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Characteristics of Information Usage in Technological Innovation

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Abstract—The characteristics of information contributing to the resolution of technical problems arising during thirty on-going innovations in British industry have been studied with the aim of determining the patterns of information flow consonant with successful innovation. A number of findings have emerged: 1) Information obtained from literature contributed as much as that from personal contact. The innovation process is most efficient when these two sources are used in a mutually supportive fashion. 2) Different sources are selectively used to obtain different types of information. The choice of appropriate sources and in an appropriate order has a considerable impact on the innovation process. The choice pattern improves with the higher levels of education of the problem-solver and of the research intensity of the firm: 3) No direct correlation was found between the frequency of use of a source and its relative contribution to the innovation. Some vital pieces of information are obtained from sources infrequently used. Implications for researchers and management are drawn.

Manuscript received June 17, 1974; revised September 3, 1974.
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INTRODUCTION

Recognition of the importance of technological innovation in promoting the national economy has stimulated much research into the nature of the process [1]. In particular, considerable attention has been paid to the role of communication. A recent paper, providing a useful review of the more significant empirical research in this field has noted that these studies "have strongly underlined the prime importance of good communications to the *successful* conclusion of technological innovation." [2].

Factors which have been singled out for detailed study include the sources of ideas contributing to the innovation process, the channels through which information is transmitted, and the characteristics of individuals who play an effective role as disseminators of information. Perhaps the most significant and certainly the most frequently cited finding has been the relative importance, as compared with other modes of communication, of personal contact. This has been succinctly expressed by Burns in his aphorism, "The mechanism of technological transfer is one of agents, not agencies." [3] While this assertion has considerable validity, it does not represent a complete explanation of the nature of information transfer. For as is apparent, not *all* information is most efficiently transferred by face-to-face contact; otherwise it is unlikely that there would continue to be such a large market for printed matter. A further step in the understanding of the communication process requires that we find an answer to such questions as which types of information are best transferred by persons as compared with other means, and what roles are played by personal contact in facilitating information flow by other channels [21].

As part of a study of the relationship between science and technology, commissioned by the Economic Benefits Working Group of the Council for Scientific Policy [4], a detailed examination has been made of the characteristics of information usage in a range of innovations in British industry. The results indicate that the findings of many previous studies may have been based on questionable assumptions.

FRAMEWORK FOR THE STUDY

Innovation and Technical Problem Resolution

During the process of innovation in the industrial firm there is clearly a great deal of information acquired and transferred which is of greater or lesser relevance to the actual innovation. Much of the variance in results between different studies can probably be attributed to the difficulty of devising criteria for assessing all the important information inputs.

In the pursuit of technological innovation it is usual to encounter a range of technical problems, the resolution of which is necessary in order to bring the innovation to the market-place; indeed, one of the major functions of an R&D laboratory is to assist in solving these problems. For the purpose of this study we have chosen to focus on the information contributing to the resolution of technical problems arising during the course of development of an innovation. This focus on technical problem-solving exposes some of the assumptions underlying the investigation.

Firstly, the study was structured around the notion of problem-solving and this suggested that the individual, or team engaged in the process of problem-solving, might be the most suitable unit to focus on. However, the type of technical problem which arises in industry is characteristically different from those conventionally used in the study of problem-solving behavior. "For a technical problem there is often no correct, or even best, solution in the long run. In fact, there is frequently no terminal state: both problems and solutions are themselves often dynamic." [5] Also, the criteria for evaluation of a potential solution are not absolute—they are ultimately a matter of judgment and different people evaluate them differently. Nevertheless, the resolution of technical problems can be viewed as the assemblage and evaluation of information.

In the event of encountering a technical problem, the problem-solver can be considered, ideally, to approach the solution by moving from the familiar to the unfamiliar and from the routine to the novel [6], [7]. Thus only if local and easily accessible sources prove inadequate will the research be extended to those less readily available. However, