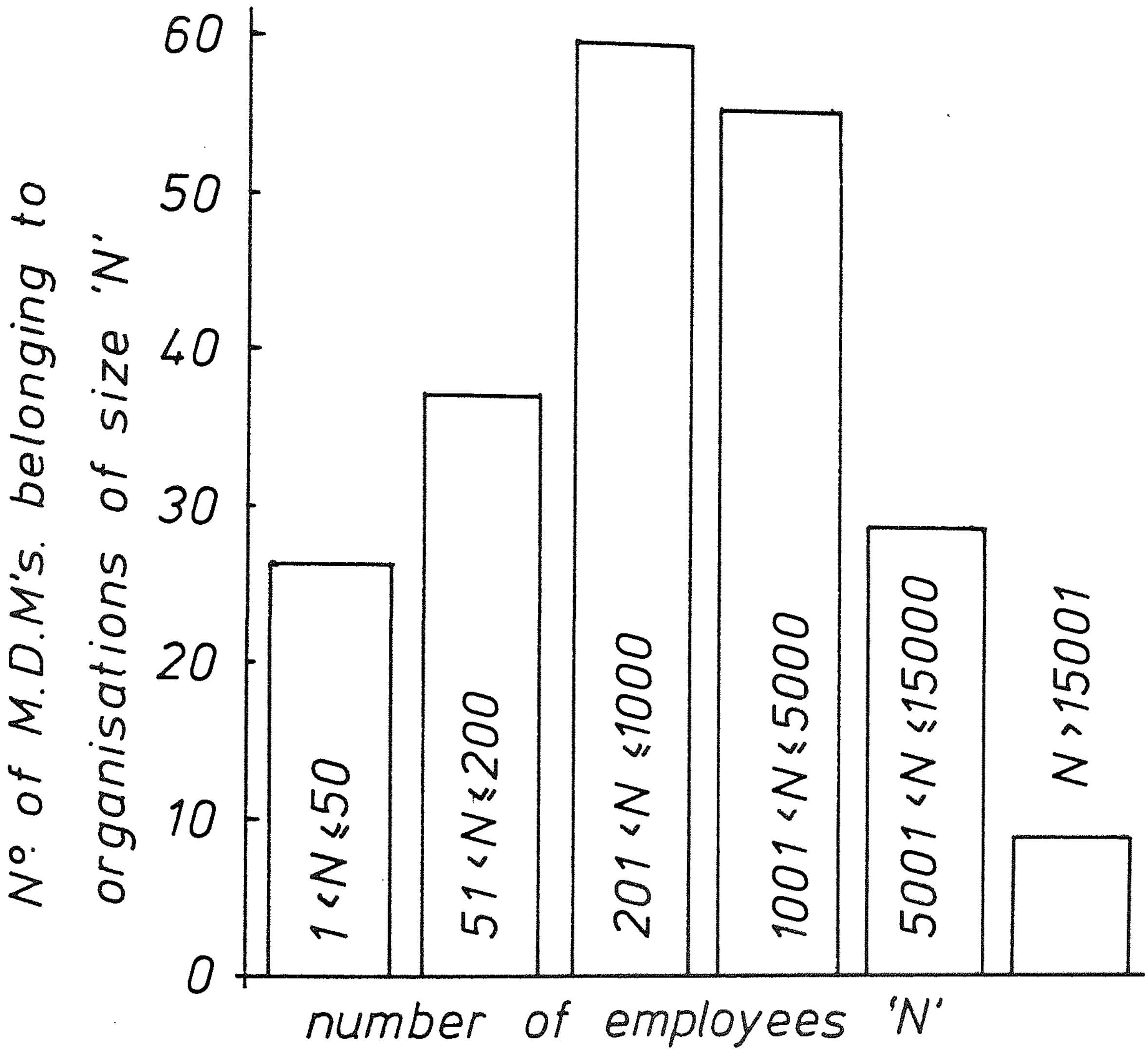


Figure 6.1 Total Spread of Companies Analysed by Size

Table 6.1 Showing the function of the material decision maker by industrial sector (% figs. are for particular sector concerned).

	Function not stated	Director (incl. general manager)	Design (incl. stress, mech'l eng'rs, chief eng'rs, tech'l managers)	Manufacturing (incl. builder works manager)
Aerospace	2 (8%)	-	10 (40%)	-
General Engineering	9 (13%)	27 (38%)	18 (26%)	2 (3%)
Material Producer	2 (8%)	9 (36%)	5 (20%)	1 (4%)
Nuclear and Power Industries	-	-	4 (24%)	-
Road Transport	2 (5%)	6 (15%)	11 (29%)	3 (8%)
Research Establishments	1 (5%)	2 (10%)	5 (25%)	-
Small Marine	1 (8%)	9 (69%)	2 (15%)	1 (8%)
Other	2 (14%)	2 (14%)	6 (42%)	-
Total	19 (8%)	55 (25%)	61 (27%)	7 (3%)

	Material Specialist (incl. metallurgists, material tech'logists material eng'rs)	R & D	Engineering Consultant	Service
Aerospace	10 (40%)	1 (4%)	-	-
General Engineering	5 (7%)	4 (6%)	5 (7%)	-
Material Producer	4 (16%)	1 (4%)	2 (8%)	-
Nuclear and Power Industries	10 (65%)	1 (6%)	-	-
Road Transport	13 (33%)	-	1 (3%)	-
Research Establishments	5 (25%)	3 (15%)	1 (5%)	1 (5%)
Small Marine	-	-	-	-
Other	2 (14%)	-	-	-
Total	49 (21%)	10 (4%)	9 (4%)	1 (½%)

	Information Service	Project Engineering	Quality	Marketing	Performance Engineering	Purchasing
Aerospace	-	1 (4%)	-	-	1 (4%)	-
General Engineering	-	-	-	-	-	1 (1%)
Material Producer	-	-	-	1 (4%)	-	-
Nuclear and Power Industries	-	2 (12%)	-	-	-	-
Road Transport	-	1 (3%)	1 (3%)	-	-	-
Research Establishments	2 (10%)	-	-	-	-	-
Small Marine	-	-	-	-	-	-
Other	-	-	-	1 (7%)	-	1 (7%)
Total	2 (1%)	4 (2%)	1 (½%)	2 (1%)	1 (½%)	2 (1%)

ingly, most respondents (27%) fell in this category, for it agrees with the findings of Buckner and The Financial Times (see Chapter 4.4). It does appear therefore, that the 'designers' play a very important part in the material selection procedure - as may have been expected. The importance attached to this function is shown most clearly in the aerospace sector - ten of the twenty five respondents having a design function.

More surprising, was that another twenty five per cent of the respondents had responsitbilities at director level. This may be explained by the fact that eighty per cent of the directors were from companies with less than 500 employees - see figure 6.2 - (note, that the average number of

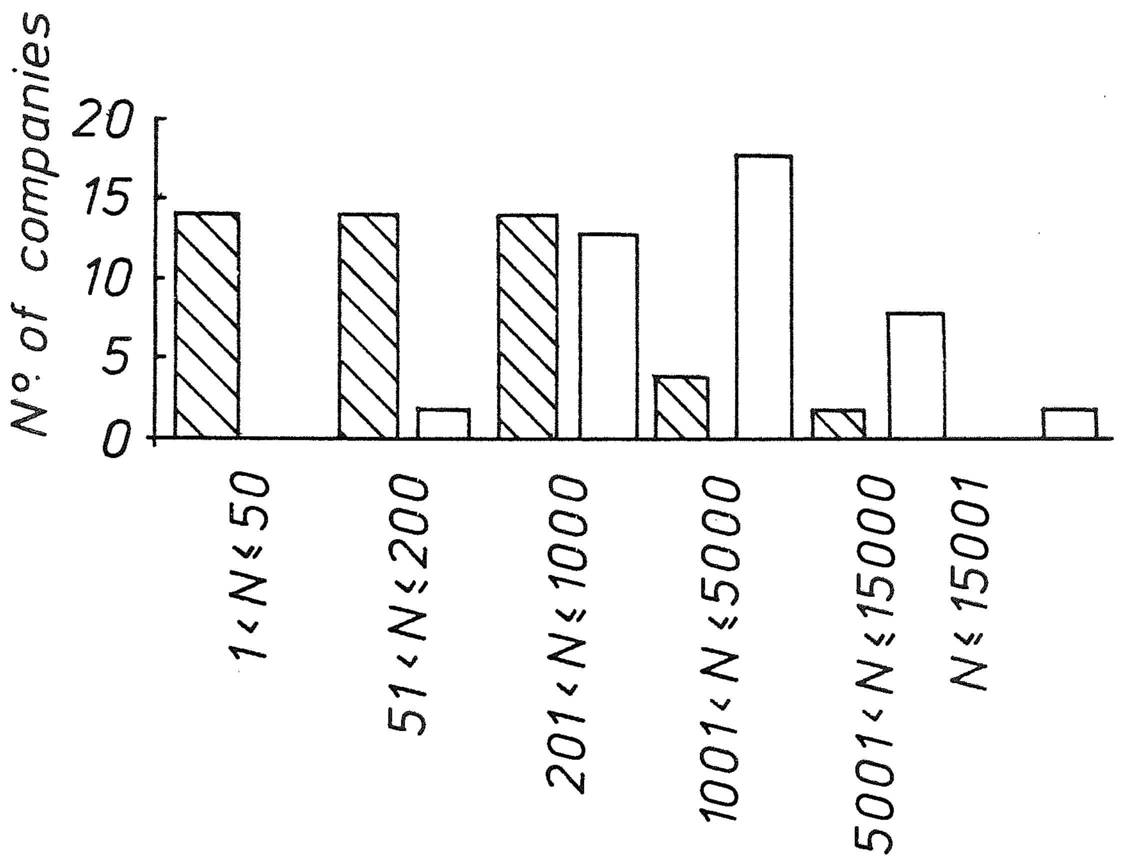


Figure 6.2 Variation of Directors ▧ and Material Specialists ☐ Across the Company Size Spectrum

employees in this survey was some 2,400 per company). And this does tend to bear out one's experience that for small firms, the directors or owners have generally set up the firm and in many cases it is their expertise that runs the business - wanting (needing) to be involved in all the decision making processes. (Such organisations are described by C. B. Handy as being run along the lines of power culture).

Such results do bear out what has recently been suggested in a report submitted to the Design Council by the Institution of Metallurgists in July 1977. And that is, that "in a small organisation, the design function may be handled by a single person who would be responsible for all aspects of the detailed design and of the process for bringing the design to fruition." Furthermore they have suggested that "the design of major products (presumably in larger organisations) ....is now generally undertaken by teams which include both engineering and industrial designers with the addition of specialists such as stress analysts, materials scientists, production engineer, manufacturing system expert and so on." The results of this study (table 6.1) presents evidence to support what the Institution of Metallurgists have been proposing. In the main, it was the medium technology industries from the small marine, general engineering and material producer sectors who had the largest percentage of 'material decision makers' as directors.

It is equally apparent from the evidence that the larger, high technology businesses - aerospace, and nuclear and power industries - do not have (at least from this survey) directors employed to make decisions about which materials should be used for particular jobs. This again is in general agreement with other findings, e.g. the Financial Times study which found that directors play a less important role as the size of the company increases.

Material specialists - metallurgists, materials technologists, materials engineers - form the next largest group (21%): though notably these come in the main from (i) nuclear and power generating industries and (ii) the aerospace industries. Other sectors, such as general engineering and the small marine industry appear to have a distinct lack of such specialists. This is understandable, as it tends to be the larger organisations generally who employ such people - over sixty five per cent of the companies employing material specialists had more than 1000 employees on site (see figure 6.2).

Is it significant that only two respondents (out of 224) stated their function as buyer? It had been assumed that the buyer played an important role in the selection of new materials. As it had been suggested in the cover letter that extra questionnaires should be given to interested colleagues, this may indicate that the buyer plays no significant role in the material selection process - apart from actual purchase, a fact which has been highlighted in Chapter 4.4.

None of the other functions mentioned by the respondents form prominent groups. For example the R & D function totals only ten; this in particular is surprising as the R & D function had been thought to be more directly involved in material innovation, and hence the decision making process (see the Financial Times study and Chapter 4.4.). The manufacturing function is another area, where one might have expected there to be more involvement - after all it is those in production who actually have to turn the raw materials into finished products. But they too (according to this survey) play only a minor role in the material selection procedure.

Apart from design, director and material specialist there are ten other functions stated - rather diverse and perhaps not significant to the overall picture. Nevertheless they should be remembered - it is not always the designer who knows most about material developments.

6.2.2 PECULIARITIES TO INDIVIDUAL INDUSTRIAL SECTORS

Apart from the variations across the different industrial sectors as described above, there are some trends peculiar to particular sectors; and these are mentioned here purely as an addendum:

- Aerospace: Respondents from the design and material specialist function totalled twenty, i.e. eighty per cent of the respondents fell into these two categories.
- Nuclear: Of the ten material specialists cited in table 6.1, four stated their role to be advisory to the decision team.

- Research Establishments: These are generally small to medium size organisations with a much greater ratio of qualified scientists and engineers (QSE) to operatives than may be expected in the other sectors. Of the twenty respondents in this sector, seven stated their role as advisory to the decision teams in industry.

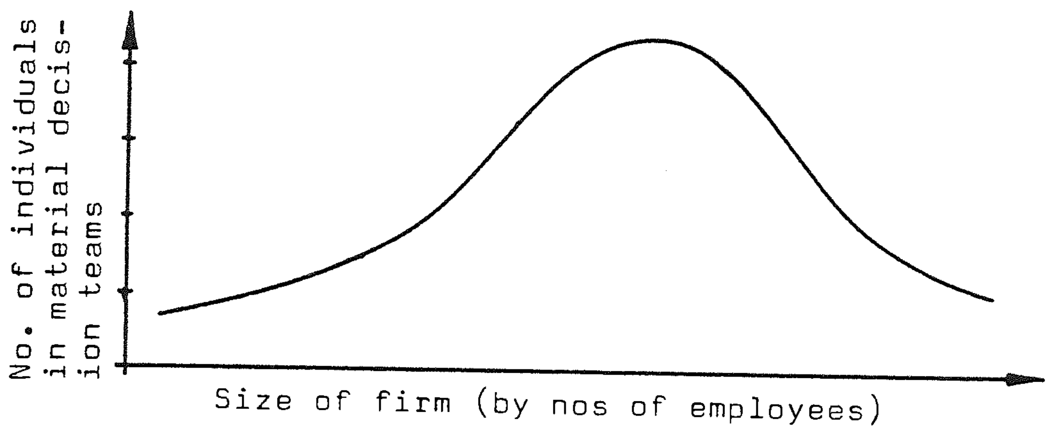
6.3 SIZE AND NATURE OF MATERIAL DECISION TEAMS

(i) As a function of the size of the firm

The size of the firm (number of employees) often plays an important part in the way an organisation is structured for the day to day business of running a firm. It was hoped, that this study would show whether or not firm size had any effect on the numbers employed in a material decision team. Having said that, it is important to understand what is meant by firm size. Many studies, that have looked at the affect firm size has on various aspects of organisation structure have taken size to mean only those employed as qualified scientists and engineers (QSE). If such a qualification was imposed on all the firms responding to this survey, many would fall by the wayside. To overcome this, and make compilation of the results the easier, it was decided that firm size should be the total number of employees employed at the particular site - regardless of qualification or whether the employees are termed as 'works' or 'staff'. This, should in no way invalidate the results - the same criterion was applied across all the industrial sectors.

One would not generally expect to find one person solely responsible for material selection in every firm, in each industrial sector. From experience it seemed possible that the size of a material decision team might vary as a normal distribution, as the size of the firm increases - see figure 6.3.

Figure 6.3 Possible distribution of material decision team size V size of organisation



Such a picture would indicate that only the very small and very large firms use one material decision maker. It could be argued that the very small firms cannot afford to employ such specialised expertise, and rely on the entrepreneur (director/owner as described in section 6.2.2) to make such decisions as part of his function in running the business. At the other end of the scale, the big/giant firms may well have the resources to employ a really expert material specialist to make the material decisions for the whole organisation.

Unfortunately, such a clear cut picture has failed to emerge from this study. Table 6.2 shows the breakdown of the team sizes across the different industrial sectors and the graph

Table 6.2 Shows the size of material decision teams across different industrial sectors. (Key: a = advisory, cs = customer specifies materials)

Industrial Segment	Nos. in decision team 1	2	3	4	5	5+	Team size unspec-ified	Other Capacity	Company size (no. of employees)
Aerospace	0	0	0	0	0	0	0	0	
General Engineering	1	4	1	0	0	0	0	0	
Material Producer	1	0	3	0	0	0	0	0	
Nuclear and Power Industries	0	0	0	0	0	0	0	0	
Road Transport	0	0	0	0	0	0	0	0	1 to 50
Research Establishments	0	0	1	0	0	0	1	2(a)	
Small Marine	3	2	2	1	1	0	0	0	
Other	0	0	2	1	0	0	0	0	
Total	5	6	9	2	1	0	1	2	
Aerospace	0	0	0	0	0	0	0	0	
General Engineering	2	1	10	4	0	1(8)	0	1(a)	
Material Producer	1	0	2	1	0	0	0	0	
Nuclear and Power Industries	0	0	0	0	0	0	0	0	
Road Transport	3	0	1	0	0	0	0	0	51 to 200
Research Establishment	0	0	3	0	1	0	0	1(a)	
Small Marine	1	1	2	0	0	0	0	0	
Other	0	0	0	1	0	1(6)	0	0	
Total	7	2	18	6	1	2	0	2	
Aerospace	0	0	2	1	0	0	1	0	
General Engineering	3	1	3	5	1	4(6,6,6,10)	0	6(1cs,5a)	
Material Producer	0	1	0	3	3	1(6)	0	0	
Nuclear and Power Industries	0	0	0	1	0	2(5+,7)	1	3(a)	
Road Transport	3	0	1	2	1	2(6,10)	0	0	201 to 1000
Research Establishments	0	0	2	1	0	2	1	3(2a,1R&D)	
Small Marine	0	0	0	0	0	0	0	0	
Other	1	0	2	0	0	1(10)	1	0	
Total	7	2	10	13	5	12	4	12	
Aerospace	0	1	3	1	2	3	3	0	
General Engineering	4	2	4	3	2	2	1	1(a)	
Material Producer	0	0	2	1	1	0	0	1(a)	
Nuclear and Power Industries	1	1	0	2	0	1(6)	1	1(a)	
Road Transport	0	3	0	1	1	3(6,6,5-10)	1	0	1001 to 5000
Research Establishments	0	0	0	0	0	0	0	0	
Small Marine	0	0	0	0	0	0	0	0	
Other	0	1	0	1	1	0	0	0	
Total	5	8	9	9	7	9	6	3	
Aerospace	0	0	2	0	1	1(6)	1	0	
General Engineering	0	0	0	0	0	0	0	0	
Material Producer	1	0	0	0	0	1(6)	0	0	
Nuclear and Power Industries	0	0	1	0	1	0	0	1(a)	
Road Transport	1	1	1	2	1	2(6,8)	6	0	5001 to 15000
Research Establishments	0	0	0	1	0	0	0	1(a)	
Small Marine	0	0	0	0	0	0	0	0	
Other	0	0	0	0	0	0	0	0	
Total	2	1	4	3	3	4	7	[illegible]	
Aerospace	0	0	0	2	1	0	0	0	
General Engineering	0	0	0	0	0	0	0	0	
Material Producer	0	1	0	0	0	0	0	0	
Nuclear and Power Industries	0	[illegible]	0	0	0	0	0	0	15001 and larger
Road Transport	2	0	[illegible]	0	0	0	0	0	
Research Establishments	0	[illegible]	0	0	0	0	0	0	
Small Marine	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	[illegible]	
Other	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
General Engineering	[illegible]	[illegible]	3	[illegible]	1	0	0	[illegible]	Company size unknown
Material Producer	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	
Other	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Total	[illegible]		4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

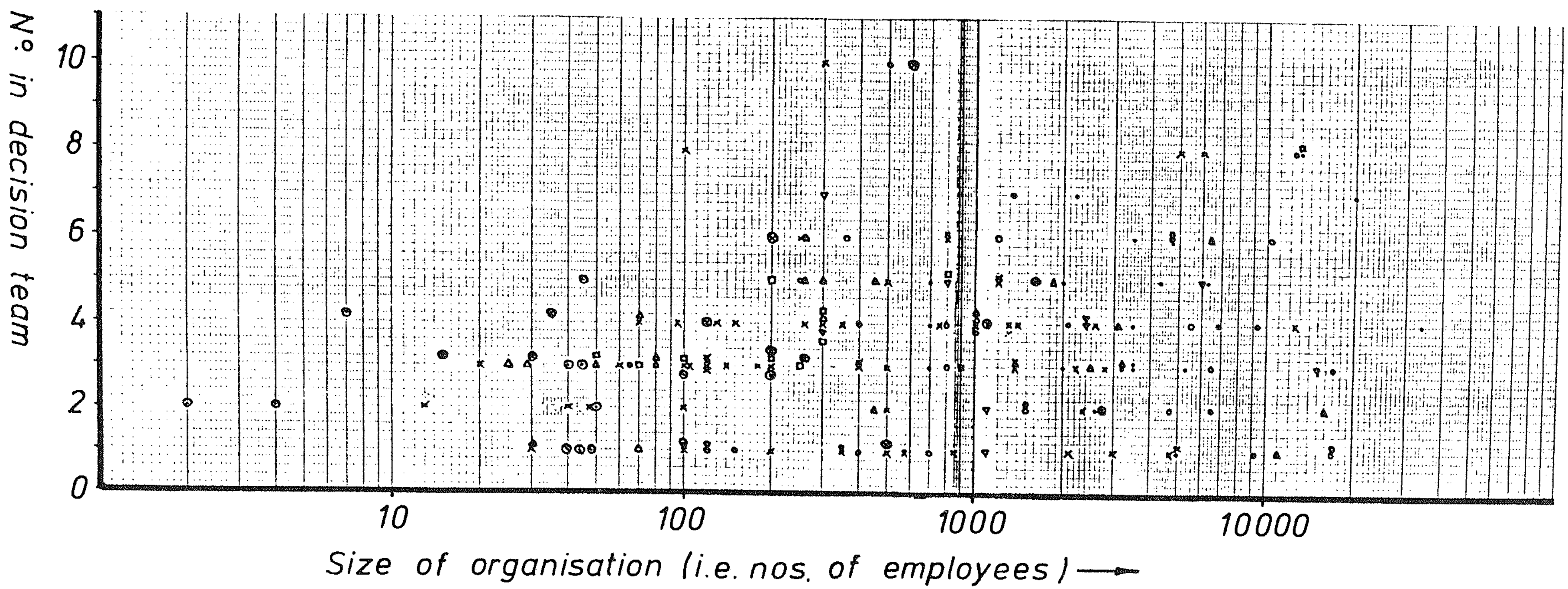


Figure 6.4 Logarithmic Distribution of Material Decision Team Size against Size of Organisation

Key:

- • aerospace
- × general engineering
- △ material producer
- ▽ nuclear & power industries
- ○ road transport
- □ research establishments
- ◉ small marine
- ⊗ 'other'

of figure 6.4 shows more clearly the random nature of such decision team sizes against size of firm. Why should it be such a random picture? There appears to be no real pattern emerging at all - what are the reasons for this? Firstly, the term "decision team" was left undefined in the questionnaire - basically because the author did not know who should or should not be included. It was therefore, left to the individual respondents to decide if they could first be classed as a 'material decision maker' and then decide if they fitted into a team. It may well be that in many firms there is a top designer who takes the final decision on material selection - but there may be several designers beneath him who also decide which options to put before the top designers. In which case, the top designer might regard himself as the sole decision maker whilst those who advised him would almost certainly see themselves as part of a team. The interpretation of "decision team" was therefore clearly a matter of individual interpretation - a fact which might play on the results as indicated.

It was clear from many of the returned questionnaires that respondents thought just that - the term 'decision team' was undefinable. Indeed there were thirty repondents who made comment on the difficulty of placing a number to such a team. A few of their quotes are reproduced here to illustrate the problem:

- "variable, depending on application - usually three to four"
- "variable, depending on product (5-20)"
- "supported by team of seven, but decisions are corporate, multi departmental, under designer (who is finally responsible)"

- "to say how many may be involved at any one time would be impossible in a Group as diverse as this one"
- "three or four, depends on project"
- "varies according to problem but usually three or four"
- "no specific team"
- "varies according to component or assembly"
- "not definable"
- "varies"

Such comments were made by firms whose size varied from 100 to 12,000 employees (mean of 3311). It serves to illustrate that such groups (for material decisions) are not static - but rather, dynamic, depending on the product - project, as indicated by the literature (see Chapter 4.4). A firm will know what expertise it needs to solve the problem, and then allocate the manpower accordingly (a task type culture according to C. B. Handy p.182). The size of the firm does not appear to affect such team sizes dramatically. For example, the larger organisations do not seem to have any more of a structured approach than do the small ones, for solving these particular problems of material selection - as has been suggested by C. B. Handy (p.187). Rather, this random picture vindicates what John Child's had already suggested, that there are "factors other than size of organisation" that affect the numbers in certain "specialized staff functions". Although Child's analysis was based on the chocolate and sweets, electronics, daily newspapers and pharmaceutical industries, his results back up these findings. Indeed the size of the design and development function from his study has a very low correlation with organisation size. Table 6.3 shows Child's results modified such that the specialised functions shown, are ranked according to their correlation with organisation size, i.e. those functions that are related to organisation size have a high correlation factor and vice versa.

Table 6.3 Correlation between the size of sixteen specialized functions and the size of the organisation

Function	Correlation with total employees	
Maintenance	·91	These functions have their size closely related to the size of the organisation
Finance	·89	
Sales and Service	·86	
Transport and Despatch	·78	
Public Relations, Advertising	·72	
Buying and Stock Control	·65	
Welfare and Security	·65	
Production Planning and Control	·45	
Legal and Insurance	·43	
Market Research	·39	
Training	·38	
Employment	·32	
Design and Development	·29	The size of these functions is not generally related to the size of the organisation
Office Services	·25	
Production Methods	·18	

(Modified Table 4 from Child)

Note: The correlation factor is a measure of the size of the particular function related to the size of the organisation.

Peculiarities to individual industrial sectors

Again, as an addendum, there are a few interesting trends associated with individual sectors:

- Material Producer: It cannot be stated categorically that the size of material decision teams decreases as the size of the firm increases. However, the author feels it necessary to point out what might well be a trend. Two large chemical companies (one with just over 10,000 employees, the other with more than 15,000) claim to have just one (in one of the firms) and two (in the other) material decision makers. These key individuals make all the decisions for material selection in their products and processes, but note that the input for these decisions came from elsewhere.

- Road Transport: The trend to one decision maker is again hinted at in the car industry for the larger firms. Two respondents from a firm employing nearly 17,000 claim to have sole responsibility for material decisions - although in this case, they truly are specialists, being responsible for particular classes of material: polymers, lubricants, metals, etc. They then presumably 'plug' into the design team - but remain responsible for material selection. Whilst there is this example of the sole material decision maker, it is equally clear that some of the large organisations (six between 6,000 and 12,000 employees) could not define such a material decision team in terms of numbers taking part.

So whilst there may be an indication that some of the larger firms are moving towards employing one specialist for such decisions, there is no hard evidence that this is a general trend.

(ii) Ignoring the effect of firm size

Because the size of the firm did not appear to affect the size of the proposed material decision teams in any significant manner, another approach was adopted. Is it possible to define the most common size of team regardless of firm size? The answer to this must be a tentative 'yes'. Figure 6.5 below shows that when the firms from all the industrial sectors are combined, the most common team size for material selection is three (Table 6.4 shows the breakdown for all industrial sectors).

If this is indeed so, and there seems no reason to doubt it, then the results are at variance with some published conclusions on groups. It has been suggested by Handy that "for best participation, for highest all round involvement, a size of between five and seven seem to be optimum." Bormann

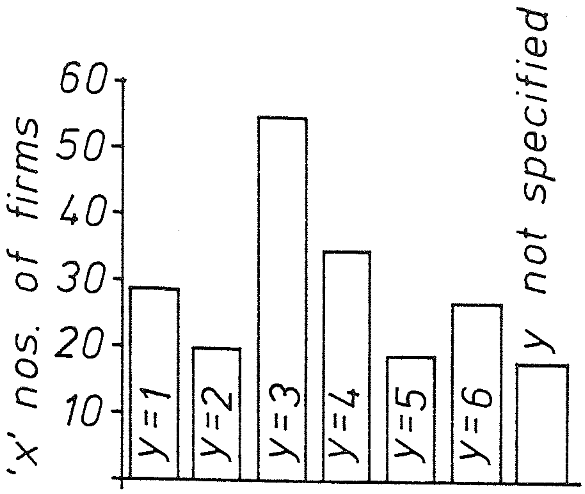


Figure 6.5 'x' number of firms use 'y' number of employees in a material decision team

Table 6.4 Illustrates the no. of firms using 'x' no. of employees in a material decision team - shown across the different industrial sectors.

Industrial Sector	'x' no of employees in a material decision team						
	1	2	3	4	5	5+	Team size unspecified
Aerospace	0	1	7	4	4	4	5
General Engineer-ing	10	8	21	12	4	7	1
Material Producer	4	2	7	5	4	2	0
Nuclear and Power Industries	1	1	1	3	1	3	2
Road Transport	9	4	4	5	3	7	7
Research Estab-lishments	0	0	6	2	1	2	2
Small Marine	4	3	4	1	1	0	0
Other	1	1	5	3	1	2	1
Total	29	20	55	35	19	27	18

and Bormann have also suggested a group of five being the optimum for an efficient work group. However, according to this study groups of five to seven are the exception rather than the rule when it comes to material decisions; and it is proposed that three is the favoured group size.

The picture of team size (table 6.4) across the individual industrial sectors is not so clear cut. And it is probably not wise to be dogmatic about the individual results because some of the samples (nuclear and power industries, research establishments and small marine sector) are not large enough to place great significance in them.

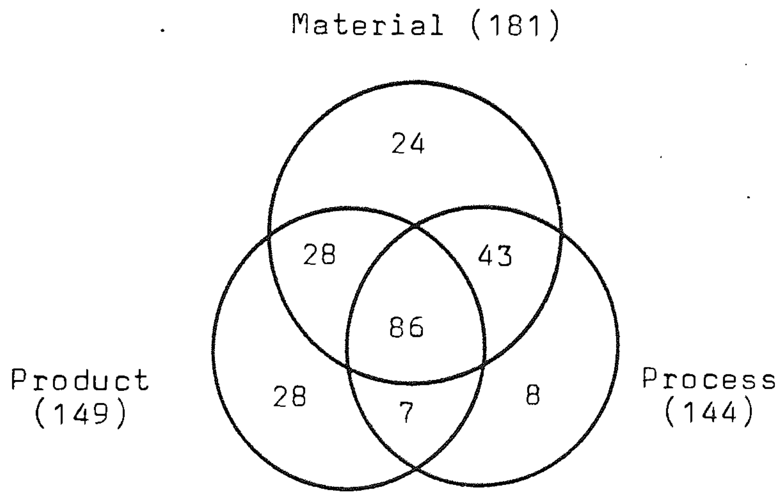
6.4 INNOVATION - THE RELATIVE IMPORTANCE OF MATERIAL, PRODUCT AND PROCESS INNOVATION

How important is material innovation for British industry? If innovation on the material front ceased would product and process innovation decline also? With the material decision maker playing an important role in his firm's product and process development, it was thought that his rating's of the relative importance of the three areas of innovation, would reflect industries general view of innovation in these important areas. The aim then, is to show the relevant importance of material, product and process innovation.

Respondents were asked to indicate their interest in these three areas of innovation. If they indicated that their interest lay completely out of these areas, then their replies were ignored - not just for this part of the exercise, but completely. Whether one can compare relative interest to a ranking of importance may be debatable - but, on the supposition that interest means that their work entails them being aware of developments in these areas - then it should give an indication of the relevant importance of material, product and process innovation.

Table 6.5 shows the distribution of the respondent's interest in the different areas of innovation - across all the different industrial sectors. The Venn diagram of figure 6.6 illustrates quite clearly (for the combined industrial sector) the breakdown of interests with corresponding overlap areas.

Figure 6.6 shows overall area of interest for material, product and process innovation.



Using this as the basis for determining the relevant importance of the three areas of innovation, then the order is material (181) product (149) and process (144) though there is virtually no difference between product and process innovation. This picture, of material innovation being the most

Table 6.5 Showing distribution of respondents' interest in different areas of innovation

Industrial Segment	Material	Process	Product	Other	Material/ process	Material/ product	Process/ product	Material/ process/ product
Aerospace	3	0	3	0	9	4	0	6
General Engineering	10	2	8	0	14	9	4	24
Material producer	1	2	2	0	4	5	1	10
Nuclear and Power Industries	2	1	0	0	3	1	1	9
Road Transport	2	2	7	0	3	6	1	18
Research Establishments	4	0	3	0	6	1	0	6
Small Marine	0	0	1	0	2	0	0	10
Other	2	1	4	0	2	2	0	3
Total	24	8	28	0	43	28	7	86

important is repeated across all the industrial sectors studied, (see figure 6.7) except for the road transport sector. In that sector product innovation appears to be the most important.

Such an analysis ignores the fact that many respondents (86 from 224) claimed to have interest in all three areas of innovation. Perhaps it is this that should be emphasized most strongly - interest in one area of innovation without reference to one of the other areas does not figure prominently. The 'material decision maker' is involved in product, process and material innovation - which is no real surprise. What would have been surprising is if the 'material decision makers' had claimed to be interested in only material innovation. Product and process innovation must to an extent involve new materials, and this is reflected in these results.

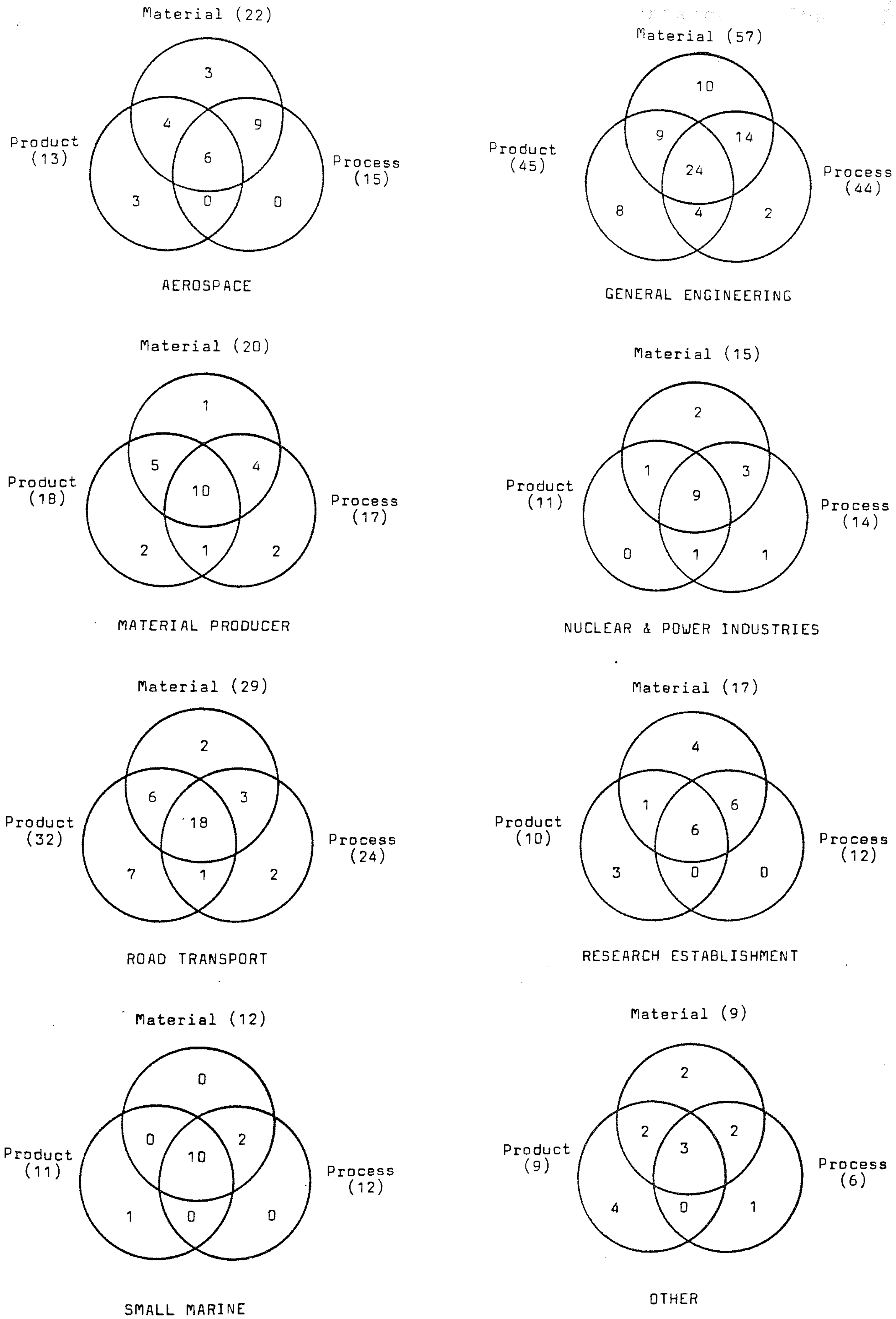
It would be dangerous to read any more than the two observations above into these results. Let us just say that material innovation plays an important part in industrial innovation today. It is not really a separate issue from product and process innovations - it plays an integral part, though the 'material decision makers' might regard it as being the most important of the three areas of innovation.

6.5 CHAPTER REVIEW

Some new light has been thrown onto the three areas studied in this chapter.

There are persons in industry who regard themselves as 'material decision makers'. They come from many differing functions, thirteen in all, but there are three different functions which

FIG. 6.7 Respondent's area of interest in Material, Product and Process Innovation across different Industrial Sectors



stand out from the rest. These three are design, director and material specialist - in that order of importance. The design function is important across all industrial sectors - but particularly so in the aerospace industry. Directors play important roles in the material selection process in the smaller firms (less than 1000 employees), in the general engineering, material producer and small marine sectors - but play no part in the high technology businesses like aerospace and nuclear and power industries. On the other hand, material specialists play important roles in just these high technology areas and not in the general engineering and small marine fields. There is almost an inverse relationship between these two functions - below 1000 employees, directors predominate; above 1000, material specialists take over.

The size and nature of the material decisions teams have shown themselves to be very random - particularly when compared with the size of the firm. There is some evidence to suggest that such teams vary in size, according to the product/project that is being studied - and that the team may well have a different composition for different projects. In general, the larger firms appear to be no more structured than the smaller ones, when it comes to material decisions. However, there is just an indication that some of the really large organisations (in the chemical and motor trades) are turning towards one material decision maker for material selection. If the size of the organisation is ignored the norm size for material decision teams appears to be three - which differs from accepted group theory where teams of between five and seven people are suggested to be the most effective.

According to the material decision makers, material innovation is just as important in industrial life today as product and process innovations. Whether product and process innovations would decline, should material innovations cease, is not known - maybe that is an area for future research. What is known, is that many of the material decision makers are interested in all three areas of innovations, and not just material innovation. It is this group, or members with this function, who are the obvious people to introduce new materials into their organisation.

7

INFORMATION SOURCES AND CHANNELS - THEIR SELECTION AND USE

7.1 CHAPTER PREVIEW

The material decision maker has to keep up-to-date with material developments to ensure his products or process equipment are using the most efficient materials. The information sources and channels that he uses are therefore of importance to material producing companies. This chapter analyses the results from 224 material decision makers as to which sources and channels are effective for seven different industrial sectors.

7.2 THE IMPORTANCE OF EFFECTIVE COMMUNICATION IN THE INNOVATION PROCESS

The importance of effective communication between innovator and potential user has been recognised for some time. Although there has been some disagreement between various researchers as to the worth of the written and unwritten word, or mass media and interpersonal channels, the vast array of possible sources available to organisational decision makers (including designers) has been shown by many authors. Few of the studies however, have examined all the information sources and channels used by decision makers, particularly material decision makers, as Chapter 4.9 has indicated.

7.2.1 THE EFFECTIVE INFORMATION SOURCES FOR MATERIAL DECISION MAKERS

An examination of ten different information sources by 224 respondents in seven different industrial sectors was made. This enabled a fairly accurate picture to be drawn of which sources were effective for keeping material decision makers up-to-date with material developments. The results of such a study are important to the material producer for the simple reason that it helps him decide which information sources should be used to promote his materials. A criterion for assessing which ones should be used could be:

(a) Those which the potential user regards as most effective

(b) Those which are used by the majority of potential users.

Table 7.1 shows how 224 respondents rated the various sources according to their industrial sector. An attempt was made to rank the sources in order of effectiveness. To do this the mean and standard deviation for each source in each industrial sector was calculated:

$$\text{Mean } \bar{x} = \frac{\Sigma fx}{f}$$

$$\text{and Variance} = (\text{Standard deviation } (\sigma))^2 = \frac{\Sigma fx^2}{f} - (\bar{x})^2$$

where f = No. of respondents who found an information source: very effective; effective; not effective or did not use.

x = weighting factor applied to effectiveness level i.e. very effective = 3; effective = 2; not effective = 1; do not use = 0.

The overall result for the 224 respondents is illustrated in figure 7.1 and for the individual sectors plus the Dunlop organisation in figure 7.2. Interpretation of such a picture for the criterion mentioned above is as follows:

(a) sources regarded as most effective have a high mean value

(b) sources used by most potential users have a low standard deviation.

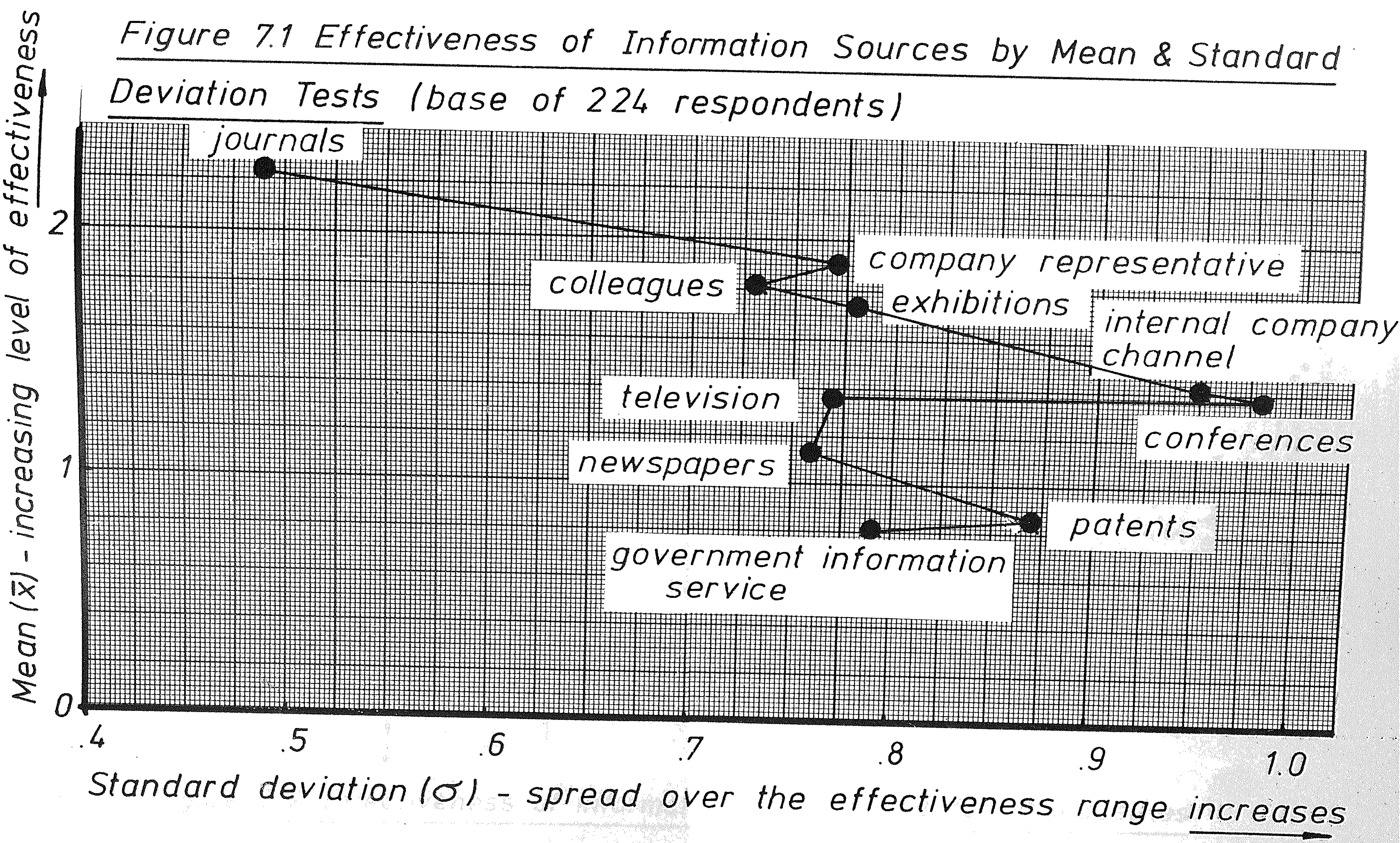
However, the majority of information sources fell in a fairly close cluster and it was only the journals that stood out significantly as being most effective. This makes absolute classification of the intermediate order impossible, but it is suggested that the overall ranking is as follows:

Table 7.1 shows effectiveness of various information sources for keeping up to date with material developments.

Key : VE = very effective E = effective NE = not effective DU = don't use

Industrial Segment	VE	E	NE	DU	Information Source	VE	E	NE	DU	Information Source
Aerospace	6	17	2	0		0	7	11	7	
(1) General Engineering	12	36	1	0		2	24	21	2	
(2) General Engineering	5	17	0	0		0	8	9	5	
Material Producer	7	18	0	0	Journals	0	13	6	6	Television
Nuclear & Power Industries	3	13	1	0		1	7	6	3	
Road Transport	13	26	0	0		1	20	13	5	
Research Establishments	6	14	0	0		1	12	4	3	
Small Marine	3	9	0	1		0	9	3	1	
Other	4	10	0	0		0	6	5	3	
TOTAL	59	160	4	1		5	106	78	35	
Aerospace	0	7	12	6		5	17	3	0	
(1) General Engineering	0	20	21	8		6	34	6	3	
(2) General Engineering	0	5	11	6		7	10	5	0	
Material Producer	0	9	10	6	Newspapers	6	13	3	3	Company Representative
Nuclear & Power Industries	0	5	11	1		0	11	5	1	
Road Transport	0	15	14	10		15	19	4	1	
Research Establishments	0	12	6	2		0	14	4	2	
Small Marine	0	0	10	3		1	8	0	4	
Other	0	3	7	4		2	9	1	2	
TOTAL	0	76	102	46		42	135	31	16	
Aerospace	1	17	3	4		0	6	10	9	
(1) General Engineering	3	18	12	16		2	4	18	25	
(2) General Engineering	0	10	7	5		0	6	7	9	
Material Producer	2	13	4	6	Conferences	2	10	3	10	Patents
Nuclear & Power Industries	4	8	2	3		0	1	6	10	
Road Transport	5	12	11	11		1	15	8	15	
Research Establishments	3	11	4	2		1	8	8	3	
Small Marine	3	1	1	8		0	0	6	7	
Other	2	6	2	4		0	2	5	7	
TOTAL	23	96	46	59		6	52	71	95	
Aerospace	0	18	4	3		2	15	6	2	
(1) General Engineering	6	28	9	6		2	23	15	9	
(2) General Engineering	3	14	4	1		1	9	8	4	
Material Producer	2	17	5	1	Exhibitions	6	7	1	11	Internal Company Channel
Nuclear & Power Industries	3	8	3	3		1	14	1	1	
Road Transport	8	22	8	1		6	19	7	7	
Research Establishments	2	9	7	2		1	8	5	6	
Small Marine	1	10	1	1		0	4	3	6	
Other	1	9	0	4		3	3	3	5	
TOTAL	26	135	41	22		22	102	49	51	
Aerospace	4	17	2	2		1	11	8	5	
(1) General Engineering	3	33	10	3		0	9	22	18	
(2) General Engineering	2	13	5	2		0	1	14	7	
Material Producer	0	21	4	0	Colleagues	1	3	10	11	Government Information Service
Nuclear & Power Industries	4	13	0	0		0	3	5	9	
Road Transport	4	26	5	4		0	10	13	16	
Research Establishments	5	12	2	1		0	4	7	9	
Small Marine	0	10	2	1		0	0	5	8	
Other	3	6	2	3		1	2	3	8	
TOTAL	25	151	32	16		3	43	87	91	

Figure 7.1 Effectiveness of Information Sources by Mean & Standard Deviation Tests (base of 224 respondents)



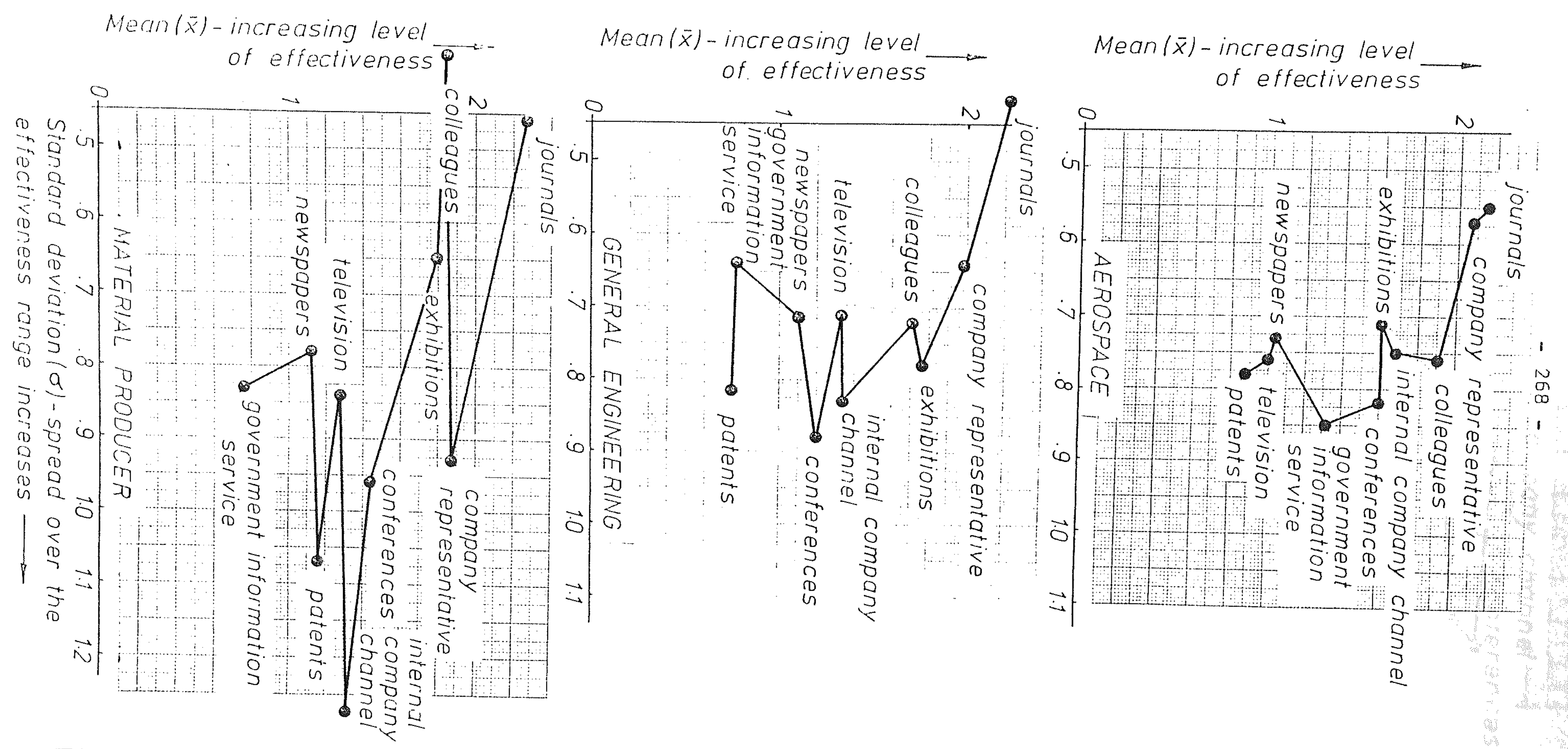


Figure 7.2 Effectiveness of information sources in different industries

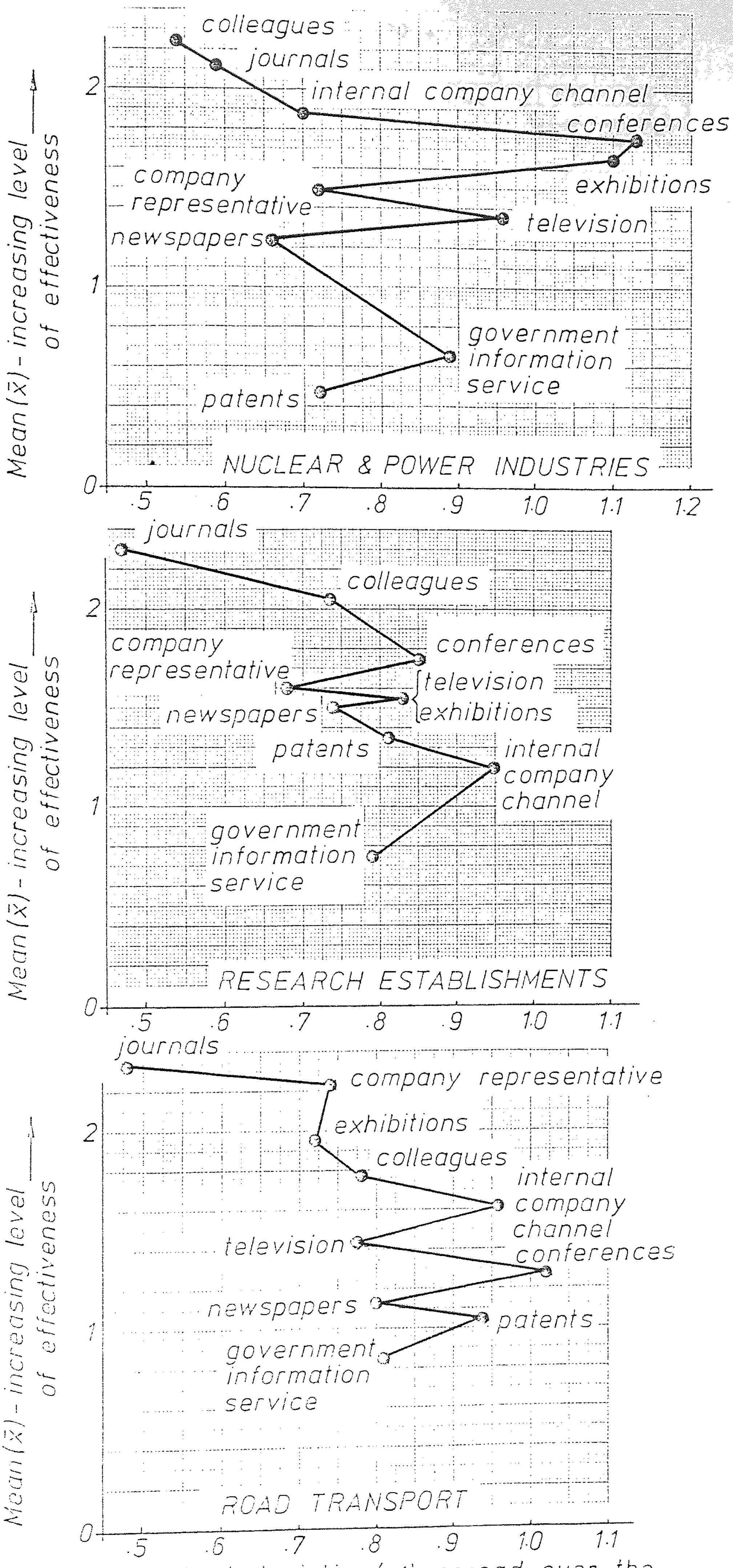


Figure 7.2 Effectiveness of information sources in different industries (cont'd.)

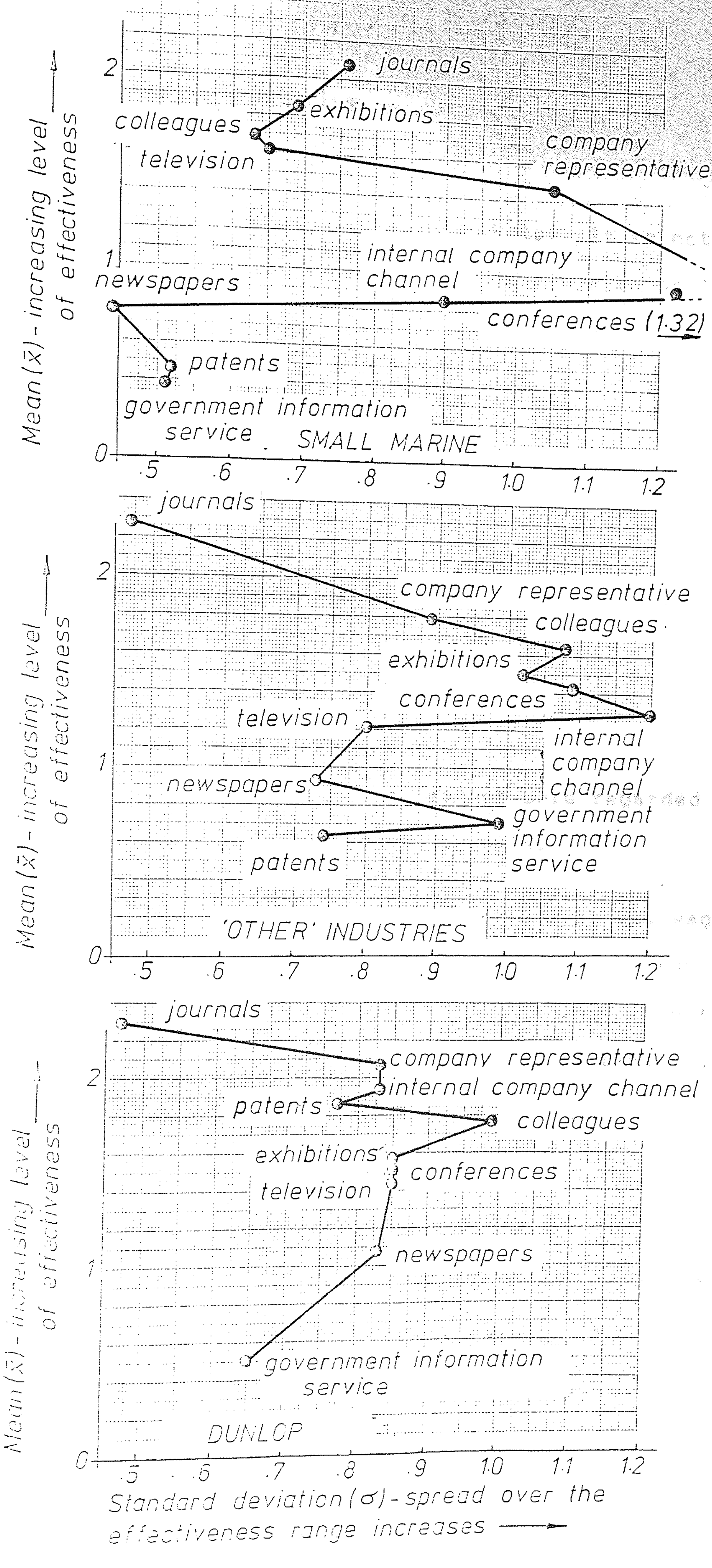


Figure 7.2 Effectiveness of information sources in different industries (cont'd.)

1 journals
↓ company representative
colleagues
↓ exhibitions
internal company channels
↓ conferences
television
↓ newspapers
patents
10 government information services

Note: it is not possible to be 100% accurate for the intermediate order

On examination of this overall result together with the results for the individual sectors, the following salient points are revealed:

- Journals were regarded as the most effective medium in each industrial sector except for the nuclear and power industries. In that sector colleagues were regarded slightly more effective than the journals.

- The spoken word via company representatives or colleagues was generally regarded as the next most effective source except for the small marine industry. In that industry colleagues were ranked third and company representatives fifth.

- Internal company channels did not stand out as being of great importance in any sector except for the nuclear and power industries and aerospace industries where it was ranked third and fourth respectively. The Dunlop organisation also ranked the internal company channel third. Such industries are mainly comprised of a few large organisations and as such the majority of people interested in the subject will work in one of the component firms. Internal company channels therefore have a large audience and are generally written by the people for the people.

- Neither patents or government information services were ranked as effective. In most cases they filled the last two places in the ranking except for the aerospace industry who ranked government information services seventh and the material producers and research establishment who ranked patents eighth. The Dunlop organisation on the other hand ranked patents fourth, which probably indicates there is a good, central patents department working effectively.

- Conferences were only given a high priority by research establishments, and the nuclear and power industries - third and fourth respectively in the ranking.

- Exhibitions were only given a high priority by the small marine industry - second, and the general engineering and road transport industries - third.

One must conclude from this that the written word - in the form of journals, not newspapers - was the most effective information source for keeping material decision makers up-to-date with material developments, particularly as company representatives and colleagues were generally regarded as the next most important source. They after all are open to the influence of journals just as much as the material decision maker. It had been thought that the 'old boy' network would play a particularly important role in such an information transfer. This supposition had been supported before the survey 'decisions on materials' when the author had been building up a list of contacts to whom the survey should be sent. It was frequently found that one MDM was able to name his opposite number in many organisations within the same industry. Obviously there are some businesses where such a network plays a part, and the two comments from a major chemical manufacturer and a small boat builder serve to indicate that the old boy network continues to function:

- "My function is to run a Group, part of whose (brief) is to maintain awareness of developments in materials and introduce them into chemical plant service. We use a variety of means for doing this, including conferences, journals of all types and personal contacts with our opposite numbers and technical (but not sales) staff in suppliers. Our approach is effective but our experience makes me sorry for smaller organisations which cannot plug into the old boy net which is the main productive source we use".

- "Conferences and Seminars are more effective than Representatives because higher powered personnel are available."

However such comments do run against the general trend of these results, and one must conclude that the old boy network is not as important for keeping MDM's up-to-date with material developments as had been thought.

The results quoted above are in agreement with other studies (Shears, and Gibbons and Johnston) and adds weight in particular to Gibbons and Johnston's findings. They investigated the information types that were used to resolve technical problems that arose during the process of a development leading to innovation. Two of their findings concerned the information inputs that describe (a) the existence or availability of materials or components with particular properties and (b) the properties or composition of materials, equipment, or components. They have been reproduced in table 7.2 and shows that they noted the trade and technical literature to be important sources of information.

Such results though suggesting that journals were a good medium for material producers to use to promote materials gave no indication of which information channels within the journal medium were best suited to the jobs. The next section examines this problem.

7.2.2 THE EFFECTIVE INFORMATION CHANNELS

Several studies in fields other than material innovation have shown the worth of studying the reading habits of technical managers and directors (Beattie and Reader, and The Financial Times for instance). Both studies highlighted the importance of the Financial Times and in the case of Beattie and Reader it was at the expense of journals which might otherwise have been regarded as more appropriate.

It was therefore proposed that this study should examine which information channels were regarded most highly for

1. Information inputs describing the existence or availability of materials or components with particular properties have the following characteristics : i) they arise more from sources outside the company; ii) they are available or comprehensible to individuals within the relevant industry; iii) they are diffused industry-wide; iv) those not within the horizon of the problem-solver are obtained primarily by active search and experimentation, but sometimes by seeking assistance; v) they supply or directly assist in the solution of the problems being worked on; vi) they originate outside the firm mainly in the trade literature; from handbooks; and from business contacts such as sales representatives, customers and supplier firms. They also arise from the problem-solver himself from his experience, education, and from reading technical literature.
2. Information inputs describing the properties or composition of materials, equipment, or components have the following characteristics : i) they arise more from sources inside the company; ii) they are mostly available or comprehensible to individuals within the relevant industry, though a considerable proportion require speciality knowledge or training; iii) they are diffused half throughout the industry, half form part of the company' knowledge; iv) those not within the horizon of the problem-solver are obtained primarily by active search and experimentation, and sometimes by seeking assistance; v) they either provide or directly assist in the solution of problems being worked on or stimulate action leading to the solution without itself being incorporated. vi) they originate primarily from trade and scientific literature, from analysis and experiment conducted in the company, and from the problem-solver's own experience and reading of trade literature.

TABLE 7.2 Information inputs related to materials (source-Gibbons & Johnston)

keeping the material decision makers in touch with (a) business developments and (b) material developments. The aim was to see if there were major differences for two such tasks or whether there were common channels that could do both jobs. The results (shown in appendix E) were analysed sector by sector. It will be noticed that a common core of twenty channels were examined for each sector but that specialist journals were included for appropriate sectors. Interpretations of these results using mean and standard deviation tests (as on page 265) showed which channels were effective for keeping the various sectors up-to-date with both business and material developments. Table 7.3 ranks the channels for each sector according to their mean and standard deviation values. Table 7.4 combines the results for each sector and presents an overall picture.

Discussion of Results

(a) Business Developments:

It will be noted that in every sector, except for the aerospace and "Other"* industries, that the Financial Times was ranked in the top six - and that overall i.e. the combined industrial sectors, the Financial Times was regarded as the most effective information channel for keeping up-to-date with business developments. Of the top nine information channels (i.e. above the mean value of x) ranked in the overall table (i.e. 7.4), five were technical journals - The Engineer, Engineering Materials and Design, Design Engineering, Engineering, and Materials Engineering - three were

* see page 18 for explanation of "other" category.

Table 7.3

AEROSPACE

Business Developments

Sample size	Information channel	$\bar{x}$	σ
17	The Engineer	2·59	1·66
16	Aviation Week & Space Technology	2·13	1·99
18	The Daily Telegraph	2·00	1·75
18	Design Engineering	1·72	1·64
18	The Sunday Times	1·72	1·74
18	Chartered Mechanical Engineer	1·61	1·69
17	Engineering	1·59	1·66
18	Engineering Materials & Design	1·56	1·42
18	BBC's Tomorrow's World	1·28	1·36
16	Aircraft Engineering	1·13	1·41
18	Metallurgist & Materials Technologist	1·06	1·43
18	New Scientist	0·94	1·11
18	What's New in Industrial Products & Equipment	0·89	1·08
18	The Financial Times	0·89	1·66
16	Aeronautical Journal	0·88	1·02
18	Plastics Engineering	0·83	1·15
18	The Times	0·78	1·27
18	Material's Engineering	0·78	1·35
18	The Guardian	0·72	1·32
18	Metals & Materials	0·72	1·45
18	Composites	0·50	1·09
18	Abstracts	0·50	1·24
18	Material's Science & Engineering	0·33	1·09
18	Nature	0·11	0·47

Material Developments

Sample size	Information channel	$\bar{x}$	σ
25	Engineering Materials & Design	2·92	1·29
22	The Engineer	2·73	1·35
25	Design Engineering	2·64	1·38
21	Aviation Week & Space Technology	2·05	1·49
25	Abstracts	1·92	2·02
22	Engineering	1·86	1·39
25	Chartered Mechanical Engineer	1·79	1·72
25	Metallurgist & Materials Technologist	1·64	1·85
21	Aircraft Engineering	1·62	1·59
25	BBC's Tomorrow's World	1·60	1·35
25	Plastics Engineering	1·52	1·48
25	Material's Engineering	1·52	1·69
21	Aeronautical Journal	1·40	1·40
25	Composites	1·36	1·75
25	Metals & Materials	1·20	1·71
25	New Scientist	1·04	1·34
25	What's New in Industrial Products & Equipment	0·84	1·14
25	The Daily Telegraph	0·80	1·04
25	The Financial Times	0·80	1·22
25	The Sunday Times	0·76	1·20
25	Material's Science & Engineering	0·52	1·26
25	The Times	0·36	0·76
25	The Guardian	0·32	0·69
25	Nature	0·24	0·88

Recommended info. channels lie above mean line ——

Table 7.3 GENERAL ENGINEERING 1

Business Developments

Sample size	Information channel	$\bar{x}$	σ
40	The Financial Times	2·48	1·98
40	Design Engineering	2·15	1·33
40	The Sunday Times	1·82	1·5
40	Engineering Material & Design	1·70	1·6
40	BBC's Tomorrow's World	1·65	1·17
40	Daily Telegraph	1·42	1·58
40	Material's Engineering	1·20	1·42
40	The Times	1·03	1·47

40	What's New in Industrial Products & Equipment	0·90	1·16
40	Chartered Mechanical Engineer	0·78	1·22
40	Metals and Materials	0·78	1·3
40	Plastics Engineering	0·55	1·07
40	The Guardian	0·55	1·22
40	Metallurgist & Materials Technologist	0·50	1·14
40	Material's Science and Engineering	0·48	1·10
40	Composites	0·40	0·66
40	Abstracts (various)	0·40	0·83
40	New Scientist	0·23	0·26
40	Nature	0·00	0·00

Materials Developments

Sample size	Information channel	$\bar{x}$	σ
49	Design Engineering	2·94	1·19
49	Engineering Materials & Design	2·59	1·68
49	BBC's Tomorrow's World	2·49	1·07
49	Material's Engineering	1·88	1·62
49	The Financial Times	1·63	1·53
49	What's New in Industrial Products & Equipment	1·35	1·53
49	Metals & Materials	1·23	1·73
49	Chartered Mechanical Engineer	1·21	2·06

49	The Sunday Times	1·04	1·25
49	Plastics Engineering	0·90	1·4
49	Metallurgist and Materials Technologist	0·90	1·58
49	Material's Science & Engineering	0·86	1·54
49	Daily Telegraph	0·76	1·06
49	Abstracts (various)	0·51	1·26
49	New Scientist	0·47	1·15
49	The Times	0·33	0·68
49	Composites	0·31	0·81
49	The Guardian	0·31	0·81
49	Nature	0.10	0.5

Recommended channels lie above mean line ▬

Table 7.3 GENERAL ENGINEERING 2

Business Developments

Sample size	Information channel	$\bar{x}$	σ
21	Design Engineering	1·95	1·75
21	Engineering Materials & Design	1·90	1·73
16	The Engineer	1·81	1·80
21	The Financial Times	1·71	1·98
21	BBC's Tomorrow's World	1·67	1·65
16	Engineering	1·31	1·62
21	The Daily Telegraph	1·10	1·61
21	What's New in Industrial Products & Equipment	0·90	1·51
21	Chartered Mechanical Engineer	0·86	1·42
23	Abstracts (various)	0·70	1·72
21	The Sunday Times	0·67	1·15
21	Material's Engineering	0·62	1·07
21	Metals and Materials	0·62	1·20
21	Metallurgist & Materials Technologist	0·57	1·12
21	Plastics Engineering	0·52	1·03
21	Composites	0·33	0·97
21	New Scientist	0·29	0·78
21	The Guardian	0·29	0·90
21	The Times	0·29	0·96
21	Material's Science and Engineering	0·24	0·62
21	Nature	0·05	0·22

Materials Developments

Sample size	Information channel	$\bar{x}$	σ
22	Engineering Materials & Design	2·55	1·68
22	Design Engineering	2·41	1·65
16	The Engineer	1·88	1·41
22	BBC's Tomorrow's World	1·73	1·42
16	Engineering	1·44	1·55
22	What's New in Industrial Products & Equipment	1·09	1·74
22	The Financial Times	0·95	1·29
24	Abstracts (various)	0·92	1·86
22	Metallurgist and Materials Technologist	0·91	1·80
22	Metals and Materials	0·86	1·78
22	Plastics Engineering	0·82	1·47
22	The Sunday Times	0·64	1·00
22	Chartered Mechanical Engineer	0·64	1·22
22	Material's Engineering	0·64	1·26
22	The Daily Telegraph	0·55	0·96
22	New Scientist	0·41	0·96
22	Material's Science and Engineering	0·32	0·84
22	Composites	0·27	0·94
22	The Guardian	0·18	0·66
22	The Times	0·14	0·47
22	Nature	0·05	0·21

Recommended info. channels lie above mean line ▬▬

Table 7.3

MATERIAL PRODUCERS

Business Developments

(Mean line falls after "BBC's Tomorrow's World".)

Sample size	Information channel	$\bar{x}$	σ
18	The Financial Times	2·72	1·96
18	The Daily Telegraph	2·00	1·68
8	The Engineer) Engineering)	1·63	1·51
8			
18	The Sunday Times	1·56	1·72
18	Abstracts (various)	1·35	1·98
18	What's New in Industrial Products & Equipment	1·28	1·71
18	The Times	1·28	1·74
18	Engineering Materials & Design	1·25	1·34
18	Design Engineering	1·22	1·48
18	BBC's Tomorrow's World	1·11	1·23
18	Metals and Materials	0·94	1·47
18	Chartered Mechanical Engineer	0·72	1·32
18	Plastics Engineering	0·67	1·24
18	The Guardian	0·66	1·37
18	Material's Engineering	0·56	1·04
18	Material's Science & Engineering	0·56	1·15
18	New Scientist	0·39	0·92
18	Metallurgist & Materials Technologist	0·39	1·04
18	Nature	0·33	0·84
18	Composites	0·22	0·55

Materials Developments

(Mean line falls after "Chartered Mechanical Engineer".)

Sample size	Information channel	$\bar{x}$	σ
25	Engineering materials & Design	2·20	1·35
25	BBC's Tomorrow's World	2·16	1·37
11	Engineering	1·82	1·54
25	Design Engineering	1·72	1·59
25	What's New in Industrial Products & Equipment	1·68	1·73
25	Abstracts (various)	1·65	1·21
11	The Engineer	1·64	1·63
25	The Financial Times	1·60	1·55
25	Metals and Materials	1·36	1·70
25	Material's Engineering	1·24	1·49
25	Chartered Mechanical Engineer	1·20	1·63
25	The Daily Telegraph	1·12	1·27
25	Metallurgist & Materials Technologist	1·00	1·71
25	Material's Science & Engineering	0·84	1·40
25	The Sunday Times	0.72	1·02
25	New Scientist	0·68	1·25
25	Plastics Engineering	0·52	1·33
25	The Times	0·44	0·77
25	The Guardian	0·28	0·68
25	Composites	0·24	0·72
25	Nature	0·20	0·58

Recommended info. channels lie above mean line ▬▬

Table 7.3 NUCLEAR SECTOR

Business Developments

Sample size	Information channel	$\bar{x}$	σ
14	New Scientist	2·78	0·97
14	The Financial Times	2·71	1·89
13	The Engineer	2·23	1·48
14	The Sunday Times	2·14	1·95
13	Engineering	2·08	1·38
14	The Times	2·00	1·66
14	The Daily Telegraph	1·79	1·72
14	Engineering materials & Design	1·71	1·38
14	Chartered Mechanical Engineer	1·71	1·86
14	The Guardian	1·64	1·69
14	Design Engineering	1·57	1·55
14	BBC's Tomorrow's World	1·36	1·39

Sample size	Information channel	$\bar{x}$	σ
14	Material's Engineering	1·29	1·44
14	Metals & Materials	1·14	1·29
14	Metallurgist & Materials Technologist	1·07	1·54
14	Material's Science & Engineering	0·79	1·37
14	Abstracts	0·75	1·18
13	Carbon	0·46	0·88
13	A.W.R.E. News	0·31	0·75
14	What's New in Industrial Products & Equipment	0·29	0·73
14	Composites	0·29	1·07
14	Plastic Engineering	0·21	0·58
14	Nature	0·14	0·36

Material Developments

Sample size	Information channel	$\bar{x}$	σ
17	Engineering Materials & Design	2·76	1·69
17	New Scientist	2·48	1·46
16	Engineering	2·38	1·54
16	The Engineer	2·31	1·49
17	Material's Engineering	2·24	1·82
17	BBC's Tomorrow's World	2·06	1·56
17	Metals & Materials	2·00	1·80
17	Chartered Mechanical Engineer	2·00	1·97
17	Metallurgist & Materials Technologist	2·00	2·00
17	Design Engineering	1·94	1·78
17	Material's Science & Engineering	1·76	1·86
17	The Financial Times	1·59	1·37
17	Abstracts	1·50	2·07

Sample size	Information channel	$\bar{x}$	σ
17	Nature	0·82	1·38
17	The Times	0·76	0·90
17	The Daily Telegraph	0·76	1·03
17	The Sunday Times	0·65	0·79
17	The Guardian	0·65	0·93
16	A.W.R.E. News	0·56	1·26
16	Carbon	0·50	1·10
17	What's New in Industrial Products & Equipment	0·47	1·07
17	Composites	0·47	1·12
17	Plastics Engineering	0·24	0·66

Recommended info. channels lie above mean line ▬

Table 7.3 ROAD TRANSPORT

Business Developments

Sample size	Information channel	$\bar{x}$	σ
34	The Financial Times	2·56	2·27
21	The Engineer	2·38	1·91
34	Design Engineering	2·00	1·49
34	The Daily Telegraph	1·94	1·77
21	Automotive Engineering	1·90	1·64
34	Engineering Materials & Design	1·79	1·47
34	BBC's Tomorrow's World	1·62	1·23
21	Engineering	1·52	1·78
34	The Sunday Times	1·38	1·69
21	SAE Journal	1·19	1·57
34	The Times	1·12	1·67
34	Chartered Mechanical Engineer	1·06	1·48
22	Commercial motor	1·05	2·22

Sample size	Information channel	$\bar{x}$	σ
34	Plastics Engineering	0·97	1·51
21	Automotive News	0·95	1·63
34	Material's Engineering	0·82	1·31
34	Metals & Materials	0·59	1·08
34	Metallurgist and Materials Technologist	0·56	1·14
34	Abstracts	0·56	1·16
34	What's New in Industrial Products & Equipment	0·53	0·93
34	The Guardian	0·41	1·02
22	Motor Transport	0·35	1·34
34	New Scientist	0·26	0·71
34	Composites	0·26	0·79
34	Material's Science & Engineering	0·24	0·74
34	Nature	0·09	0·38
21	Motor Trade Executive	0·00	0·00

Material Developments

Sample size	Information channel	$\bar{x}$	σ
39	Design Engineering	2·87	1·61
39	Engineering Materials & Design	2·82	1·62
25	Automotive Engineering	2·44	1·83
39	BBC's Tomorrow's World	2·26	1·12
25	The Engineer	2·08	1·78
39	Abstracts	2·05	1·17
25	Engineering	1·80	1·78
39	Plastics Engineering	1·67	1·79
25	SAE Journal	1·64	1·85
39	Chartered Mechanical Engineer	1·56	1·77
39	Material's Engineering	1·56	1·89
39	The Financial Times	1·38	1·52

Sample size	Information channel	$\bar{x}$	σ
39	What's New in Industrial Products & Equipment	1·15	1·48
39	Metals & Materials	1·15	1·73
39	Metallurgist & Materials Technologist	1·10	1·85
39	The Sunday Times	0·95	1·29
25	Automotive News	0·92	1·63
26*	Commercial Motor	0·92	1·84
39	The Daily Telegraph	0·90	1·02
39	The Times	0·67	1·13
39	Material's Science & Engineering	0·56	1·31
26*	Motor Transport	0·50	1·25
39	New Scientist	0·46	1·02
39	Composites	0·46	1·14
39	The Guardian	0·26	0·64
39	Nature	0·18	0·68
25	Motor Trade Executive	0·12	0·60

Recommended info. channels lie above mean line ——

* Mentioned by 1 respondent in original survey under 'others'
Therefore 26 not 25 samples

Table 7.3 RESEARCH ESTABLISHMENTS AND INFORMATION SERVICES

Business Developments

Sample size	Information channel	$\bar{x}$	σ
16	The Financial Times	3·00	1·86
15	The Engineer	2·07	1·58
16	The Sunday Times	2·06	1·81
16	BBC's Tomorrow's World	1·81	1·56
16	Engineering Materials & Design	1·75	1·57
16	New Scientist	1·63	1·41
15	Engineering	1·53	1·41
16	The Daily Telegraph	1·44	1·59
16	Design Engineering	1·38	1·36

Sample size	Information channel	$\bar{x}$	σ
16	Material's Engineering	1·25	1·53
16	The Times	1·25	1·57
16	Metallurgist & Materials Technologist	1·06	1·39
16	Chartered Mechanical Engineer	1·00	1·59
16	The Guardian	0·88	1·50
16	Abstracts	0·85	1·18
16	Metals & Materials	0·81	1·17
16	Nature	0·69	1·08
16	What's New in Industrial Products & Equipment)	0·56	1·09
16	Composites)		
16	Material's Science & Engineering	0·44	0·96
16	Plastics Engineering	0·38	0·88

Material Developments

Sample size	Information channel	$\bar{x}$	σ
20	Engineering Materials & Design	2·85	1·79
20	New Scientist	2·63	1·49
20	BBC's Tomorrow's World	2·60	1·50
19	The Engineer	2·26	1·66
20	The Financial Times	2·15	1·60
20	Design Engineering	2·15	1·76
20	Abstracts	2·05	2·09
19	Engineering	1·84	1·74
20	The Sunday Times	1·65	1·23

Sample size	Information channel	$\bar{x}$	σ
20	Material's Engineering	1·50	1·91
20	Metallurgist & Materials Technologist)	1·50	1·93
20	Metals & Materials)		
20	Nature	1·40	1·67
20	Chartered Mechanical Engineer	1·10	1·59
20	Material's Science & Engineering	1·05	1·67
20	The Times	0·95	1·19
20	The Daily Telegraph	0·85	1·09
20	Composites	0·85	1·57
20	The Guardian	0·65	1·18
20	What's New in Industrial Products & Equipment	0·65	1·23
20	Plastics Engineering	0·65	1·46

Recommended info. channels lie above mean line ▬

Table 7.3 SMALL MARINE

Busniess Developments

Sample size	Information channel	$\bar{x}$	σ
10	Yachts & Yachting	2·30	1·64
10	BBC's Tomorros's World	1·70	1·42
10	Yachting Monthly	1·60	1·43
10	The Daily Telegraph	1·60	1·78
10	The Sunday Times	1·50	1·72
10	The Financial Times	1·40	1·58
10	Design Engineering	1·20	1·62
10 10	Engineering Materials & Design What's New in Industrial Products & Equipment	0·80	1·32
10	Dinghy Sailing	0·70	1·06
10	The Engineer	0·60	1·26
10 10	The Times International Dinghy	0·50	1·08
10 10 10	Chartered Mechanical Engineer Engineering Plastics Engineering	0·30	0·95
10 10 10	Composites The Guardian New Scientist	0·20	0·63
10 10 10 10 10 10	Abstracts Material's Engineering Material's Science & Engineering Metallurgist & Materials Technologist Metals & Materials Nature	0·00	0·00

Material Developments

Sample size	Information channel	$\bar{x}$	σ
12	Yachts & Yachting	2·75	1·71
13	BBC's Tomorrow's World	2·69	1·03
12	Yachting Monthly	1·67	1·57
13	Design Engineering	1·31	1·84
13	Plastics Engineering	1·08	1·50
13	New Scientist	0·92	1·26
12 12	Dinghy Sailing International Dinghy	0·92	1·31
13	Engineering Materials & Design	0·92	1·50
13	The Daily Telegraph	0·77	0·93
13	The Engineer	0·69	1·32
13	What's New in Industrial Products & Equipment	0·54	1·05
13	The Sunday Times	0·46	0·78
13	The Financial Times	0·46	0·88
13	Chartered Mechanical Engineer	0·46	1·20
13 13	Engineering Material's Engineering	0·38	0·96
13	Composites	0·31	0·75
13	Metals & Materials	0·23	0·83
13	The Times	0·08	0·28
13 13 13 13 13	Abstracts The Guardian Material's Science & Engineering Metallurgist & Materials Technologist Nature	0·00	0·00

Recommended info. channels lie above mean line ——

Table 7.3

OTHER

Business Developments

Sample size	Information channel	$\bar{x}$	σ
9	The Engineer	2·11	1·76
11	Design Engineering	1·82	1·54
11	BBC's Tomorrow's World	1·73	1·35
11	Engineering Materials & Design	1·73	1·56
11	What's New in Industrial Products & Equipment	1·55	1·29
11	Chartered Mechanical Engineer	1·45	1·69
8	Engineering	1·38	1·60
11	The Sunday Times	1·36	1·36
11	The Daily Telegraph	1·27	1·56
11	The Financial Times	1·27	1·90
11	The Guardian	1·18	1·40

11	New Scientist	0·56	1·29
11	Composites	0·55	1·21
11 11 11	Material's Engineering) Material's Science & Engineering) Metallurgist & Materials Technologist)	0·45	1·04
11 11	Metals & Materials) Plastics Engineering)	0·36	0·81
11	The Times	0·36	1·21
11	Nature	0·27	0·90
11	Abstracts	0·00	0·00

Material Developments

Sample size	Information channel	$\bar{x}$	σ
14	Design Engineering	3·43	0·94
14	Engineering Materials & Design	2·50	1·51
11	The Engineer	2·45	1·13
10	Engineering	2·20	1·62
14	BBC's Tomorrow's World	2·07	1·27
14	What's New in Industrial Products & Equipment	1·50	1·29
14	New Scientist	1·36	1·50
14	Plastics Engineering	1·29	1·94
14	Chartered Mechanical Engineer	1·21	1·53

14	The Daily Telegraph	1·07	1·14
14	The Financial Times	1·00	1·47
14 14	Composites) Material's Engineering)	0·79	1·37
14	The Sunday Times	0·71	1·07
14	Metallurgist & Materials Technologist	0·71	1·54
14	Metals & Materials	0·64	1·08
14	The Guardian	0·46	0·97
14	Material's Science & Engineering	0·43	1·16
14	The Times	0·29	1·07
14 14	Abstracts) Nature)	0·21	0·80

Recommended Info. channels lie above mean line ▬▬

Table 7.3

DUNLOP

Business Developments

Sample size	Information channel	$\bar{x}$	σ
12	Engineering Materials & Design	2·25	1·76
12	The Financial Times	2·10	1·67
12	Design Engineering	2·00	1·65
12	The Engineer	1·92	1·83
12	BBC's Tomorrow's World	1·75	1·48
12	The Daily Telegraph	1·75	1·86
12	Engineering	1·50	1·62
14	Abstracts	1·46	2·18
12	The Sunday Times	1·25	1·60
12	The Guardian	1·08	1·62
12	New Scientist	1·00	1·28
12	Material's Engineering	0·92	1·38
12	What's New in Industrial Products & Equipment	0·83	1·40
12	Chartered Mechanical Engineer	0·75	1·42
12	Material's Science & Engineering	0·67	1·23
12	Plastics Engineering	0·58	1·38
12	Composites	0·50	0·80
12	The Times	0·50	1·17
12	Nature	0·42	0·67
12	Metals & Materials	0·17	0·58
12	Metallurgist & Materials Technologist	0·00	0·00

Material Developments

Sample size	Information channel	$\bar{x}$	σ
14	Engineering Materials & Design	2·50	1·87
14	BBC's Tomorrow's World	2·21	1·19
14	Design Engineering	2·07	1·77
14	The Engineer	1·93	1·77
14 14	Engineering The Financial Times	1·57	1·70
16	Abstracts	1·56	2·16
14	New Scientist	1·21	1·53
14	What's New in Industrial Products & Equipment	1·07	1·54
14	The Sunday Times	0·93	1·21
14 14	Material's Engineering Material's Science & Engineering	0·93	1·59
14	Composites	0·79	1·12
14	Nature	0·79	1·31
14	The Daily Telegraph	0·64	0·93
14	Plastics Engineering	0·64	1·34
14	Chartered Mechanical Engineer	0·57	1·09
14	The Times	0·57	1·22
14	The Guardian	0·57	1·02
14	Metals & Materials	0·43	1·16
14	Metallurgist & Materials Technologist	0·29	1·07

Recommended info. channels lie above mean line ▬

Table 7.4 TOTAL FOR ALL INDUSTRIAL SECTORS

Business Development

Sample size	Information channel	$\bar{x}$	σ
182	The Financial Times	2·20	2·04
111	The Engineer	2·14	1·65
182	Engineering Materials & Design	1·83	1·25
182	Design Engineering	1·78	1·51
182	The Daily Telegraph	1·63	1·46
182	The Sunday Times	1·57	1·64
182	BBC's Tomorrow's World	1·56	1·32
109	Engineering	1·48	1·55
182	Material's Engineering	1·21	0·92

Sample size	Information channel	$\bar{x}$	σ
182	Chartered Mechanical Engineer	1·02	1·47
182	The Times	0·98	1·51
182	What's New in Industrial Products & Equipment	0·82	1·22
182	Metals & Materials	0·70	1·21
182	Metallurgist & Materials Technologist	0·63	1·20
182	Plastics Engineering	0·60	1·10
182	New Scientist	0·58	1·05
198	Abstracts (various)	0·51	1·27
182	The Guardian	0·41	1·28
182	Material's Science & Engineering	0·39	0·96
182	Composites	0·33	0·88
182	Nature	0·15	0·34

Material Development

Sample size	Information channel	$\bar{x}$	σ
224	Engineering Materials & Design	2·56	1·61
224	Design Engineering	2·50	1·61
224	BBC's Tomorrow's World	2·20	1·30
137	The Engineer	2·13	1·56
133	Engineering	1·75	1·53
224	Material's Engineering	1·43	1·69
224	The Financial Times	1·35	1·49
224	Chartered Mechanical Engineer	1·29	1·62

Sample size	Information channel	$\bar{x}$	σ
224	Metals & Materials	1·18	1·70
224	What's New in Industrial Products & Equipment	1·10	1·46
224	Metallurgist & Materials Technologist	1·10	1·74
230	Abstracts (various)	1·08	1·10
224	Plastics Engineering	1·01	1·51
224	New Scientist	0·97	1·41
224	The Sunday Times	0·89	1·16
224	The Daily Telegraph	0·83	1·06
224	Material's Science & Engineering	0·72	1·71
224	Composites	0·53	1·19
224	The Times	0·46	0·83
224	The Guardian	0·34	0·79
224	Nature	0·31	0·90

Recommended info. channels lie above mean line ——

newspapers, and one a television programme. These five technical journals figured prominently in keeping the material decision maker in touch with business developments. Very few of the industrial sectors studied appeared to rely on specialist journals for keeping them in touch with business developments. The only exceptions were the aerospace and small marine industries who used Aviation Week and Space Technology, Yachts and Yachting and Yachting Monthly respectively. The nuclear and power industries and research establishments were the only two sectors to rank the New Scientist highly for this function - first and sixth respectively - though it is doubtful whether the New Scientist could be regarded as a specialist journal to those areas.

(b) Material Developments:

In every sector, except the small marine industry, Engineering Materials and Design was ranked either first or second. Overall, Engineering Materials and Design was ranked first. The New Scientist which was ranked second by the nuclear and power industries and research establishments did not figure prominently in any other sector. A large number of abstracts, twenty four, were cited by the comparatively few material decision makers who used them. Although they were ranked quite highly by some sectors - aerospace (fifth), material producer (sixth), road transport (sixth), research establishments (seventh) - they were not regarded at all highly by the small marine and "other" industries. This tended to bring their ranking down in the overall picture - though it must be pointed out that there was no single abstract which really stood out from the other twenty three. Therefore, although they appear to be an important information channel when considered under the general label of 'abstracts' it would be difficult to recommend a particular example. Although television was not regarded as an effective information source for material information - see page 271 - the BBC's Tomorrow's World programme was ranked third overall. It is interesting to note that the results of the information channel study are in agreement with the order for the information sources, i.e.

Information Source	Information Channel
1 Journals	1 Engineering Materials and Design
7 Television	2 Design Engineering
8 Newspapers	3 BBC's Tomorrow's World
	7 The Financial Times

(Comparison of source ranking p.271 and channel table 7.4)

It will be noticed that the Financial Times was the only newspaper to be ranked in the top eight information channels for material developments. This is probably due to the fact that it is the only newspaper to carry a technical page. Many of the journals that apparently specialise in news about materials - Metallurgist and Materials Technologist, Plastics Engineering, Materials Science and Engineering, Metals and Materials, and Composites - were not rated at all highly by the material decision makers in most of the industrial sectors studied.

7.3 RECOMMENDED INFORMATION CHANNELS

To recommend which information channels are the most effective may at first glance appear to be easy. For example, the first three in each sector could be recommended, or where there appears to be a discontinuity in the mean ($\overline{x}$) rating, those above the discontinuity could be recommended. Such methods however, were overruled in favour of a less fickle criterion. The recommended information channels have been chosen by assuming that all those above the average of the mean ($\overline{x}$) level are useful channels. A cut-off line has accordingly been drawn across each column for tables 7.3 and 7.4. An easier interpretation of this may be seen in figure 7.4 where a plot of the mean value for business developments has been set against the mean value for material developments, for the combined sectors. The cut-off lines have been drawn at 1·07 for business developments and 1·23 for material developments - see table 7.4. Thus, those channels to the right of the abscissa cut-off are recommended for material developments, and those above the ordinate cut-off are recommended for business developments. It is interesting to note that two straight lines can be drawn through the newspapers (line A-A) and journals (line B-B). All the newspapers have a displacement from line B-B indicating a bias toward business activity, as would be expected.

Such a recommendation, particularly for material producers wishing to promote materials does however ignore the coverage that these channels actually give to materials. A study of ten selected channels was made to investigate the

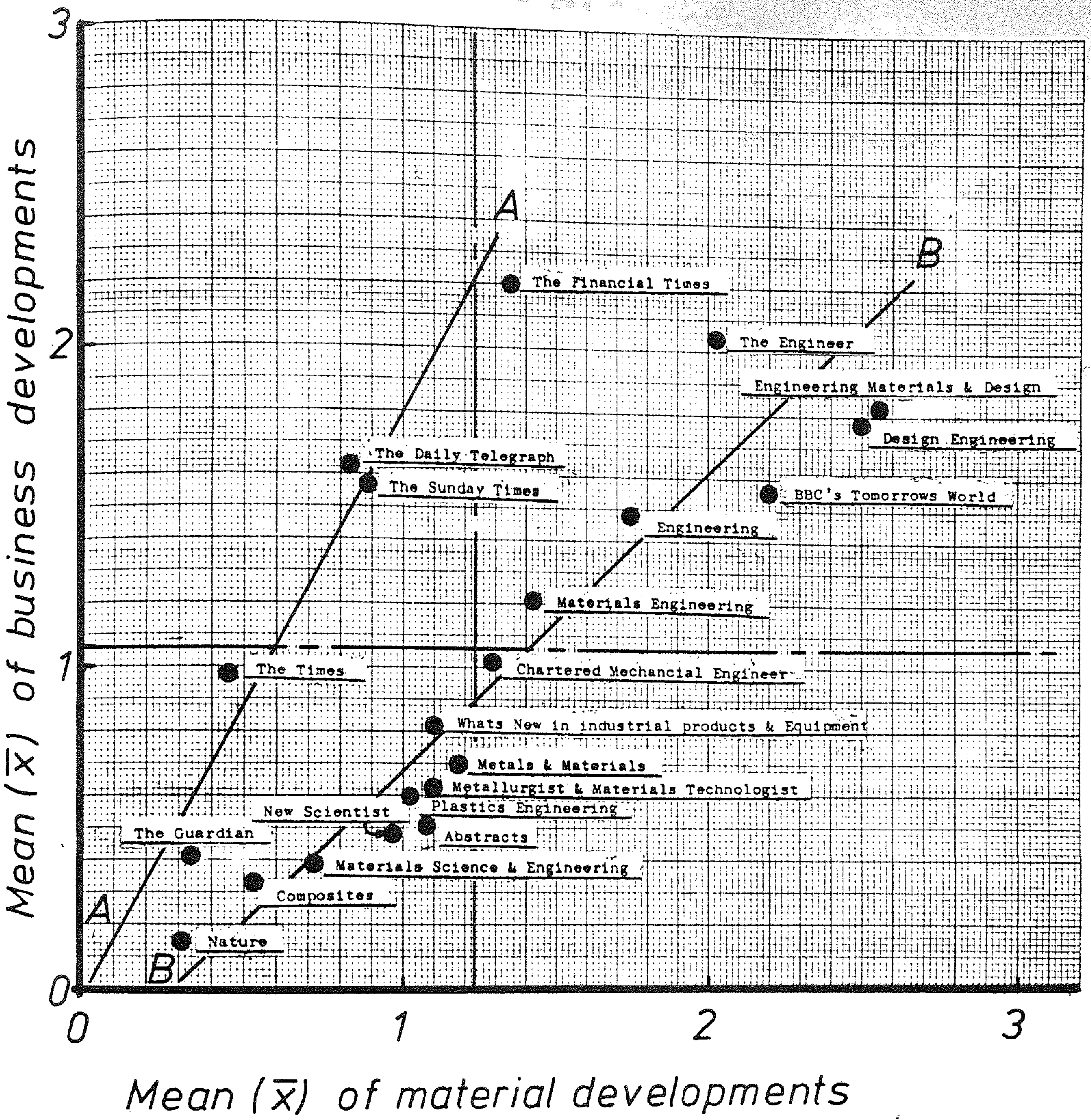


Figure 7.4 Illustrates which Information Channels Should be Used for Business Developments and Material Developments as Indicated by 224 Material Decision Makers (i.e. all industrial sectors)

coverage that they gave to materials; both structural and non structural, i.e. oil, paints, foams and so forth. Table 7.5 shows the result of such a study over a six month period. On the basis of the number of feature articles on structural materials per issue as the criterion for selecting information channels, then the following should be used in order of preference:-

Engineering Materials and Design

Design Engineering

Materials Engineering)
Metals and Materials) ranked equal

Chartered Mechanical Engineer

Metallurgist and Materials Technologist

The Engineer

Engineering

New Scientist

BBC's Tomorrow's World

Engineering Materials and Design and Design Engineering thus stand out as the two most prominent journals for promoting materials, on the basis that they (i) are rated highly by the material decision makers and (ii) they give the most coverage to structural materials.

Such results broadly agree with the findings of other authors. For example Turner, who studied the best format for design information concluded that ninety five percent of designers did not generally use data sheets, whereas design journals were widely used (90% used some number or other). Shears, who studied the information requirements of design engineers

Table 7.5 Indicates the coverage given to materials by some selected communication channels

Information channel (and country of origin)	Nos. of feature articles (A)	Nos. of feature articles on structural materials (B)	Nos. of feature articles on non-structural materials (C)	B/ Issue	B/A%	No. of issues in period studied
BBC's Tomorrow's World (UK)	147	1	4	0·042	·68	24
CME (UK)	48	6(10) *	1(36)	1·0	12·5	6
Design Engineering (UK)	103	12(27)	13(34)	2·0	11·64	6
The Engineer (UK)	194	10	3	0·42	5·15	24
Engineering (UK)	56	2(7)	3(9)	0·3	3·57	6
Engineering Materials & Design (UK)	66	14(15)	6(49)	2·23	21·2	6 —Jan. to July exc. April
Material's Engineering (USA)	29	7(10)	10(81)	1·17	24·1	6
Metallurgist & Materials Technologist (UK)	19	5(13)	1(3)	0·83	26·3	6
Metals & Materials (UK)	30	7(8)	0(2)	1·17	24·1	6
New Scientist (UK)	71	2(12)	8(18)	0·08	0·03	26

Key: *( ) indicate the number of editorial articles, including those on product pages where applicable.

Note: Each channel was studied over a six month period from January to June 1977 except where stated.

showed that on a month to month basis, journals were the most frequently consulted information sources. As designers have already been identified as the major material decision maker (see page 239) it is perhaps not surprising that such results should be in agreement. The conclusion by Rothwell (1975) - see Chapter 4.9.1 - that technologists, in this case material decision makers, use secondary source literature (trade journals, textbooks and so on) in their information habits has also been vindicated. Hardly any of the MDM's regarded Materials Science and Engineering - the only scientific type journal - as being effective.

The overall result presented in this chapter either adds to or detracts from the claims made by various information channels concerning their effectiveness. For example The Engineer's claim to be 'the best read publication - bar none' in the engineering industries is very nearly true for the MDM's. The Financial Times has claimed to be the best read publication for businessmen over many years, most recently stated on the 26th January, 1978, and this seems to be fully justified. The same cannot be said, at least not according to the MDM's, of New Scientist. During 1977 (e.g. 29 September) they were suggesting that they reached all the decision makers in a company. Perhaps this is so in the nuclear power engineering industries, but not apparently for all industrial sectors for business and material developments. The moral for all would-be innovators must be to check the effectiveness of information channels for themselves, before actually going into print with information concerning the innovation.

7.4 CHAPTER REVIEW

The literature review of Chapter 4.9 showed the importance of studying the effectiveness of various information sources and channels. This study has shown that contrary to some thinking, the literature - in the form of journals - is an important information source for material decision makers. Indeed, of the many information sources available to MDM's, it has been shown that journals are not only the most effective source but also the most widely used source for keeping the MDM's in touch with material developments. Sources such as patents and government information services have been shown to be ineffective and not widely used. Such findings serve to back up previous research which have suggested that mass media channels are important at the awareness stage of the innovation process.

Although more than twenty information channels were investigated for their effectiveness in keeping MDM's in touch with (a) business developments and (b) material developments, only seven have been identified as being capable of performing both functions. Five of these were engineering journals, the other two being a newspaper - The Financial Times - and a television programme - BBC's Tomorrow's World. Of the seven different industrial sectors studied, only two, aerospace and small marine rely on specialist journals to their industry for keeping them in touch with business developments. The others apparently are quite happy with general journals. After studying the effectiveness - as viewed by the MDM's - and coverage given by various information channels to materials, two journals in particular stand out: Engineering Materials and Design and Design Engineering for keeping the MDM's in touch with material developments.

8

THE ADOPTION RATE OF NEW MATERIALS

Page

8.1 CHAPTER PREVIEW

The adoption and diffusion process can be a lengthy part of an innovation. It is recognised that the awareness or knowledge phase is an important prelude to adoption, and the familiarity of 224 material decision makers with various new materials is investigated. Familiarity with material developments does not necessarily mean that adoption is rapid. This negative relationship has been investigated for several different industrial sectors.

8.2 ADOPTION AND ITS PLACE IN THE INNOVATION PROCESS

Material producers have of necessity to involve themselves in, and understand, the likely adoption pattern that their customers experience. As with many innovators, material producers do not just adopt the innovation within their own organisation, they are in business to sell the innovation to others. To do this they must understand the characteristics of the innovation which make it sell, know the likely innovators and early adopters, and be aware of the time scale between awareness and adoption. Although much of the literature covers this ground (see Chapter 4.10) the picture generated by these works shows a variety of industries, the consumer public included, taking different times to adopt different types of innovation. However, there is no published work that helps identify the early adopters of materials; and it was thought that the adoption of new materials by a variety of organisations in different industrial sectors would be different again from the adopters of product innovations. For a material producer who is introducing a new material, any sort of identification of the innovating or early adopting sectors of industry is useful. The following sections show the awareness that seven different industrial sectors have of new materials and the likely period for adoption.

8.3 AWARENESS AND RATE OF ADOPTION FOR NEW MATERIALS

The replies to questions six, seven and eight of the survey* "Decisions on Materials" have given a better understanding of (a) the level of awareness of new materials and (b) the rate of adoption that can be expected by various industrial sectors. Before presenting and discussing the implication of these results, it should be recognised that question six contained a spurious material: "Hi-sil", a high-strain silicon was the illegitimate material. It was included to try and detect any "tick-happy" respondents who might otherwise have influenced the overall result. Unfortunately, this ploy backfired, inasmuch that the trade name "Hi-Sil" and other similar names (hysil) have been used in the past - and in some cases are still in use today - for material descriptions. This necessitated a re-check with some of the material decision-makers who were aware of Hi-sil in forms other than a high-strain silicon to ensure the results would be as accurate as possible. Hi-sil was subsequently removed from analysis in the results.

8.3.1 MATERIAL DECISION MAKERS AND THEIR AWARENESS OF NEW MATERIALS

The 224 MDM's who replied to the survey were asked to indicate their familiarity with fourteen materials, on the basis that they: had used it, had investigated it for use, were familiar with it, or were unfamiliar with it. Table 8.1 shows the results tabulated for the individual industrial sectors and also the overall total. By combining the responses under the headings of use, have investigated for use, and familiar, into the one category of familiar, it has been possible to perform a χ^2 test.

TABLE 8.1 224 MDM's familiarity with various materials classified by Industrial Sector
(Key : HIFU = Have Investigated for Use)

INDUSTRIAL SECTOR	MATERIAL	USE	HIFU	FAMILIAR	UNFAMILIAR	MATERIAL	USE	HIFU	FAMILIAR	UNFAMILIAR
Aerospace	Antiphon M.P.M. - a metal /plastic/ metal sandwich			3 12%	22 88%	Kevlar	2 8%	8 32%	6 24%	9 36%
General Engineering		2 3%	4 6%	8 11%	57 80%		2 3%	5 7%	3 4%	61 86%
Material Producer			6 15%	4 10%	29 74%		1 3%	6 15%	2 5%	30 77%
Nuclear & Power Ind.				3 18%	14 82%		3 18%		1 6%	13 76%
Research Estab'ments			1 10%	3 15%	16 75%		4 20%	3 15%		13 65%
Road Transport			2 8%	8 32%	15 60%		1 4%	2 8%	2 8%	20 80%
Small Marine				1 8%	12 92%		2 15%	4 31%	3 23%	4 31%
Other					14 100%			3 21%	2 14%	9 64%
Total		2 1%	13 6%	30 13%	179 80%		15 7%	31 15%	19 9%	159 71%
Aerospace	Boron Nitride	2 8%	4 16%	14 56%	5 20%	Lamina-bronze surfaced steel				25 100%
General Engineering		5 7%		19 27%	47 66%			2 3%	13 18%	56 79%
Material Producer			2 5%	14 36%	23 59%		2 5%	1 3%	5 13%	31 80%
Nuclear & Power Ind.		3 18%	5 29%	6 35%	3 18%		1 6%			16 94%
Research Estab'ments		1 5%	4 20%	7 35%	8 40%				1 5%	19 95%
Road Transport		1 4%	4 16%	10 40%	10 40%				5 20%	20 80%
Small Marine				1 8%	12 92%				1 8%	12 92%
Other			1 7%	3 21%	10 72%				3 21%	11 79%
Total		12 5%	20 11%	74 33%	118 53%		3 1%	3 1%	28 13%	190 85%
Aerospace	Carbon/carbon- a carbon fibre reinforced carbon composite	3 12%	2 8%	8 32%	12 48%	Retimet Foam Metal	3 12%	2 8%	6 24%	14 56%
General Engineering		1 2%	5 7%	21 29%	44 62%			5 7%	12 17%	54 76%
Material Producer			2 5%	14 36%	23 59%			2 5%	12 31%	25 64%
Nuclear & Power Ind.			1 6%	7 41%	9 53%			2 12%	1 6%	14 82%
Research Estab'ments		2 10%	1 5%	13 65%	4 20%		2 10%	2 10%	3 15%	13 65%
Road Transport			1 4%	8 32%	16 64%			3 12%	5 20%	17 68%
Small Marine			2 15%	5 37%	6 46%					13 100%
Other				7 50%	7 50%		1 8%		2 14%	11 79%
Total		6 3%	14 6%	83 37%	121 54%		6 3%	16 7%	41 18%	161 72%
Aerospace	Carbon Fibre reinforced plastic	13 52%	5 20%	5 20%	2 8%	Samarium cobalt	3 12%		4 16%	18 72%
General Engineering		3 4%	12 17%	27 38%	29 41%				3 4%	68 96%
Material Producer		1 3%	11 28%	17 44%	10 26%			1 3%	1 3%	37 95%
Nuclear & Power Ind.		1 6%	4 24%	10 59%	2 12%			1 6%	3 18%	13 76%
Research Estab'ments		4 20%	4 20%	9 45%	3 15%				7 35%	13 65%
Road Transport		1 4%	3 12%	10 40%	11 44%				2 8%	23 92%
Small Marine		4 31%	7 54%	2 15%					1 8%	12 92%
Other		1 7%	4 28%	8 57%	1 7%		1 7%			13 93%
Total		28 13%	50 22%	88 39%	58 25%		4 2%	2 1%	21 9%	197 88%

/contd.

TABLE 8.1 (contd) 224 MDM's familiarity with various materials classified by Industrial Sector

INDUSTRIAL SECTOR	MATERIAL	USE	HIFU	FAMILIAR	UNFAMILIAR	MATERIAL	USE	HIFU	FAMILIAR	UNFAMILIAR
Aerospace				10 40%	15 60%		6 24%	7 28%	8 32%	4 16%
General Engineering			3 4%	17 24%	51 72%		3 4%	6 8%	17 24%	45 63%
Material Producer			2 5%	11 28%	26 67%		3 8%	3 8%	13 33%	20 51%
Nuclear & Power Ind.	Cem-Fil - Glass reinforced concrete		2 12%	4 24%	11 65%	Silicon nitride	3 18%	5 29%	5 29%	4 24%
Research Estab'ments			1 5%	10 50%	9 45%		3 15%	4 20%	8 40%	5 25%
Road Transport		2 8%		8 32%	15 60%		3 12%	6 24%	6 24%	10 40%
Small Marine			1 8%	3 23%	9 69%				3 23%	10 77%
Other				2 14%	12 86%			1 7%	5 36%	8 57%
Total		2 1%	9 4%	65 29%	148 61%		21 9%	32 14%	65 29%	106 47%
Aerospace		4 16%	6 24%	10 40%	5 20%		21 84%		4 16%	
General Engineering			8 11%	20 28%	43 61%		13 18%	3 4%	35 49%	20 28%
Material Producer		2 5%	12 31%	7 18%	18 46%		4 10%	2 5%	22 56%	11 28%
Nuclear & Power Ind.	Super-plastic alloys		4 24%	7 41%	6 35%	Titanium	6 35%	4 24%	7 41%	
Research Estab'ments			4 20%	7 35%	9 45%		3 15%	2 10%	13 65%	2 10%
Road Transport			5 20%	8 32%	12 48%		5 20%		13 52%	7 28%
Small Marine				3 23%	10 77%		1 8%	2 15%	3 23%	7 54%
Other		2 14%	2 14%	4 28%	6 43%		5 36%	1 8%	3 21%	5 36%
Total		8 4%	41 18%	66 29%	109 49%		58 26%	14 6%	100 45%	52 23%
Aerospace		6 24%		9 36%	10 40%				6 24%	19 76%
General Engineering		2 3%	2 3%	9 27%	18 68%			1 2%	14 20%	56 79%
Material Producer				11 28%	28 72%				8 20%	31 80%
Nuclear & Power Ind.	Tantalum	6 35%	3 18%	6 35%	2 12%	Vitreous metal	1 6%		5 29%	11 65%
Research Estab'ments		3 15%		8 40%	9 45%				9 45%	11 55%
Road Transport		2 8%	1 4%	9 36%	13 52%				6 24%	19 76%
Small Marine					13 100%					13 100%
Other		1 7%	2 14%	3 21%	8 57%				3 21%	11 79%
Total		20 11%	8 4%	65 29%	131 59%		1 5%	1 5%	51 23%	171 76%

Such a test shows which materials are significantly better (or less) known than a chosen reference material, in this case, carbon/carbon. This test was carried out on each set of materials for the different industrial sectors. Table 8.2 shows the result of the χ^2 test for the combined sectors only. It effectively allows a ranking to be formulated showing which materials are better or less known than carbon/carbon. For some there is no significant difference between the respondents' awareness of carbon/carbon and material x. Table 8.3 shows the ranking of awareness that the MDM's had for each material compared with carbon/carbon. From this, it can be seen that there is a band of materials that are not significantly more (or less) familiar to the MDM's than the control, carbon/carbon. Overall, this band includes boron nitride, silicon nitride, superplastic alloys and tantalum, although it does vary from sector to sector. Two materials, titanium and carbon fibre reinforced plastic stand out as being the only materials (from this list) that are significantly more familiar to the MDM's than carbon/carbon. That is not to say that these two have reached the hundred per cent awareness level with the people who really matter, the material decision-makers. There were more than twenty per cent of the MDM's who were unfamiliar with either of these materials. And although titanium and carbon fibre reinforced plastic were familiar to the majority of sectors, there were MDM's in individual sectors who were less familiar with them. For example, fifty four per cent of the small marine MDM's were unfamiliar with titanium whilst forty four per cent of the road transport MDM's were unfamiliar with carbon reinforced plastic. The other seven materials - cem-fil, kevlar,

Table 9.2 χ^2 test on 13 materials with respect to carbon/carbon, as indicated by 224 material decision-makers.

$$\left(\chi^2 = \frac{\Sigma(O-E)^2}{E} \quad : \text{ if } \chi^2 > 3\cdot84 \text{ (5\% level) reject Ho (null hypothesis)}\right)$$

Null hypothesis (Ho) - there is no significant difference between the MDM's awareness of carbon/carbon and material x.

	Familiar		Unfamiliar				
	Observed O	Expected E	Observed O	Expected E	Σ	χ^2	Comment
Carbon/carbon	103	74	121	150	224	34·74	reject Ho - Antiphon less familiar than carbon/carbon
Antiphon MPM	45	74	179	150	224		
Σ	148		300		448		
Carbon/carbon	103	104·5	121	119·5	224	0·08	accept Ho
Boron Nitride	106	104·5	118	119·5	224		
Σ	209		239		448		
Carbon/carbon	103	134·5	121	89·5	224	36·94	reject Ho - CFRP more familiar than carbon/carbon
CFRP	166	134·5	58	89·5	224		
Σ	269		179		448		
Carbon/carbon	103	89·5	121	134·5	224	6·8	reject Ho - Cemfil less familiar than carbon/carbon
Cemfil	76	89·5	148	134·5	224		
Σ	179		269		448		
Carbon/carbon	103	84	121	140	224	13·74	reject Ho - Kevlar less familiar than carbon/carbon
Kevlar	65	84	159	140	224		
Σ	168		280		448		
Carbon/carbon	103	68·5	121	155·5	224	50·06	reject Ho - Lamina less familiar than carbon/carbon
Lamina	34	68·5	190	155·5	224		
Σ	137		311		448		
Carbon/carbon	103	83	121	141	224	15·32	reject Ho - Retimet less familiar than carbon/carbon
Retimet	63	83	161	141	224		
Σ	166		282				
Carbon/carbon	103	65	121	159	224	62·56	reject Ho - samarium cobalt less familiar than carbon/carbon
Samarium Cobalt	27	65	197	159	224		
Σ	130		318		448		
Carbon/carbon	103	110·5	121	113·5	224	2·00	Accept Ho
Silicon nitride	118	110·5	106	113·5	224		
Σ	221		227		448		
Carbon/carbon	103	109	121	115	224	1·29	Accept Ho
Superplastic alloys	115	109	109	115	224		
Σ	218		230		448		
Carbon/carbon	103	98	121	126	224	0·91	Accept Ho
Tantalum	93	98	131	126	224		
Σ	196		252		448		
Carbon/carbon	103	137·5	121	86·5	224	44·44	reject Ho - titanium more familiar than carbon/carbon
Titanium	172	137·5	52	86·5	224		
Σ	275		173		448		
Carbon/carbon	103	78	121	146	224	24·58	reject Ho - vitreous metal less familiar than carbon/carbon
Vitreous metal	53	78	171	146	224		
Σ	156		292		448		

Table 8.3 Materials ranked according to familiarity (i.e. familiar, have investigated for use and used, have been combined under one heading - familiar) by the material decision-makers in each industrial sector.

	Aerospace	General Engineering	Material Producer	Nuclear & Power Industries	Research Establishments	Road Transport	Small Marine	Other	Total
Antiphon MPM	13	12	10^{x}	$12=^{x}$	13	$7=^{x}$	8=	14	12
Boron Nitride	4=	6^{x}	$5=^{x}$	4	5^{x}	$2=^{x}$	8=	8^{x}	5^{x}
Carbon/carbon	8^{x}	3^{x}	$5=^{x}$	7^{x}	3^{x}	9^{x}	3^{x}	4^{x}	6^{x}
CFRP	2	2	1	2=	2^{x}	4^{x}	1	1	2
Cem-fil	10^{x}	8^{x}	8^{x}	$8=^{x}$	$6=^{x}$	$7=^{x}$	5^{x}	12=	8
Kevlar	6^{x}	14	11^{x}	$10=^{x}$	10=	$12=^{x}$	2=	7^{x}	9
Lamina	14	10=	$12=^{x}$	14	14	$12=^{x}$	8=	$9=^{x}$	13
Retimet	9^{x}	9^{x}	7^{x}	$12=^{x}$	10=	10^{x}	12=	$9=^{x}$	10
Samarium Cobalt	11	13	14	$10=^{x}$	10=	14	8=	12=	14
Silicon Nitride	3	5^{x}	4^{x}	5^{x}	4^{x}	$2=^{x}$	$6=^{x}$	$5=^{x}$	3^{x}
Superplastic alloys	4=	4^{x}	3^{x}	6^{x}	$6=^{x}$	5^{x}	$6=^{x}$	3^{x}	4^{x}
Tanatalum	7^{x}	7^{x}	9^{x}	2=	$6=^{x}$	6^{x}	12=	$5=^{x}$	7^{x}
Titanium	1	1	2	1	1^{x}	1	4^{x}	2^{x}	1
Vitreous metal	12	10=	$12=^{x}$	$8=^{x}$	9	11^{x}	12=	$9=^{x}$	11

Note: x indicates that there is no significant difference between that material and the control carbon/carbon.

= indicates that the materials were ranked equally retimet, vitreous metal, antiphon-MPM, lamina and samarium cobalt - were all significantly less familiar to the MDM's than carbon/carbon. Whilst some of these are not well known generally to all of the industrial sectors there are some that are well known to particular sectors. Kevlar, for instance, is familiar to sixty nine per cent of the small marine MDM's, whereas overall, seventy one per cent of the MDM's were unfamiliar with it. Tantalum and silicon nitride are other examples of materials that are familiar to particular sectors, but not well known generally. Nearly ninety per cent of the MDM's in the nuclear and power sector were familiar with tantalum, and a similar figure (84%) of the aerospace MDM's were familiar with silicon nitride. Some materials, therefore, obviously have some properties which make them peculiarly familiar to sectors:

Titanium	familiar	to	100%	of	MDM's	in	aerospace and nuclear sectors
CFRP	"	"	100%	"	"	"	small marine sector
CFRP	"	"	92%	"	"	"	aerospace sector
CFRP	"	"	88%	"	"	"	nuclear power sector
Tantalum	"	"	88%	"	"	"	" " "
Boron Nitride	"	"	82%	"	"	"	" " "
Boron Nitride	"	"	80%	"	"	"	aerospace sector
Kevlar	"	"	69%	"	"	"	small marine sector
Kevlar	"	"	64%	"	"	"	aerospace sector

Such results show which materials are well-known throughout the various sectors of industry but do not show which sectors are more adept at keeping up-to-date with material developments. Using the results of Table 8.1 a material mean familiarity index has been calaculated for each sector.

Material Mean Familiarity Index

$$(\text{MMFI}) = \frac{\text{familiarity with each material}}{\text{number of materials}}$$

Table 8.4 thus shows the overall familiarity that each sector had with the fourteen materials quoted. Only three sectors, aerospace, research establishments and the nuclear and power industries were familiar with more than fifty per cent of the materials quoted.

Table 8.4 Material Mean Familiarity Index for different sectors of industry

	MMFI
Aerospace	54·3%
Research Establishments	52·5%
Nuclear and Power Industries	50·4%
Road Transport	42·0%
Material Producers	37·3%
Other Industries	35·6%
General Engineering	31·6%
Small Marine	27·0%
Total	40·4%

On average it could be expected that MDM's from any of these sectors would be familiar with just over 40 per cent of the new materials quoted. The results from the fourteen Dunlop MDM's were extracted from the other 224 respondents so that a comparison with the Dunlop organisation could be made. Table 8.5 shows their familiarity with the various materials. Their

Table 8.5 Familiarity of Dunlop MDM's with some new materials

Note: Material Mean Familiarity Index = 43·9%

Material	Use	Have investigated for use	Familiar	Un-Familiar
Antiphon MPM - a metal plastic/metal sandwich			2 14%	12 86%
Boron Nitride	1 7%	1 7%	4 29%	8 57%
Carbon/carbon - a carbon fibre reinforced carbon composite	3 21%		9 64%	2 14%
Carbon fibre reinforced plastic	4 28%	1 7%	5 36%	4 28%
Cem-fil - glass reinforced concrete			4 29%	10 71%
Kevlar	3 21%	6 43%		5 36%
Lamina - bronze surfaced steel			1 7%	13 93%
Retimet - foam metal	3 21%	4 28%	6 43%	1 7%
Samarium cobalt			2 14%	12 86%
Silicon Nitride		1 7%	5 36%	8 57%
Superplastic alloys		2 14%	6 43%	6 43%
Tantalum			2 14%	12 86%
Titanium	1 7%		8 57%	5 36%
Vitreous metal		1 7%	1 7%	12 86%

MMFI of 43·9 per cent was slightly above the average, although two of the materials quoted, carbon/carbon and retimet are Dunlop products, which probably raised their MMFI.

8.3.2 THE ADOPTION RATE OF NEW MATERIALS

It might be thought that those sectors of industry that are most familiar with material developments would also be the ones to adopt new materials into their products or processes most rapidly. Such a hypothesis has been investigated for the various industrial sectors mentioned.

Each material decision-maker was asked to list those new structural* materials that had been used in their products or processes within the last ten years. A total of 234 materials were mentioned by 143 of the MDM's. The remaining eighty one MDM's claimed to have no knowledge of any new materials being introduced into their organisation over the last ten years! Table 8.6 shows the breakdown of these materials adopted over a time scale of twenty five years, by the various industrial sectors. The overall pattern of adoption is shown in figure 8.1 and appears to be similar in most sectors (figure 8.2), inasmuch that relatively few materials (about 20%) are adopted within the first year of the MDM's awareness of it+. Two exceptions to this, are in

* Although interpretation of structural material was left to the individual MDM's any material performing a structural function was permitted, be it a shoe leather, hydraulic hose, a bone prosthesis or building structural material, the criterion being that it should be used in a load-bearing application. A new material has been defined as being new to a particular organisation. As an example, it could be that aluminium (the new material), hitherto unused by the MDM's organisation, is used to replace copper.

\+ The MDM's awareness to adoption time of a new material is taken to mean the time from which he was aware that the material was a candidate for his particular application, and not just a general awareness of its existence.

Table 8.6 Adoption of new materials by various sectors of industry, as indicated by 143 Material Decision-Makers

Industrial sector	Nos of new materials adopted after "n" years awareness by MDM: Less than 1 yr	1-2 yrs	2-5 yrs	5-10 yrs	10-17 yrs	17-25 yrs	Nos. of MDM's in sector	Nos of MDM's with no knowledge of new material intro. in past 10 yrs.
Aerospace	4(9%)	9(19%)	22(47%)	12(26%)			25	4
General Engineering	20(36%)	14(25%)	10(18%)	7(13%)	1(2%)	3(5%)	71	28
Material Producer	3(14%)	9(41%)	3(14%)	6(27%)		1(5%)	25	9
Nuclear & Power Industries	5(24%)	12(57%)	4(19%)				17	5
Research Establishments	4(17%)	8(33%)	10(42%)	2(8%)			20	9
Road Transport	6(17%)	12(33%)	13(36%)	3(8%)	2(6%)		39	18
Small Marine	10(71%)	1(7%)	1(7%)	2(14%)			13	4
Other	2(13%)	7(47%)	3(21%)	3(21%)			14	4
Total	54(23%)	72(31%)	66(28%)	35(15%)	3(1%)	4(2%)	224	81
Dunlop	4(20%)	3(15%)	9(45%)	2(10%)	1(5%)	1(5%)	14	4

Note: ( ) indicates the percentage of materials adopted in that period.

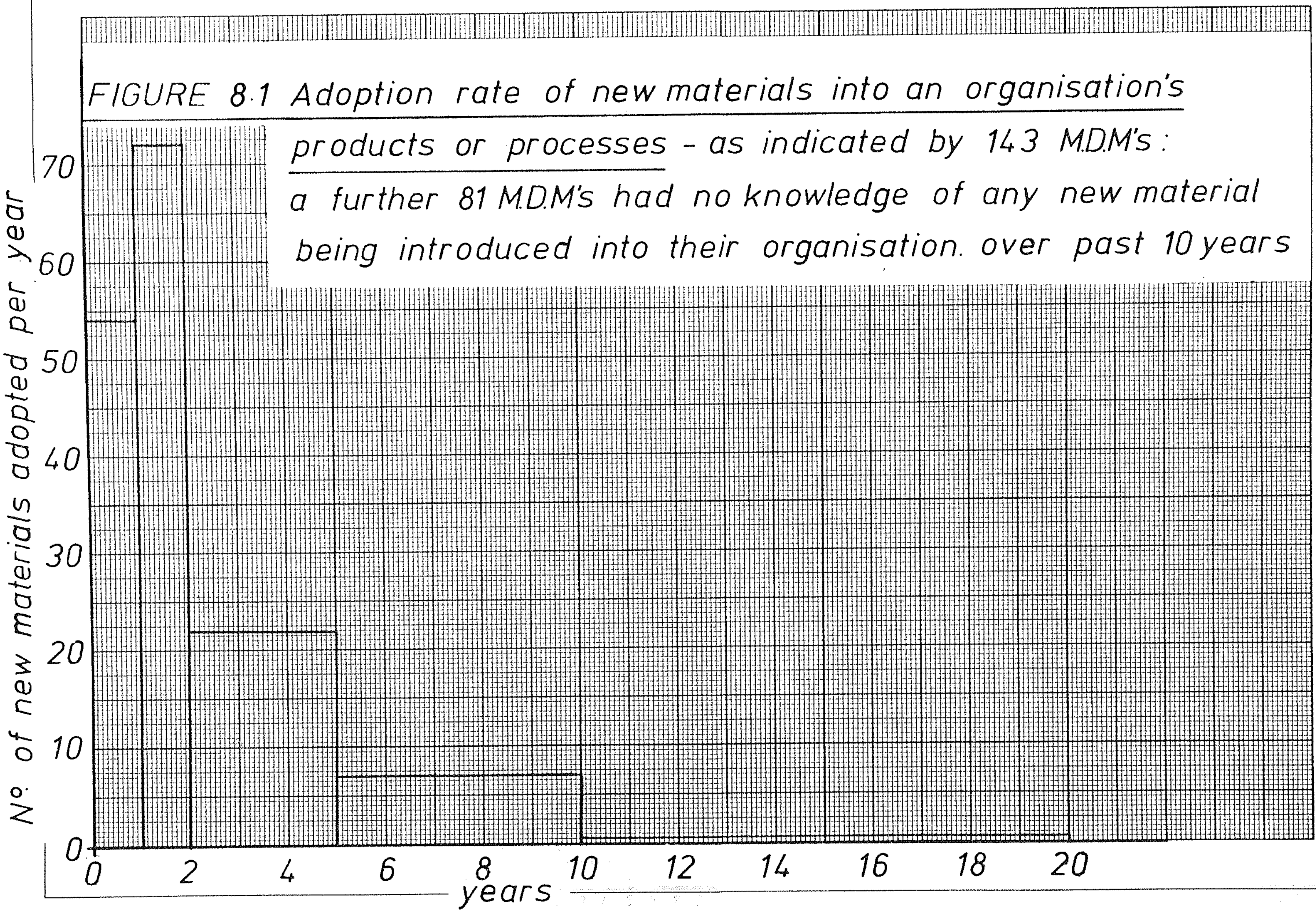
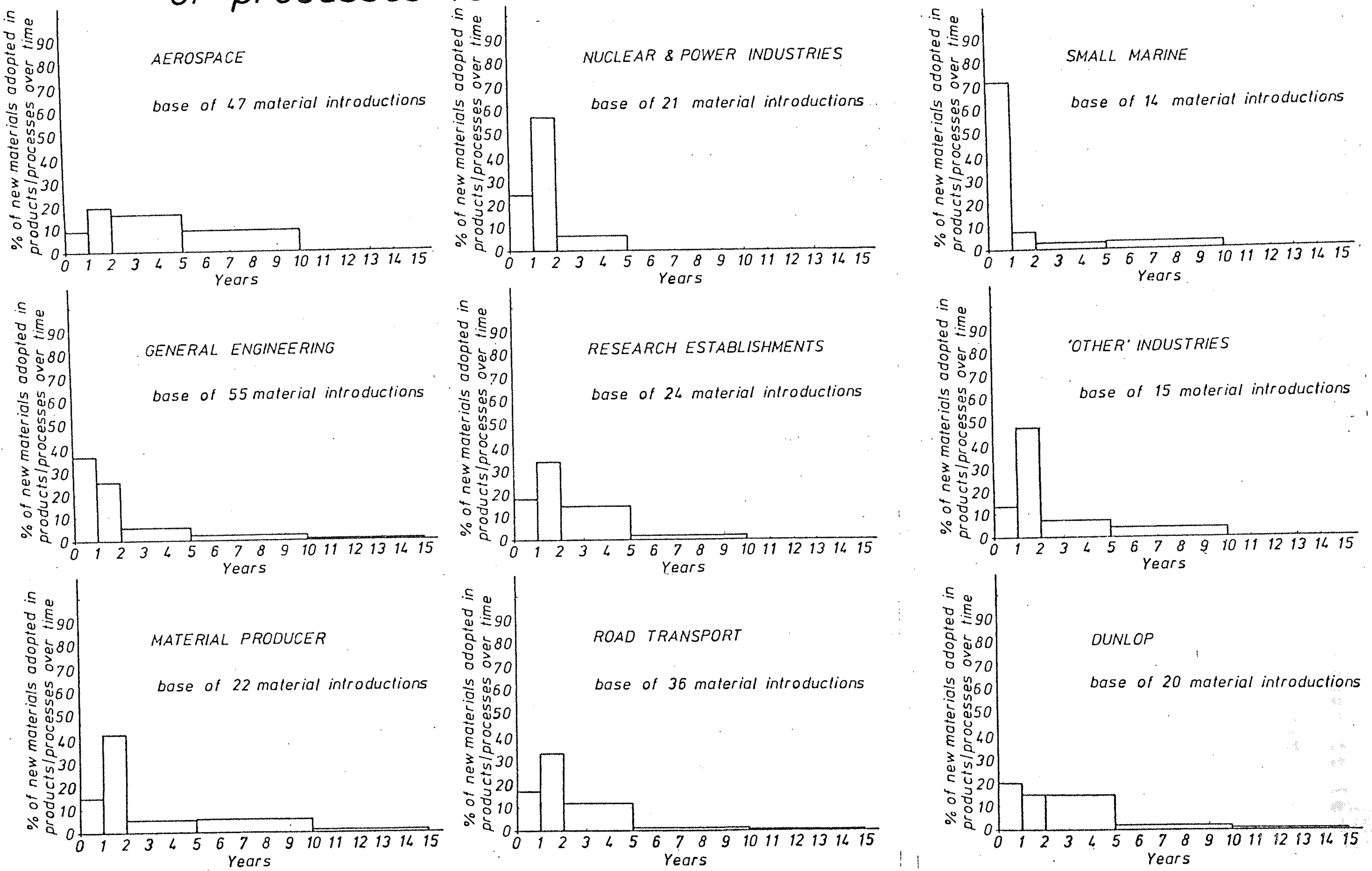


FIGURE 8.1 Adoption rate of new materials into an organisation's products or processes - as indicated by 143 M.D.M's: a further 81 M.D.M's had no knowledge of any new material being introduced into their organisation. over past 10 years

Figure 8.2 Adoption rate of new materials into an organisations products or processes for different industrial sectors



the small marine and general engineering sectors where seventy one per cent and thirty six per cent respectively of new materials are adopted within the first year. In most cases it is between years one and two that the largest percentage (31%) of materials are adopted. Again, there are exceptions to this: the aerospace sector adopted forty seven per cent of their new materials after two to five years awareness of it, and similarly forty two per cent and thirty six per cent were adopted by the research establishments and road transport industry in this period. Some sectors do appear to take longer than this to adopt - twenty six per cent were not adopted in the aerospace industry until five to ten years had elapsed of the MDM's awareness of it, similarly twenty seven per cent took the same time in the material producing sector. Overall, though, it would appear that if a new material is going to be adopted by an organisation for its products, then the vast majority (82%) will have been used within five years of the MDM's first awareness of it.

Whilst the small marine and general engineering sectors appear to be the two that can be expected to adopt new materials, most rapidly, it should not be overlooked that thirty one per cent and thrity nine per cent respectively of the MDM's in those sectors had no knowledge of any new material introduction into their organisation over the last ten years. Another comparatively rapid adopter, the road transport industry - eighty seven per cent of new materials adopted by year five - had a staggering forty six per cent of their MDM's who were unaware of new material introductions. A similar figure, forty five per cent, for the research establishment MDM's might be explained by the fact that they are not directly associated with manufacturing products. However, a sector that appears to adopt new materials more warily, the aerospace industry, had only sixteen per cent of their MDM's with no knowledge of new material introductions over the last ten years. It had been expected that results in the nuclear and power industries would follow a similar adoption pattern to that of the aerospace sector, both being involved with advanced technology products and having similar stringent safety procedures to meet. That all new materials in the nuclear and power industry should be in use after only five years awareness by the MDM's seems quite remarkable. The discrepancy between those MDM's indicating a rapid adoption of new materials and other MDM's being unaware of new material introductions over the past ten years distinguishes those organisations who are innovators and early adopters from the late majority or laggards. And, although the small marine and general engineering industries appear to adopt materials most rapidly, material producers should be aware that it is only about two-thirds of the organisations in those sectors that actually adopt at that fast rate.

The adoption habits of the Dunlop organisation have been distilled from the overall picture, and a plot of their adoption rate is included in figure 8.2. Their rate of adoption appears to be rather slower than the norm, and there were twenty eight per cent of the MDM's who had no knowledge of new material introductions in the last ten years.

Comparison of the adoption habits and material mean familiarity index between the various industrial sectors presents some interesting issues. It would appear that the advanced technology industries adopt more slowly than the medium technology industries although they have a better awareness of material developments. A pattern of some industrial sectors adopting a material more rapidly than others is perhaps a little misleading without actually examining the reasons behind the adoption rate. Industries that are involved with advanced technology products*, such as aerospace and nuclear and power industries have stringent quality control requirements to meet - for instance, materials to be used in civil airliners have to meet the Civil Aviation Authority's requirements. Such procedures may tend to slow down the rate of adoption of new materials, perhaps as indicated by the aerospace adoption rate (figure 8.2). However, if the technology is advancing rapidly enough, probably because of large investments in manpower and machinery the adoption is likely to be that much faster. Dunlop themselves provide an example of such a rapid adoption with carbon/carbon: it took just five years (1969 to 1974) for Dunlop to investigate and develop carbon/carbon brakes and have the first set flying on Concorde (see Appendix A). Another example of such a rapid adoption from the case histories is that of polyethylene submarine cables (see Appendix B). The cables underwent trials with the Telegraph Construction and Maintenance Company only six

* The definition of advanced technology products used in this thesis is that stated by O'Sullivan, i.e. advanced technology products have: a high degree of technical complexity in themselves: or are part of an overall complex system of technology action giving resulting product: or are part of a system behaving in a complex manner to perform a new function.

months after they became aware of polyethylene. As a result of that successful trial, an order for 150 tons of polyethylene was placed with ICI. The example of the CEGB taking fifteen years before placing a firm order for titanium condenser tubes at the West Thurrock power station (Appendix D) should not be taken out of context here. The CEGB had been using a copper based alloy tube for many years and although it was not completely satisfactory they at least knew its operating characteristics. Therefore, before changing over to a new material they had to be certain that the material they changed to had no hidden problems. In their case "better the devil you know than the one you don't". Thus, project evaluation for new materials can vary from a few years to more than ten. Although advanced technology industries may have long lead times on projects, if the technology is being pushed forward quickly, then the development with materials is also fast. This has certainly been the case with the nuclear industry over recent years, and goes a long way to explain the nuclear and power industries rapid adoption of new materials, for there have been huge investments in the nuclear programme over recent years.

Conversely, in those industries manufacturing medium technology products, the adoption rate is likely to be affected by other factors. A few examples will illustrate the point. For the small marine industry the adoption of new materials may be related to whether racing or cruising boats are being built. If the ultimate performance is required and the object is to win races at all costs, then new, high performance materials are likely to be used, recent examples being a spent uranium keel on 'Pen Duick VI' and a carbon fibre mast on 'Heath's Condor', two of the boats in the 1977/78 Round-the-World race. Even the smaller racing dinghies use advanced technology materials if the owner believes it will make his boat go faster. Many owners of small craft are not as competent as say industrial buyers and will readily accept material failure of spars for instance because they do not understand the implications of stress raising holes in critical sections. In other words, the private user is prepared to accept failure more readily than his industrial counterpart. This means the manufacturer in turn does not need to undertake such severe development work or use such stringent quality controls. The multiplicity of users who are testing material innovations, in many cases by real trials on the craft itself, helps to speed the adoption (or rejection) rate. For owners of such craft the risk of failure is relatively low (compared with say industrial users) and there is the chance of a big pay-off if the material innovation contributes to winning races. Another reason for rapid adoption in this area must be because there is no organisational inhibitor, i.e. the owner of the craft can specify his requirements with no recall on anyone else.

General engineering was the other sector to adopt materials rapidly and an example of such an adoption is given in Appendix D. Hoover (Washing Machines) Limited investigated titanium anode jigs to replace plastic coated aluminium racks which required a major overhaul every six weeks. It took Hoover just one year from their initial awareness of titanium to actually adopt such jigs. Some of the factors affecting medium technology industries and their adoption habits are therefore related to the end user and his needs (and also technical capability) and a general desire to reduce manufacturing costs. Obviously some organisations adopt more rapidly than others in a given industrial sector, and this has been reflected in the MDM's indication of their adoption habits.

The hypothesis that high technology industries are more familiar with material developments but slower adopters than the medium technology industries, may be regarded as generally true but additional evidence must be gathered for its complete vindication.

In fact this chapter has only scratched the surface of the adoption habits of various industrial sectors. It has shown the adoption times that can be expected but does not explain fully the discrepancies that exist between the different sectors. Indeed future studies might do well to investigate the hypothesis that the adoption rate of new materials is related to the advance of technology, and in particular to the product user's ultimate aims and objectives. For the material producer, it is the time from his initial promotional activities to actual adoption by users that is all important. It may be that although the small marine and general engineering sectors adopt materials most rapidly once they know of the materials development, the actual adoption time from the initial promotional activity may be the same (or longer) than those sectors that are familiar with material developments, i.e. aerospace, research establishments, nuclear and power industries. Whilst these results distinguish the innovators from the laggards by industrial sector it should not be forgotten that there will be the same range of innovators to laggards within each and every sector.

8.4 CHAPTER REVIEW

The familiarity of 224 material decision-makers with new materials has been examined, as has the likely adoption times for new materials. From this it is recognised that a considerable time delay may accrue between actual awareness of an innovation and its adoption.

The study of the awareness and adoption rate that material decision-makers have for materials has indicated the following results. By using a material mean familiarity index it has been possible to show which sectors of industry have the greatest awareness of material developments. Only the MDM's in three sectors, aerospace, research establishments and the nuclear and power industries were familiar with more than fifty per cent of the materials cited. Of the fourteen materials quoted, only two, titanium and carbon fibre reinforced plastic were significantly more familiar to all the MDM's than the control material, carbon/carbon. However, of the seventy seven per cent who were familiar with titanium, and forty six per cent who were familiar with CFRP, only twenty six per cent and thirteen per cent respectively claimed to be using these new materials in their products/processes.

The investigation into the adoption habits of the various sectors for material innovations showed that the vast majority (82%) of new materials would be in use five years after the MDM's awareness of it. There is however, a variation in this figure from sector to sector. Although 224 MDM's were asked about the adoption of new materials into their organisation, over one third claimed to have no knowledge of a new material being introduced into their organisation over the past ten years. Again, this figure varied from sector to sector. A comparison of the MDM's familiarity with new materials and the rate of adoption that can be expected in various sectors has suggested there is some evidence to support the hypothesis that: high technology industries are more familiar with material developments but slower adopters than the medium technology industries.

9

RESPONSE TESTING OF INFORMATION CHANNELS

9.1 CHAPTER PREVIEW

The effectiveness of various information sources and channels used by material decision-makers was examined in Chapter 7. This chapter reviews the responses gained from actually testing some information channels that carried information about carbon/carbon.

9.2 TESTING SOME EFFECTIVE COMMUNICATION CHANNELS

The results from the research cited in the preceding four chapters and in particular those results from Chapter 7 (on information sources and channels) prompted a desire to test the "effective" channels. Rather than accept the results as to which information channels were effective for keeping MDM's up-to-date with material developments, it was decided to probe them further by publishing information about Dunlop's carbon/carbon and to monitor all subsequent enquiries.

It had been recognised that the time delay existing between (a) awareness of a new material and its capabilities and (b) actually adopting it into a product by the MDM's organisation could be five years or more (see Chapter 8). A further aim of the publicity given to carbon/carbon was to shorten this time delay. Rogers and Shoemaker have stated that the perceived characteristics of an innovation, as seen by the adopter play an important role in the adoption process. One of the characteristics they put forward was that trialability of an innovation affected the potential users perception and hence his rate of adoption of an innovation, although other authors have disputed this, see Chapter 4.10.3. However, the vast majority of product ideas, particularly for a material, arise outside the manufacturing organisation, see Chapter 4.9.1. It was therefore decided that besides actually publishing information about carbon/carbon, potential users should also have the option of testing the material in their own laboratories. Sample blocks of material and detailed data, in the form of a brochure (see appendix F) were prepared in readiness for enquiries. These sample blocks were advertised separately to the feature articles. A price of £15 per block was arbitrarily fixed (a) to discourage indifferent respondents and (b) as a reasonable economic price for material made to the specification of Concorde brakes. The blocks were however cut from a brake disc that had been discarded after previous experimental tests had been carried out.

9.2.1 THE JOURNALS CHOSEN FOR STUDY

The choice of the individual information channels to take part in such a trial was decided after approaching eight of a possible twenty channels (as indicated in Chapter 7). The only proviso was that a selection should be chosen over the effectiveness range as indicated in table 7.4, with the restraint that only six pieces of literature were available for publication. It had previously been decided that each channel should carry a different article giving details of various aspects of the research programme and its relation to carbon/carbon. The eight channels approached were: Chartered Mechanical Engineer, Design Engineering, The Engineer, Engineering, Engineering Materials and Design, The Financial Times, Metallurgist and Materials Technologist and New Scientist. Some were very keen to take part (The Engineer and CME) whilst other showed complete indifference (New Scientist and The Financial Times). Six of the information channels agreed to take part either by carrying an article, an article and advertisement or an advertisement alone, see table 9.1.

9.2.2 THE RESPONSE TO THE PUBLICITY

Before describing the results that the publicity has given carbon/carbon a note of caution should be counselled for the response to Engineering. In the article "Ten ways not to market a new material" all the references to carbon/carbon and its capabili-

Table 9.1 The information channels chosen and the message they carried.

Information Channel	Message Article	Advert-isement
CME	How should industry keep up-to-date with material developments.	Yes
Design Engineer	No	Yes
The Engineer	This hot composite is just waiting for the brakes to be taken off.	No
Engineering	10 ways not to market a new material.	No
Engineering Materials & Design	No	Yes
Metallurgist & Materials Technologist	Materials looking for markets.	Yes

Note: Appendix F carries copies of the articles and a specimen advertisement.

ties were edited out. This meant that no mention to carbon/carbon was made, and has effectively ruled out Engineering for comparison with the other journals.

The response described below is for those enquiries received within twenty weeks of the journal's publication. A total of 172 enquiries were made, mainly for further information on carbon/carbon. Six of these respondents were not interested in carbon/carbon in particular but in the research applicable to materials in general. Table 9.2 shows the breakdown of the enquiries per journal together with a rating according to the number of enquiries per circulee. The circulation figure is that quoted by the Audit Bureau of Circulations (ABC), though it should be recognised that

Table 9.2 Enquiries received from a variety of publicity for carbon/carbon.

Journal	Article	Advert.	Reader Reply Card	Direct to Author	% of Enquiries	ABC Circulation Y	Nos of Sample Block Request	$\frac{X}{Y} \times 10^{-3}$
CME	✓	✓	33	4	22	44,412	3	0·83
Design Engineering	✓	✓	17	-	10	22,215	-	0·77
The Engineer	✓	-	68	2	41	37,728	1	1·86
Engineering	✓	-	-	1	-	17,574	-	-
Engineering Materials & Design	-	✓	29	-	17	24,485	-	1·18
Metallurgist & Materials Technologist	✓	✓	17	1	10	9,840	-	1·83

many journals have a large hidden readership as companies circulate journals to a number of employees - see The Trade Press in Britain, Benn Publications, 1977.

It is extremely difficult to compare the responses between the journals because each carried information about carbon/carbon in different format. The two journals that carried the advertisement alone account for only twenty seven per cent of the enquiries, seventeen per cent from Engineering Materials and Design and ten per cent from Design Engineering. The order of these responses was in agreement with that quoted for the effective information channels in table 7.4. The Engineer which carried an article alone had forty one per cent of the enquiries and also the best ratio of enquiries to circulation numbers, $1{\cdot}86 \times 10^{-3}$. The Metallurgist and Materials Technologist had a similar ratio, $1 \cdot 83 \times 10^{-3}$ but only ten per cent of the enquiries. CME with the largest ABC circulation (though possibly not the largest if hidden circulation could be taken into account) had only $0 \cdot 83 \times 10^{-3}$ enquiries per circulee but had three requests for sample material. The Engineer was the only other journal from which a request for a sample arose. The requests for samples was disappointingly low and may be attributed to two factors. First, it may be as Fliegal and Kivlin suggest that small scale trials have little effect on the adoption process (see Chapter 4.10.3). If this suggestion is correct, then potential users would not be inclined to investigate the properties of the material from a standard shaped specimen. There is however another possible explanation for the low response to sample material, which had not been foreseen before the trial. That is, that the price of the blocks (£15) would probably be too high for individual MDM's to consider purchasing the material themselves out of curiosity; whilst the difficulty of raising a cheque for such a purpose within the organisation may well be great. If access to the petty cash for such a purchase is at all difficult it is probable that the MDM would not bother. An example of an MDM who did not have such a problem is provided by a Dunlop competitor who also manufactures carbon/carbon and who purchased a block of material. That cheque was signed by the managing director of the organisation! The rate of enquiry for each journal is shown in figure 9.1. In all cases enquiries had ceased by week seventeen: i.e. the number of weeks after the publication date and for some

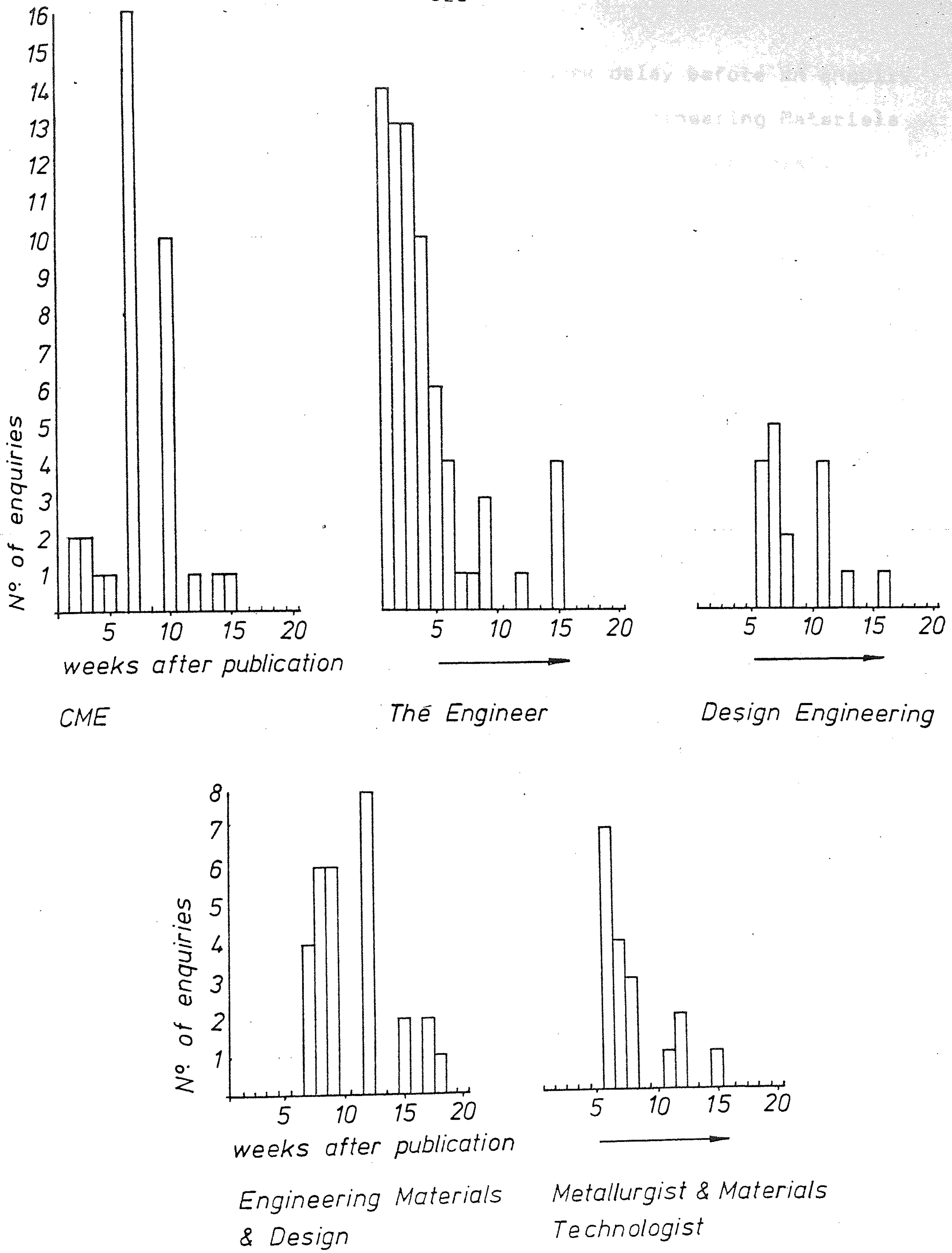


Figure 9.1 Response rate to carbon/carbon publicity in various technical journals

journals there was a five or six week delay before an enquiry was received, e.g. Design Engineering, Engineering Materials and Design and Metallurgist and Materials Technologist. This, to a large part must be the responsibility of the journals and their turn round time for the reader enquiry cards. A breakdown of the areas of interest by the enquirers for each journal is given in table 9.3. The Engineer appears to have the greatest variety of readers and Design Engineering the least. A total of fourteen overseas enquiries were received for carbon/carbon, five of which came from Engineering Material and Design. The first overseas enquiry (from Design Engineering) was received six weeks after the publication date. It can be seen from table 9.3 that requests from general engineering industries predominated (about 30%) for all journals except Engineering Materials and Design. For that journal, the greatest number of enquiries came from the aviation industries (17%). Other points to note are that twenty seven per cent of enquiries from CME and twenty two per cent from Metallurgist and Materials Technologist were for universities or similar establishments. It was only from Design Engineering that a reasonable percentage (24%) of the enquiries came from chemical and material manufacturing concerns. No enquiries from nuclear or power engineering establishments were received from the advertisement placed with Design Engineering.

From the 164 initial enquiries on carbon/carbon, seven made specific requests about the suitability of carbon/carbon for particular products. These product enquiries came from a variety of industries as indicated by table 9.4. Five of

Table 9.3 An analysis of enquiries by area of interest for each journal.

Journal / Interest/Industry	CME	The Engineer	Engineering Materials & Design	Design Engineering	Metallurgist & Materials Technology
Aerospace	4(11%)	6(9%)	5(17%)	1(6%)	1(6%)
Chemical & Material Manufacture	1(3%)	12(17%)	1(3%)	4(24%)	2(11%)
Defence	-	2(3%)	1(3%)	-	-
Electrical/Electronic	-	5(7%)	2(7%)	-	-
Food Processing	-	1(1%)	-	-	-
General Engineering	11(30%)	20(29%)	3(10%)	5(29%)	6(33%)
General Interest	2(5%)	-	-	-	1(6%)
Heat Treatment	-	2(3%)	-	-	1(6%)
Information Processing	-	2(3%)	-	-	-
Medical	-	2(3%)	1(3%)	2(12%)	-
Nuclear & Power Industries	6(16%)	5(7%)	1(3%)	-	2(11%)
Rail Transport	-	1(1%)	-	-	-
Research Establishments: Industrial	-	1(1%)	-	-	-
Research Establishments: University	10(27%)	-	1(3%)	1(6%)	4(22%)
Road Transport	-	5(7%)	1(3%)	-	-
Scientific	-	-	1(3%)	-	-
Sports	-	-	1(3%)	-	-
Foreign	3	2	5	3	1
Unknown	3(8%)	6(9%)	11(38%)	4(24%)	1(6%)
Total	37	70	29	17	18

Table 9.4 Product enquiries for Carbon/carbon by industrial sector and information source.

Type of Industry	Number of Enquiries	Information Source
Bearing	1	CME
Automative	2	The Engineer
Industrial Power Tools	1	CME
Chemicals	1	The Engineer
Medical Equipment	1	The Engineer
General Engineering	1	?

these enquirers wished to substitute carbon/carbon for another material in an existing product and two wanted to investigate it for use in a new product. All these enquiries came from two journals, The Engineer and CME. However, it will be noticed that one of the enquirers could not identify the information channel he used to stimulate his enquiry for carbon/carbon, albeit only a matter of days after he had read about it! Gibbons and Robertson (1976) have both suggested that the written word probably plays a more important part in innovation than is currently thought (see Chapter 4.9.1). This example suggests that they are probably right.

After an initial appraisal by the companies concerned, three of these product ideas are being pursued, though in all cases they are undergoing comparative studies with other materials. Another company that bought a carbon/carbon sample decided the material was not suitable for their application. However, after discussion between Dunlop and this potential user, it was suggested that another Dunlop material, one of the cermets, might be suitable, and the feasibility of this is being examined. The other three potential users have fallen by the wayside for a variety of reasons - one is developing a product in competition with Dunlop, and therefore Dunlop are not pursuing the product, the second wanted a material that could be easily formed, resist a severe environment and cost next to naught, and nothing has been heard of the third since a price was quoted for some test blocks. Thus only three product ideas, or less than two per cent of the initial enquiries received in the first twenty weeks of publicity are being pursued. But at least those product ideas are from potential users with a need for such a material, and as such are more likely to succeed. It should be pointed out that two of the ideas had not previously been thought of by Dunlop. They thus provide an example of external ideas being more prominent than internal for innovating organisations.

9.2.3 IMPLICATIONS FOR MATERIAL PRODUCERS

In conclusion, under the current state of the media, feature articles carry more power than advertisements in terms of generating enquiries but we have been unable to assess the worth of advertisements alongside features or editorial comment on the basis of this study. The recommendations for effective journals as cited in Chapter 7 have not been disproved.

For an innovative company that wishes to communicate its innovation to attract potential users then ideally the source and receiver should be homophilous (similar in certain attributes, i.e. beliefs, values, education, etc.) for the communication to be effective. Rogers and Shoemaker believe that a major problem occurs in communicating innovations because of the heterophilous (opposite of homophilous) nature of source and receiver. At least if the common communication channels can be identified, as this study has done for material producers and the adopting MDM's, then the homophilous innovating organisations should link more rapidly. The only problem arises from the fact that the very nature of innovation requires some degree of heterophily to be present between innovator and adopter.

It was pointed out in Chapter 4.9 that the communication industry has been expanding rapidly for over a century. Although this study has identified the effective communication channels for material innovators there is no guarantee that these findings will be just as valid in years to come. Indeed another journal has only recently been introduced, specialising in materials and promoting applications, namely "Materials in Engineering Applications". This was introduced in the summer of 1978 by the Fulmer Research Institute and will add yet another dimension to the already vast array of material journals.

9.3 CHAPTER REVIEW

Six different journals carried different information about carbon/carbon in an attempt to justify the effectiveness rating of the various information channels mentioned in Chapter 7. The publicity gained from this exercise led to over 170 enquiries for further information about carbon/carbon, and three firms are carrying out detailed investigations of the possibility of using carbon/carbon in their products. It has not been possible from this study to either prove or disprove the recommendations that were made in Chapter 7 regarding effective journals, and they therefore remain as stated.

10

A N   O R G A N I S E D   M E T H O D   F O R   N E W   M A T E R I A L   I N T R O D U C T I O N

10.1 CHAPTER PREVIEW

It will be recalled from Chapter 1 that many new materials appear to be introduced to the world's market place in a rather disorganised fashion. This chapter suggests that new material introductions can be undertaken in an organised and systematic fashion. It proposes a flow chart that material producers should consider before and during the marketing of new materials.

10.2 A FLOW CHART FOR MATERIAL PRODUCERS THAT ARE PLANNING THE INTRODUCTION OF A NEW MATERIAL

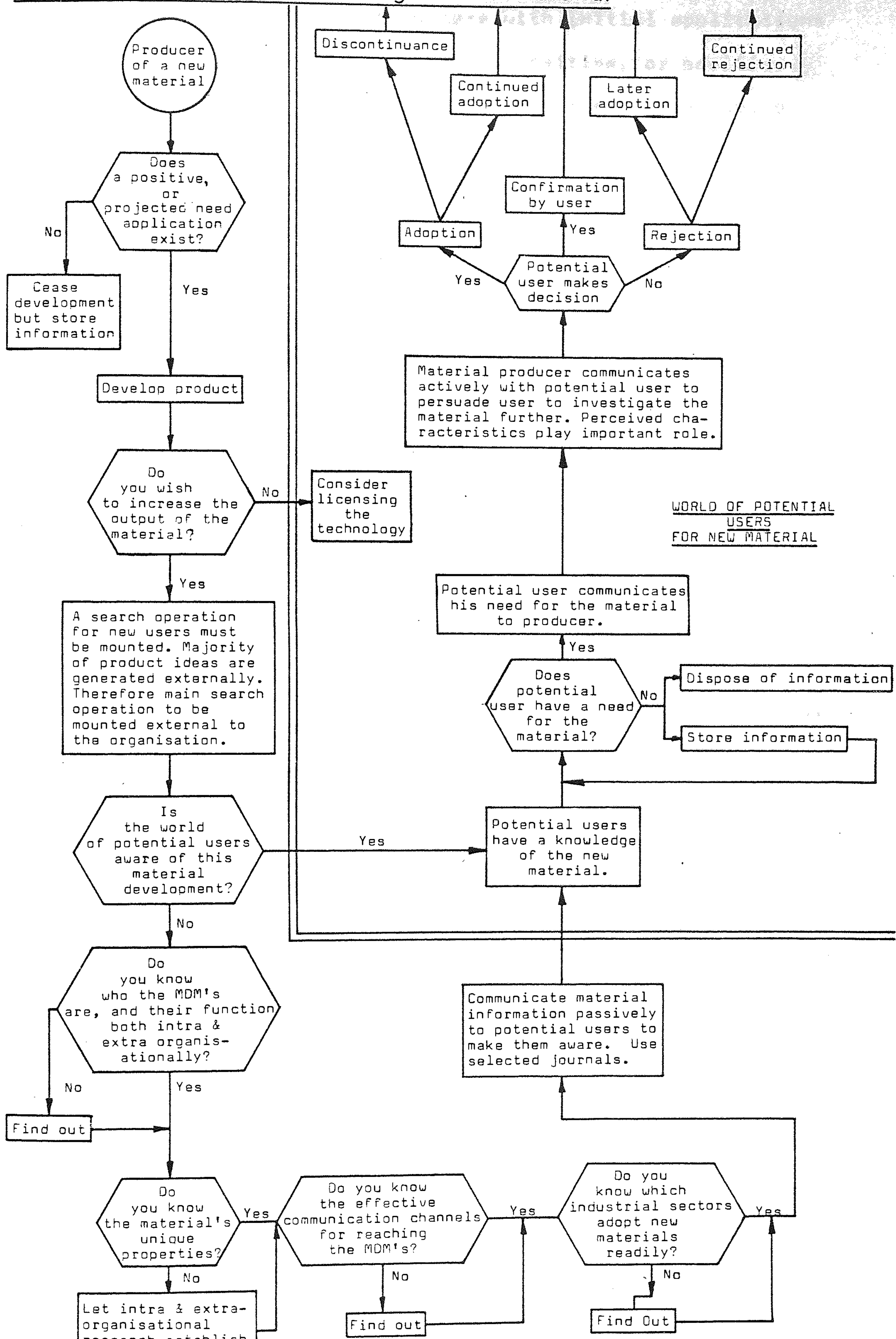
It will be recalled from Chapter 3 that the aim of this research had four functions, namely to:

- identify suitable search operations which would enable new uses for new materials to be sought.
- identify those persons in industry responsible for material selection decisions.
- understand how organisations keep up-to-date with material developments.
- investigate the likely awareness to adoption period that could be expected for new materials.

The result of the work has given a better understanding of many of the problems associated with the above aims, and it culminated in the initiation of an actual search operation for a new material, as described in the previous chapter. The experiences gained herein, have enabled a flow chart to be proposed of some of the fundamental operations that a producer of a new material will have to go through if he is to develop suitable product outlets. This flow chart is shown in figure 10.1.

Producers of new materials are not necessarily in the business of manufacturing and selling such materials. For some organisations the development of a new material has arisen as part of their normal business development. Whether or not the producer of such a material is in the business of actually manufacturing and selling materials the question that still has to be asked is, "is there a positive, or a positive and projected need application for this new material?" If a negative answer to this question is given, then it is probably wise to cease developments with the material until more favourable conditions (i.e. when there is a positive

Figure 10.1 Flow Chart of the Operations that a Material Producer Should Follow when Introducing a New Material



need) arise. Instances of success with initial applications are minimal if there is not either a positive, or positive and projected need application - see Chapter 5. Assuming a successful product was developed by the material producer the next question likely to arise is whether or not he should increase production of the material and sell it to the world. The search operation, matching potential user with material producer, is very complex. If the material producer is not in business to manufacture materials it might be wise to consider licensing the technology to others whose business is material manufacture, and letting them take the risk. They after all have been in the position of matching potential users and materials before. Whether the material producer should license the technology or go ahead with a search depends on the situation. The problems facing either the original material producer or the licensed material manufacturer will be much the same when trying to identify users. It is generally accepted that at least two out of three product ideas originate external to the innovating organisation. This is the case for product innovations, but it is likely that a far greater proportion (i.e. greater than the 60% suggested by Langrish et al.) of product ideas for a new material will be generated externally. This is because the material manufacturer has first to stimulate the potential users before potential products can be suggested. Material manufacturers have only a limited awareness of the material's capabilities. Although the search for product ideas for a new material should be carried out both intra and extra-organisationally it is obvious that the main search should be to find new uses outside the organisation.

The fact that a search has to be mounted external to the organisation makes it more complex. For example, it is unlikely at this stage that the potential users are aware of the new material. Ideally the material manufacturer should carry out a preliminary study of the industries to be approached before launching out information in a haphazard manner. There will be cases where the material manufacturer is familiar with particular industries, but on the other hand he may be trying to introduce a new material into an industry of which he has no knowledge. In both instances, but particularly for the latter, there are some relevant questions to be answered:- 1) Who are the people who take the decisions about materials? (i.e. the decision-maker for which material is to be used for a particular component or product), 2) What function do these people have in their organisation? (can these people be identified within your own organisation?), 3) What means of communication should be used to reach these people?, 4) Are there different sectors of industry that adopt new materials more readily than others? (how long will adoption take? are there sectors of industry that do not adopt new materials unless certain specifications are met?) Such questions are seldom answered by material manufacturers but if they were, the likelihood of communicating effectively, rapidly and with the most likely adopters would be greatly increased. The main content of this thesis has gone a long way to answering many of these questions (see Chapters 6, 7 and 8).

Before communicating with the outside world of potential users can be contemplated the material manufacturer has to be certain of the unique properties that the material possesses. Both intra and extra-organisational research establishments can be used to determine these properties. In this way a suitably comprehensive dossier on the properties can be drawn up, which will go some way to answering a potential user's queries. A further advantage of giving such work to outside organisations is that they can often act as a very effective source, or link for new product ideas.

The material manufacturer can, with such a wealth of information amassed begin the actual search operation. Selected journals and newspapers will probably have been chosen from the mass media channels to communicate information about the material development passively to the potential users (see Chapter 4.8.3). When communicating such information to the world of potential users it should be understood that some industries are better equipped for keeping up-to-date with material developments. That is not to say that those industries that are most familiar with material developments are likely to be the most rapid adopters. In fact the evidence presented in Chapter 8 suggests that the contrary is true.

Once information about the material has been communicated to the outside world further developments are outside the control of the material manufacturer. The material manufacturer has provided the world of potential users with knowledge of the material, its properties and capabilities (as known) and it is then up to the potential user to ask himself whether he has a need for such a material. Unfortunately many will have no immediate use and may simply store the information for future reference, others will dispose of the information.

If the potential user has a need for such a material - either to substitute for a less efficient material or to complete a design with a new material the properties of which have hitherto been unattainable - then it is for him to communicate his need to the material manufacturer. An active communication pattern then emerges between the material manufacturer and potential user to investigate the material further; this is usually by personal contact. At this stage the perceived characteristics of the innovation as seen by the potential user play an important role in the adoption process. It helps persuade a potential adopter if he can see the material manufacturer is working with him in developing the material for the product. For many new materials, the manufacturer can expect to see the material being adopted within one or two years, depending on the user. However, the material manufacturer cannot expect adoption as a right and in the majority of cases the time delay between a potential user's awareness of the material and his adoption of it into a product can take five years or more.

Most organisations suffer barriers being raised to new innovations; new materials striving for a place in products can expect the same barriers. It helps of course if there is a product champion to see the new material through both the user organisation and just as importantly in the material manufacturer's organisation.

Even if the potential user should decide to adopt the material there is no guarantee that he will continue with it, since he may decide to reject it at a later date. Conversely a potential user who rejected the material may at a later date decide to adopt it, or he can continue to reject it.

The innovation of new materials into new or old products is not an easy business. Many companies are able to testify to the many variables that play a part in the process. The development of this work has shown some of these variables, and has also answered some of the questions that should help minimise the risk of introducing new materials. Time will tell if the search procedures suggested here are indeed of use to material manufacturers in their quest for product outlets for their new materials.

10.3 CHAPTER REVIEW

A flow chart which should help material producers introduce new materials to the world in a systematic manner has been proposed. It recognises that only those materials with either positive, or positive and projected needs should be developed by the material manufacturer. If and when a search operation has to be mounted for more users of the material this should mainly be undertaken external to the organisation. As external searches are a complicated business the material manufacturer needs to be aware of his potential customers habits before approaching the search. The information channels used to communicate with the MDM have to be carefully considered at all stages of the passive and active search operation; and knowledge of the likely barriers and probable time scale of adoption by users should be understood.

11

A REVIEW OF THE RESEARCH

11.1 ACHIEVEMENTS OF THE RESEARCH

The project has undoubtedly achieved one of the original objectives, in as much that a search for new product ideas for carbon/carbon was started. This in turn has opened up discussion for a variety of products with several potential users. The route followed in actually doing this work was very different from that first envisaged and has allowed a better understanding of the innovation process, particularly with materials, to be achieved. A summary of the achievements of the work is therefore given.

The review of the literature indicated that there were at least nine different areas of work that a material producer should be aware of before introducing new materials:

1. Factors affecting material selection. This showed that materials were selected for products for a variety of reasons, i.e. the obvious technical and economic factors and the not so obvious political and social factors.

2. Industrial buyer behaviour studies have shown that a number of models of buyer behaviour exist. None however allow accurate predictions of buyer behaviour to be made.

3. Decision making unit (DMU). Empirical evidence has shown that the constitution of the DMU varies through the different purchase stages. Some indication of the people responsible for decision making was given for different types of purchase, but materials were generally regarded as "repetitive" buys and the "new" buy situation was not considered. It was also recognised that the advice given about who to see in buying organisations when selling new materials was misleading, i.e. the purchasing staff are not always best placed for judging the worth of new material.

4. Groups responsible for promoting materials, and those that are in any way associated with the development of engineering materials were reviewed.

5. Innovation: models and case histories. Models of innovation tend to be of the sequential, descriptive type which do not allow behaviour to be predicted. However, most models contain some elements that are of use to prospective innovators and their content should

be understood. The analysis of case histories has allowed a set of characteristics of the technologically innovative firm to be proposed. Nevertheless, it should be realised that only a few characteristics have proved to be common between the studies.

6. Pre-requisites for stimulating demand. Empirical evidence has shown that material usage generally follows a set sequence. Forecasting the demand for materials has been shown to be a difficult task, and although methods of creating demand in consumer and industrial markets have been described, very little is known of the pre-requisites necessary for stimulating demand.

7. Search methods for finding users were described by reference to operations research, organisational behaviour, and child psychology. The factors affecting the start-up and close-down of typical search situations were reviewed although nothing has been described on the material front.

8. Effective communication networks. This reviewed the information sources used in the adoption process and considered the methods used to communicate with decision makers.

9. Organisational adoption habits showed that users who adopted innovations fell in different categories and had their own characteristics which affected the adoption rate. The rate of adoption of a particular product can also be affected by its own characteristics, and these were reviewed.

A review of ten material case histories has further demonstrated how such cases can be of use to would-be innovators. In particular, they have shown that new materials must have positive or projected need application to justify the initial development of the material. The subsequent uses that are developed for the material arise mainly from unforeseen needs, i.e. the material producer is unable to foresee many of the applications for which the material may be used, and chance can often play an important part in bringing together potential user and material producer. Unfortunately, this case history study has dealt with only a small part of the innovation sequence. However, besides describing the various need classifications that give rise to material developments it has been possible to suggest some basic guidelines for a material producer to follow when developing a new material, namely: (i) do not place too much reliance on one customer, or customers within one industrial sector, (ii) initial product successes are more likely if the new material is used as a substitute for less efficient materials, rather than in radical product innovations, (iii) carry out a detailed search for prospective users of the material. The vast majority of product ideas for materials came from outside the material producing organisation and therefore the main search operation must be external to the organisation. Unfortunately no rules as to which are the best sources for product ideas can be given; the number and variety of sources are large. Most producers have, up to now, not used the theoretical methods of product idea generation advocated in the literature. They prefer instead to rely on user orientated sources. This in turn means that communication with the correct people, the material decision makers, by the correct channels is imperative.

The survey, "Decisions on materials", enabled a cross-industry study of these material decision makers to be made. It has been shown that there are a great many functions that MDM's can have. The three most important functions however are designer, director and material specialist. Whilst the design function appears to be the most important, particularly as there is no variation with company size, the same can not be said of the other two functions. Directors play an important role in material selection for the smaller company, i.e. those companies with less than one thousand employees, whilst material specialists (metallurgists, material technologist, etc.) play an important part in those companies with more than one thousand employees. For many companies a team of MDM's will take part in product projects, but the size of this team is not related to the size of the organisation, and indeed the team will vary from project to project, and also at different phases of the project. However the most common number of MDM's in a team is three. The importance of material innovations in comparison to product and process innovations was also investigated. This has shown that the MDM's regard material innovations to be just as important as their own product or process innovation.

Having identified the important technical functions that the MDM's have, it is important to know how to communicate with them. It has been shown that effective communication plays a very important role with successful innovations, particularly when communicating with the outside world. According to the 224 MDM's investigated, journals are an important source of information for keeping up-to-date with material developments. Conversely the ineffective information sources for the MDM's are patents and government information services. Such a result does indicate what other students of innovation have suggested, that mass media channels are important for communicating knowledge of a certain innovation. The inter-personal channels are more important at the persuasion stage in the innovation process. Those channels that are important within the journal communicating medium have been identified for keeping the MDM's up-to-date with both business developments and material developments. The Financial Times is the most important channel for business developments - it is also highly regarded as a channel for material developments - and The Engineer is the second most important channel. However, the two journals that are regarded most highly by the MDM's throughout all the industrial sectors for material developments are Engineering Materials and Design and Design Engineering. Although Engineering Materials and Design, and Design Engineering have been shown by the survey to be the most effective journals it should be remembered that it was two other journals - The Engineer and Chartered Mechanical Engineer - which produced the product idea responses when trial publicity was given to carbon/carbon. There is very little reliance placed on specialist journals for particular industrial sectors. It is well known that a time delay between a potential user's awareness of an innovation and actually adopting it exists. The adoption of new materials by prospective users is no different in this respect to other types of innovation. By examining the adoption habits of 224 MDM's it has been possible to show which industries are most adept at keeping up-to-date with material developments - aerospace, research establishments, nuclear and power industries - and those that adopt material innovations most rapidly - small marine and general engineering establishments adopt most materials within one or two years of becoming aware of it. Having said that, over eighty per cent of new materials can expect to be adopted into an organisation's products or processes just five years after the MDM's initial awareness of the material's potential. This applies even to advanced technology industries where huge resources will be expended if it is necessary to get the technology developed rapidly. This picture of rapid material adoption in various industries must be tempered by the fact that a third of the 224 MDM's had no knowledge of new material introductions over the past ten years. By studying the familiarity that the MDM's had of various new materials it was possible to judge carbon/carbon's standing. Of the fourteen materials cited, only two, titanium and carbon fibre reinforced plastic were more familiar than carbon/carbon. There were four other materials, boron nitride, silicon nitride, tantalum and super-plastic alloys, that were no more or less familiar than carbon/carbon but the rest were less familiar, including 'Retimet' another Dunlop product.

11.2 USE OF THE RESEARCH

One of the major uses of the work described above has been the publicity given to carbon/carbon. Five different journals carried a variety of information about carbon/carbon and also some detail of the work described in this thesis (see Appendix F). A technical brochure (see Appendix F) was prepared in readiness for any enquiries that might arise. Such publicity resulted in over 170 enquiries within the first twenty weeks of each publication. Seven of these led to product enquiries, four of which are undergoing further investigation. A major presentation of the material was also given to a large gathering of scientists and engineers at the Atomic Energy Authority's site at Harwell, developments from which will probably not be known for several months. A less successful part of the exercise was the proposed sale of sample carbon/carbon blocks by advertisement in appropriate journals. No more than ten blocks were either given away (because sample did not meet user's requirements) or sold. Nevertheless, the overall response has been quite successful particularly when the inestimable number of potential users with details of carbon/carbon filed away for future reference is considered.

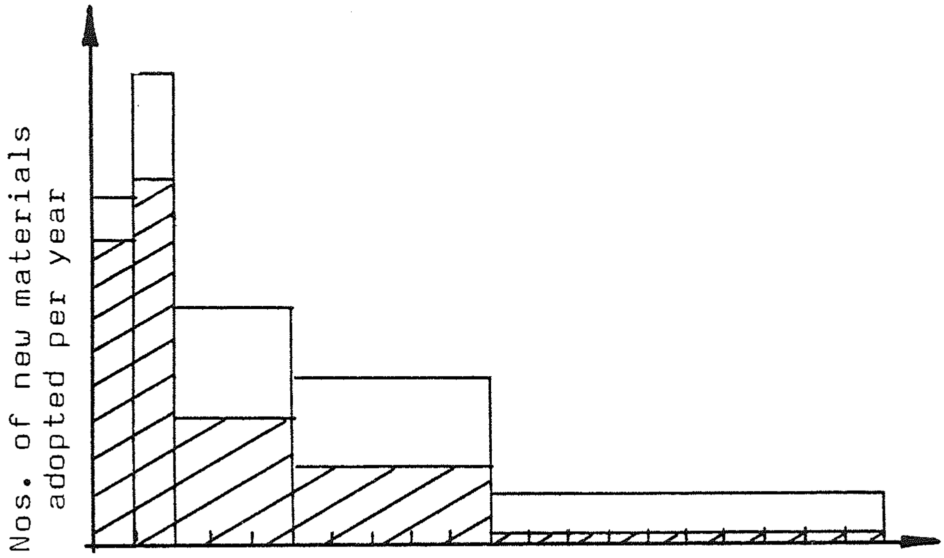
The result of the publicity to carbon/carbon went some way to confirming the earlier study of the effective communication channels. These results will no doubt be of general use to any organisation wishing to communicate to material decision makers for some years to come.

Another use of the work, of a more general nature is that it has been possible to propose a flow chart of the innovation sequence for material producers. This flow chart poses some of the pertinent questions that a material producer will have to ask himself if he wishes to expand his material output. It should be realised that the flow chart does not cover all the aspects that a material producer will have to go through when innovating with a new material. Rather, it tackles the search and adoption aspects that a material producer should be aware of when trying to develop and diversify new material usage.

11.3 SUGGESTIONS FOR DEVELOPING THE FINDINGS

The importance of case histories cannot be overstressed (see Chapter 4) and whilst it is recognised that it is extremely difficult to get cases dealing with the 'micro' aspects of the innovation process, all effort should be made to fill this gap. All too often published cases deal only with the 'macro' aspects, ignoring the whys and wherefores because (a) company data is difficult to come by and (b) any results that are published have to be disguised to protect the company. The author wishes to join his call for more 'micro' type studies with those issued by Cahn and Nabseth and Ray.

This thesis has only scratched the surface of how users for new materials are sought, far more can be done. In particular a study of the relevance of product champions, or power promoters,* both in the producer's and adopter's organisation would be useful. It has been suggested that material innovations are first used in incremental type product innovations rather than radical innovations. Such a hypothesis is worthy of further study. A useful area to begin with, would be to investigate the ratio of substitution uses to new uses for new materials and plot the adoption rate as shown:



Key:

new material substituted for a less efficient material in an existing product.

new material used in a new product.

A detailed understanding of the adoption sequence of new materials into products would not only help students of the innovation process but also the material producers. Dunlop could help with this, knowing the source of the product ideas that were generated by the carbon/carbon publicity. Actual examples of the awareness to adoption phase with new materials could then be cited. It would be interesting to monitor such developments, and at the end of the day check with the adopter if he could remember the product idea source. This would help throw some light on the subject as to whether the written or oral word plays the more important role in product idea generation.

This research has generally indicated that high technology industries are far more familiar with material developments, but slower adopters than the medium technology industries. Some further research would be useful to investigate the relationship between the adoption rate of new materials and the advance of technology. For example, do the aims and objectives of an organisation influence its adoption of its own and others innovations?

Two other areas that this research has not attempted to investigate but which would be worthy of further study are, (i) a cost per unit function analysis and (ii) a study of the effects of economies of scale on the development of materials. Both these topics have been described briefly in an earlier chapter - cost per unit function analysis in Chapter 4.2.1, and economies of scale in Chapter 4.6.5. All material producers would be well advised to monitor the developments that are bound to take place with cost per unit function analysis. Should such a system become computer based on either an industry wide or national scale it will be imperative for material manufacturers to ensure that their materials are listed on the computer file. It is also suggested that material producers seriously examine (a) the potential outlets that economies of scale can give, and (b) the process requirements necessary for the introduction of such scaling operations. Studying such economies may well give a foresight of new markets opening up for the material.

BIBLIOGRAPHY *

Achilladelis, B.G. (1973) "Process Innovation in the Chemical Industry", Ph.D. thesis, University of Sussex.

Ackoff, R.L. and Sasieni, M.W. (1968) "Fundamentals of Operations Research", New York, London: Wiley.

Alexander, R.S., Cross, J.S., and Hill, R.M. (1961) "Industrial Marketing", Illinois: Irwin.

Alexander, W.O. and Appoo, P. (1974) "Energy Content: A Vital Factor in Assessing Materials Demand and Use", Metals and Materials, Oct., pp 458-459.

Allen, J.A. (1967) "Studies in Innovation in the Steel and Chemical Industries", Manchester University Press.

Allen, N.P. (1964) Proceedings of Royal Society (London), Series A, 282, 572.

Allen, T.J. and Sloan, A.P. (1971) "Communication Networks in R & D Laboratories", R & D Management 1,1, pp 14-21.

Appoo, P. and Alexander, W.O. (1976) "Computer Analysis Speeds Assessment of Engineering Materials", Metals and Materials, July/Aug., pp 42-45.

Baker, M.J. (1971) "The Adoption of Industrial Products: An Exploration of the Influence of "Management Attitudes" on Acceptance of Two Industrial Innovations", Marketing Science Working Paper, p. 64.

Baker, N.R., Siegman, J. and Rubenstein, A.H. (1967) IEEE Trans. Eng. Mang., EM-14, 156, December.

Bartlett, F.C. (1968) "Adventurous Thinking", in Wason, P.C. and Laird, P.N. (eds) Thinking and Reasoning, Penguin.

* Each case history has its own set of references which are documented at the end of the appropriate case study.

Bauer, R.A. (1960) "Consumer Behaviour as Risk Taking", in Dynamic Marketing for a Changing World, Hancock, R.S. (Ed), Chicago, American Marketing Association, pp 389-398.

Beattie, C.J. and Reader, R.D. (1971) "Quantitative Management in R & D", Chapman and Hall Ltd.

BMRC (1973) "Readership Survey in the UK", Research Services Ltd. Feb/July.

BMRC (1977) "Businessman Readership Survey" Research Services Ltd., August.

Bormann, E.G. and Borman, N.C. (1972) "Effective Small Group Communication", Minneapolis, Burgess Publishing Co.

Boulton's Papers, Transcripts Keir J. to Boulton, M. (1770-1790), Keir Box, Birmingham City Library.

Bradbury, F.R., McCarthy, M.C., Suckling, C.W. (1972) "Patterns of Innovation", Chemistry & Industry, Jan. 1st, pp 22-26.

Brand, G.T. "The Industrial Buying Decision", London: Cassell, 1962.

Briggs, E. and Rees, A.M. (1978) "How Word Gets Round", New Society, 29 June, p. 716.

Buchanan, J.A.F. (1975) "Commercial Super Plastic Aluminium", in The Institute of Metallurgists, op cit.

Buckner, H. (1967) "How British Industry Buys", London: Hutchinson.

Burns, T. and Stalker, G.M. (1961) "The Management of Innovation", Tavistock Publications.

Cahn, R.W. (1970) "Case Histories of Innovations", Nature, 225, Feb 21, pp 693-5.

Cardozo, R.N. (1968) "Segmenting the Industrial Market", in King, R.L. (ed), "Marketing and the New Science of Planning", American Marketing Association.

Carter, C.F. and Williams, B.R. (1957) "Industry and Technical Progress: Factors Governing the Speed of Application of Science", Oxford University Press.

Child, J. (1973) "Parkinson's Progress: Accounting for the Number of Specialists in Organisations", Administrative Science Quarterly 18, pp 328-348.

Child, V.G. quoted by Gregory, S.A. "Steel Industry Futures: Approaches and Techniques", p. 391 in Arnfield, R.V. (ed) (1969) Technological Forecasting, Edinburgh University Press.

Cohen, J. and Christensen, I. (1970) "Information and Choice", Edinburgh.

Commander, M.W. (1978) "How Should Industry Keep up-to-date with Material Developments?", C.M.E., March, pp 105-106.

Copeland, M.T. (1924) "Principles in Merchandising", A.W. Shaw Co., Chicago.

Corey, E.R. (1956) "The Development of Markets for New Materials", The Riverside Press, Cambridge, Massachusetts.

Crowther, J. (1974) "Substitution - for communal or sectional benefit?" Proc. Harwell Conference on Conservation of Materials, p. 263.

Cunningham, M.T. and White, J.G. (1974) "The Behaviour of Industrial Buyers in their Search for Suppliers of Machine Tools", Journal of Management Studies, 11, 2, pp 115-28.

Cyert, R.M., Dill, W.R. and March, J.C. (1967) "The Role of Expectations in Business Decision Making", in Alexis, M. and Wilson, C.Z. (eds) "Organisational Decision Making", Prentice Hall, pp 33-47.

Cyert, R.M., Simon, H.A. and Trow, D.B. (1956) "Observation of a Business Decision", Journal of Business, 29, pp 237-248.

Danhoff, C. (1949) "Observation of Entrepreneurship in Agriculture: From Change to the Entrepreneur", Harvard University Press.

Davis, H.L. and Silk, A.J. (1971) "Behavioural Research on Personal Selling: A Review of some Recent Studies of Interaction and Influence Processes in Sales Situations", Marketing Science Institute.

Downs, G.W. (Jr), and Mohr L.B. (1976) "Conceptual Issues in the Study of Innovation", Administrative Science Quarterly, 21, pp 700-14.

Duncan, D.J. (1940) "What Motivates Business Buyers", HBR.

Duncan, D.J. (1965) "Some basic determinants of behaviour in industrial purchasing", Pacific Purchaser, May-June-July, quoted in G.A. Luffman, "Industrial Buyer Behaviour - some aspects of the search process", European Journal of Marketing, 8, 2, Summer 1974.

Enos, J. (1962) "Invention and Innovation in the Petroleum Refining Industry", The Rate and Direction of Inventive Activity, National Bureau of Economic Research, Princeton University Press, pp 229-321.

Etzioni, A. (1968) "The Active Society", Collier-Macmillan.

Evans, F.B. (1963) "Selling as a Dyadic Relationship - A New Approach", American Behavioural Scientist, 6, May, pp 76-79.

Ferrari, A. (1973) "Innovation: Myths & Realities", Industrial Marketing Management, 2, pp 391-398.

The Financial Times, 11th April 1967, p.4.

The Financial Times, "How British Industry Buys", joint Financial Times/Industrial Market Research Ltd. survey, 1974.

The Financial Times, Carbon Fibre: The Tale of a "Wonder Material", 12th October, 1977.

Fisher, L. (1969) "Industrial Marketing - An Analytical Approach to Planning and Execution", London: Business Books.

Fliegal, F.C. and Kivlin, J.E. (1966) "Attributes of Innovation as Factors in Diffusion", Amercian Journal of Sociology, 72, 3.

Freeman, C. et al. (1971) "The role of small firms in innovation in the UK since 1945", Committee of Inquiry on Small Firms, Research Report No. 6, H.M.S.O.

Freeman, C. (1974) "The Economics of Industrial Innovation", Penguin.

Frost, P.A. and Whitley, R. (1971) "Communication Patterns in a Research Laboratory", R & D Management, 1, 2, pp 71-79.

Gaudin, T. (1973) "On Innovation", Industrial Marketing Management, 2, pp 295-306.

Gibbons, M. (1973) "Factors Affecting Technological Innovation in British Industry", Industrial Marketing Management, 2, pp 101-112.

Gibbons, M. and Johnston, R.D. (1972) "The Interaction of Science and Technology", Dept. of Liberal Studies in Science, Manchester University, October.

Gilfillan, S.C. "Sociology of Invention", quoted in Robertson, A.B. (1977), op cit.

Globe, S. et al. (1973) "Key Factors in the Innovation Process", Research Management, July, pp 8-15.

Goldhar, J.D. (1970) Thesis, George Washington University.

Gordon, J.E. (1968) "The New Science of Strong Materials", Pelican.

Gould, R.T. (1958) "John Harrison and His Timekeepers", National Maritime Museum.

Gregory, S.A. "The Changing Use of Materials", Course Lecture Notes.

Gregory, S.A. ed (1972) "Creativity and Innovation in Engineering", 313, London.

Gregory, S.A. (1977) "Towards Design Science: A Review of Twenty Years", paper presented to science of science committee Polish Academy of Science, Radzie Jowice, Spetember.

Gross, I. (1968) "Purchasing Decisions under Conditions of Uncertainty", Journal of Purchasing, 4, 2, pp 17-38.

Hall, K.R. and Ritchie, E. (1975) "A study of Communication Behaviour in an R & D Laboratory", R & D Management, 5, 3, pp 243-244.

Hammett, D.A. (1972) "Industrial Buying Influences and Attitudes", paper presented to a Roles and Parker Seminar at the European Headquarters of Dupont, Geneva.

Handy, C.B. (1976) "Understanding Organisations", Penguin Books.

Hawgood, J. and Mumford, E. (1971) "Decision Strategy", in Morris, W.E.M. (ed), Economic Evaluation of Computer Based Systems, Book 1, Manchester, National Computing Centre.

Hayhurst, R. (1967) "The Dynamics of Innovation", British Journal of Marketing, 2, pp 131-138.

Henderson, H.D. (1922) "Supply and Demand", Cambridge University Press.

Hill, R.W. and Hillier, T.J. (1977) "Organisational Buying Behaviour", The Macmillan Press Ltd.

Hollander, S. (1965) "The Sources of Increased Efficiency: A Case Study of Du Pont Rayon Manufacturing Plants", MIT Press, Cambridge, Mass.

Holmes, P.L. (1974) "The Role of Information in Science and Technology", OSTI Report No. 5180.

Holt, K. (1974) "The Role of Information for Creation of Ideas", paper presented at VI International FEANI Congress of Engineers - "Creativity and Innovation - A Challenge of the World to the Capability of Engineers", Barcelona, 7-10 Oct.

Holt, K. (1977) "Product Innovation", Newnes - Butterworths.

Howard and Moore Unpublished monograph quoted in J.N. Sheth, op. cit.

Institution of Metallurgist, (1978) "Education of Design Engineers and Industrial Designers in the use of Materials", The Metallurgist and Materials Technologist, Jan. pp 13-16.

The Institute of Metallurgists, (1975) "Innovation Management in Metallurgy", Autumn Review Course, Series 3, No. 4, 811-75-T.

Jervis, P. (1975) "Innovation and Technology Transfer - The Roles and Characteristics of Individuals", IEEE Transactions on Engineering Management, EM-22, 1, pp 19-27.

Jewkes, J., Sawers, D. and Stillerman, R. (1969) "The Sources of Invention", Macmillan, 2nd ed.

Jobling, J.A. (1970) "Survey of Customer Purchasing Procedures in the UK", internal company report, quoted by Hill and Hillier, op. cit.

Karger, D.W. (1960) "The New Product".

Kettlewood, K. (1971) "The Marketing of Freight Transport with Special Reference to Buyer Behaviour", M.Sc. dissertation, UMIST.

Klass, B. (1961) "What Factors Affect Industrial Buying Decisions", Industrial Marketing, May.

Knight, K.E. (1967) "A Descriptive Model of the Intra-Firm Innovation Process", Journal of Business, 40, 4, pp 478-96.

Koopman, B.O. (1956) "The Theory of Search I", Operational Research, 4, pp 324-46.

Kotler, P. (1965) "Behavioural Models for Analysing Buyers", Journal of Marketing, 29, 4, October, pp 37-45.

Kotler, P. (1967) "Marketing Management: Analysis, Planning and Control", Prentice-Hall.

Langrish, J. Gibbons, M. Evans, W.G. Jevons, F.R. (1972) "Wealth from Knowledge", Macmillan, London.

Layton, C. (1972) "Ten Innovations", Allen & Unwin.

Leduc, R. (1966) "How to Launch a New Product", Crosby, Lockwood & Son Ltd.

Liversey, F. (1972) "Economics", Polytech Publishers.

Lynn, quoted by Rosenbloom, R.S. (1975) "Technological Innovation in Firms and Industries", from Technological Innovation: A Critical Review of Current Knowledge, Vol. 2, pp 143-184, Georgia Institute of Technology.

Mansfield, E. (1968) "Industrial Research and Technological Innovation: An Econometric Analysis", Norton, New York.

March, J.G. (1965) "Handbook of Organisations", Rand McNally.

March, J.G. and Simon, H.A. (1966) quoted in Mumford and Pettigrew (1975) op. cit.

Marino, S.F. (1961) "Five Hidden Obstacles to Industrial Selling", Industrial Marketing, May.

McGrath, E.J. (1976) "Industrial Buyer Behaviour - Prediction of the Unpredictable", Unpublished monograph, University of Aston, June.

McGraw-Hill (1963) "A Special Report on the Buying and Selling Techniques in the British Engineering Industry" London, McGraw-Hill.

McKinsey Associates (1968) "Unlocking the Computer's Profit Potential", The McKinsey Quarterly, 5, 2.

Menzel, quoted in Holmes op. cit.

Morris, W.T. (1964) "The Analysis of Business Decisions", Irwin.

Mueller, W.F. (1962) in Nelson, R.R. (ed) pp 323-360, op. cit.

Mumford, E. and Pettigrew, A. (1975) "Implementing Strategic Decisions", Longman.

Myers, J.M. (1968) "Innovation for Profit", Paper in proceedings of Sira Conference, London: Adam Hilger.

Myers, S. and Marquis, D.G. (1969) "Successful Industrial Innovations", NSF 69-71, National Science Foundation, Washington.

Nabseth, L and Ray, G.F. (1974) "The Diffusion of New Industrial Processes", Cambridge University Press.

Napper, J.L. (1975) "The Long Week-End", RIBAJ, November/ December, pp 26-32.

National Economic Development Office (UK), "The Role of Engineering Materials in the UK Economy", report to be published, but quoted by Pick and Becker (1978) op. cit.

Nelson, R.R. (1962) "The Rate and Direction of Inventive Activity: Economic and Social Factors", Princeton University Press.

New Scientist, (1974) "Survey of Readership in Western Europe".

Nielson, O. (1973) "Models of Industrial Buyer Behaviour", paper presented at the Marketing Workshop, International Institute of Management, Berlin, May (European Marketing Education Association).

O'Sullivan, E.T., quoted from American Marketing Association's "New Ideas for Successful Marketing", J.S. Wright and J.L. Goldstucker eds., 1966.

Owen, B.S. (1977) "Three Retrospective Studies of Information Communication in Mechanical Engineering Projects", Conference Proceedings Information Systems for Desingers, University of Southampton, pp 33-38.

Ozanne, U.B. and Churchill, G.A. (1968), "Adoption Research: Information Sources in the Industrial Purchasing Decision", in King, R.L. (ed) "Marketing and the New Science of Planning", American Marketing Association, pp 352-359.

Parker, R.C. (1978) "How Management Innovate ", Management Today, September, pp 43, 44, 48.

Parkinson, S.T. (1975) "The Role of Information in the Diffusion of Industrial Innovation", a field study - University of Strathclyde, Dept. of Marketing, Glasgow, 1.12.75.

Parkinson, S.T. (1975) "The Role of Information in the Diffusion of Industrial Innovation", Marketing Communications Workshop, Brussels.

PERA, (1977) "Replacement of Metals with Plastics", Report No. 319.

Pick, H.J., "Invited Review: Some Economic Consequences of Technical Decisions", Materials Science and Engineering, Vol. 10, 1972, pp 301-323.

Pick, H.J. and Becker, P.E. (1978) "Some Economic Aspects of the Conversion of Raw Materials into Final Products", Applied Energy, 4.

Pingry, J.R. (1972) "An Examination of the Purchasing Process for Technical Industrial Products", Ph.D. thesis, Ohio State University.

Platten, J.H. (1955) "How Industry Buys", Scientific American, New York.

"Project SAPPHO - A Comparative Study of Success and Failure in Industrial Innovation", S.P.R.U., 1972.

Robertson, A.B. (1974) "Innovation Management", Management Decision Monograph, 12, 6, pp 329-372.

Robertson, A.B. (1976) "The Role of the Written Word in Technological Innovation", Proposal for Feasibility Study, British Library.

Robertson, A.B. (1977) "The Corfam Story", C.E.I. Committe on Creativity and Innovation, Working Party Case Study 77/03.

Robinson, P.J. and Faris, C.W. (1967) "Industrial Buying and Creative Marketing", Boston: Allyn and Bacon.

Rogers, E.M. (1962) "The Diffusion of Innovation", Free Press of Glencoe.

Rogers, E.M., Eveland, J.D. (1975) "Diffusion of Innovations Perspectives on National R & D Assessment: Communication and Innovation in Organisations", Technological Innovation: A Critical Review of Current Knowledge, 2, Feb. 1975, pp 301-368, Georgia Institute of Technology.

Rogers, E.M. and Shoemaker, F.F. (1971) "Communication of Innovations", The Free Press.

Rosenbloom, R.S. (1975) "Technological Innovation in Firms and Industries", Technological Innovation: A Critical Review of Current Knowledge, 2, pp 143-184, Georgia Institute of Technology.

Rothwell, R. (1975a) "Factors for Success in Industrial Innovation", Journal of General Management, 2, 2, Winter.

Rothwell, R. (1975b) "Patterns of Information Flow During the Innovation Process", Aslib proceedings, 27, 5, pp 217-226.

Rothwell, R. (1977) "The Relationship Between Technical Change and Economic Performance in Mechanical Engineering: Some Evidence", paper read to International Symposium on Industrial Innovation at the University of Strathclyde, 5 - 9th September.

Rothwell, R. et al. (1974) "Sappho updated: Project Sappho Phase II", Research Policy, 3, 3, pp 258-291.

Ryan, B. and Gross, N.C. (1943) "The Diffusion of Hybrid Seed Corn in Two Iowa Communities", Rural Sociology, 8, pp 15-24.

Sales Management (1963) "Profiles in Purchasing".

Sambell, R.A.J. and Davidge, R.W. (1974) "Ceramics - Engineering Materials of the Future?" Atom, No. 215, Sept., pp 215-229.

Sawyer, H.G. (1959) "What Does the Industrial Buyers Emotional Involvement Mean to You?" Industrial Marketing, May.

Schon, D.A. (1963) "Champions for Radical New Inventions", Harvard Business Review, March/April.

Schramm, W. (1954) "How Communications Work", in Schramm, W. (ed) The Process and Effects of Mass Communication, Urbanna, Illinois, University of Illinois Press.

Shankleman, E. (1970) "A Study of Industry Buying Decisions", New Scientist, September.

Sharp, H.J. (1966) "Engineering Materials", London Heywood Books.

Sharp, P. (1977) "Sources of Information", Engineering, Oct. pp 853-855.

Shears, P.A. (1971) "Engineering Design as an Information Processing Activity", Electronics and Power, June, pp 233-236.

Sherwin, C.W. and Isenson, R.S. (1967) "Project Hindsight", Science, 156, p. 1571-1577.

Sheth, J.N. (1973) "A Model of Industrial Buyer Behaviour", Journal of Marketing, 37, 4, pp 50-56.

Shoaf, R.F. (1959) "Here's Proof - The Industrial Buyer is Human", Industrial Marketing, May.

Simon, H.A. (1956) "Rational Choice and the Structure of the Environment", Psychological Review, 63, pp 129-38.

Simon, H.A. (1961) "Administrative Behaviour", New York, Macmillan.

Simon, H.A. (1965) "The New Science of Management Decision", in The Shape of Automation for Men and Management, Harper and Row.

Smallbone, D.W. (1969) "Is Industrial Marketing Different", British Journal of Marketing, 3, Summer.

Sowter, Gabor and Granger (1971) "The Effect of Price on Choice: A Theoretical and Empirical Investigation", Applied Economics, September.

Starr, C.H. (1957) "The Specification and Management of Materials in Industry", Thames & Hudson.

Strauss, G. (1962) "Tactics of Laterial Relationship: The Purchasing Agents", Admin. Science Quarterly, 7, September, pp 161-186.

Strauss, G. (1964) "Work Study of Purchasing Agents", Human Organisation, 33.

Tanenbaum, M. et al. (1966) "Materials Advisory Board of the National Research Council, Report". (Washington, A.R.P.A., M.A.B. - 222 - M).

Tauber, E.M. (1974) "How Market Research Discourages Major Innovation", Business Horizons, 17, pp 22-26.

Thain, D.H., Johnston, C.B. and Leighton, D.S.R. (1959) "How Industry Buys: With Conclusions and Recommendat-ions on Marketing to Industry", Business Newspapers Association of Canada, and the Toronto, Hamilton and Montreal Chapters of the National Industrial Advertisers' Association.

Tinnesand, B. (1973) "Toward a General Theory of Innovation", Ph.D. thesis, University of Wisconsin, Madison, 258.

Tofte, A.R. (1969) "They Don't Buy Bulldozers the Way They Buy Beer", Industrial Marketing, March.

"TRACES - Technology in Retrospect and critical Events in Science", Illinois Institute of Technology Research Institute, 15th Dec. 1968.

Turner, B.T. (1977) "The Best Format for Design Engineers", Conference Proceedings, Information Systems for Designers, University of Southampton, pp 87-93.

Utterback, J.M. (1969) Thesis, Massachusetts Institute of Technology.

Utterback, J.M. (1971) "The Process of Innovation, a Study of the Origination and Development of ideas from New Scientific Instruments", IEEE Transactions on Engineering Management, EM-18, p. 124.

Walsh, V.M. and Baker, A.G. (1972) "Project Management and Communication Patterns in Industrial Research", R & D Management, 2, 3, pp 103-108.

Ward, E.P. (1970) "The Dynamics of Planning", Pergamon Press.

Webster, F.E. (1965) "Modelling the Industrial Buying Process", Journal of Marketing Research, 2, November, pp 370-376.

Webster, F.E. (1969) "New Product Adoption in Industrial Markets - A Framework for Analysis", Journal of Marketing, 33, pp 35-39.

Webster, F.E. (1971) "Communication and Diffusion Processes in Industrial Markets", European Journal of Marketing, 5, 4, pp 178-188.

Webster, F.E. and Wind, Y. (1972a) "Organisational Buyer Behaviour", Eaglewood Cliffs, New Jersey: Prentice-Hall.

Webster, F.E. and Wind, Y. (1972b) "A General Model for Understanding Organisational Buying", Journal of Marketing, 36, 2, pp 12-19.

Webster, F.E. Jr. (1968) "Word of Mouth Communication and Opinion Leadership in Industrial Markets", paper presented at the National Conference of the American Marketing Association, Denver.

Weigan, R.E. (1968) "Why studying the Purchasing Agent is not enough", Journal of Marketing, 32, 1, pp 41-45.

Weston, P. (1978) "What Marketing Means", Management Today, June, p.92.

White, R.W. (1959) "Motivation Reconsidered: The Concept of Competence", Psychological Review, pp 297-333.

Whittle, F. (1953) "Jet", London, Muller.

Willsmer, R.L. (1975) "Directing the Marketing Effort", Pan Books Ltd.

Wind, Y. and Robinson, P. (1968) "Simulating the Industrial Buying Process" in King, R.L. (ed), "Marketing the New Science of Planning", American Marketing Association.

Witte, E. (1973) "Organisation fur Innovationsentscheidungen", Schwartz, Gottingen.

Yousoufian, H.H. (1970) "The New Product Development Process", Building Systems Design, 67, September, pp 38-39.

BIBLIOGRAPHY RELATED TO TABLE 5.6 - "TWENTY SIX METHODS THAT CAN BE USED TO GENERATE IDEAS".

Ayres, R.U. (1968) "Envelope Forecasting", in Bright, J.R. (ed), "Technological Forecasting for Industry and Government", Prentice-Hall.

Ayres, R.U. (1969) "Technological Forecasting and Long-Range Planning", McGraw - HILL.

Cetron, M.J. (1969) "Technological Forecasting: A Practical Approach", New York.

Cheaney, E.S. (1966) "Technological Forecasting as a Basis for Planning", ASME, New York.

Claude, J.C. and Morize, F., (1972) "Delphi in the Assessment of R & D Projects", Futures, 5.

Derviniotis, E.S. (1973) System Dynamics, DTEH Copenhagen.

Durard, U. (1972) "A New Method for Constructing Scenarios", Futures, 325.

Ekvall, G. (1971) "Creativity at the Workplace", International Publications Service.

Enzer, S. (1969) A Case Study Using Forecasting as a Decision Making Aid, 42 Middletown, Conneticut (1969).

Esca, M.E. (1965) "Planning Assistance Through Technical Evaluation of Relevance Numbers", IEEE Trans., 346-360.

Forrester, J.W. (1961) "Industrial Dynamics", MIT Press.

General Electric (1969) "The Effects of Organisational Climate on Performance", Project Report No. 2, 12, New York.

Creschka, H. et al. (1973) "Modern Techniques for Solving Problems", Chemical Engineering, 6 August.

Gordon, W.J.J. (1961) "Synectics", Harper and Row.

Gome, P. and Long, J. (1973) "Essentials of Product Planning", McGraw-Hill.

Gregory, S.A. (1972) "Creativity and Innovation in Engineering", Butterworths.

Hake, B. (1971) "New Product Strategy", Beekman Publications.

Hamilton, P. (1967) "Espionage and Subversion in an Industrial Society", Hutchinson.

Helmer, O. (1966) "Social Technology", Basic Books.

Helmer, O. (1972) "On the Future State of the Union", Merlo Park.

Holt, K. (1971) "Creativity and Organisational Climate", Work Study and Management Services, 576-583, September.

Holt, K. (1972) "The Scanship Case". A Programme for Promotion of Innovation, 69, Milan.

Holt, K. (ed) (1973) Innovation, 396, Milan.

Holt, K. (1973) "Notes on Innovation and Creativity", 131, Trondheim.

Holt, K. (1975) "Generating Creativity, Ideas and Inventions - Information and Needs Analysis in Idea Generation", Research Management, May, 24-27.

Jantsch, E. (1967) "Technological Forecasting in Perspective", 401, Paris.

Kahn, H. (1966) On Alternative World Futures: Some Basic Techniques, Issues, Theories and Variables, 44, Chicago.

Kelly, W.T. (1968) "Marketing Intelligence", 248, London.

Martine, J.P. (1972) "Technological Forecasting for Decision Making", 750, New York.

Maynard, H.B. (ed) (1963) Industrial Engineering Handbook, 1856, New York.

Parnes, S.J. and Harding, H.F. (1972) "A Source Book for Creative Thinking", 393, New York.

Parnes, S.J. (1967) "Creative Behaviour Guidebook", 312, New York.

Prince, G.M. (1970) "The Practice of Creativity", 197, New York.

Rhyme, R. (1974) "Technological Forecasting Within Alternative Whole Futures Projections". Technological Forecasting and Social Change, 133-162.

Tagiuri, R. and Litwin, G. (1968) "Organisational Climate", 246, Boston.

Taylor, C., and Barron, F. (eds) (1963) "Scientific Creativity, its Recognition and Development", 419, Wiley, New York.

Twiss, B. (1974) "Managing Technological Innovation", 237, London.

Wade, W. (1968) "Industrial Espionage and Misuse of Trade Secrets", Advance House Publisher, Pennsylvania, USA.

Wonacott, R. and Wonnacott, T. (1970) "Econometrics", 445, Wiley, New York.

Zwicky, F. (1969) "Discovery, Invention, Research Through The Morphological Approach", 276, New York.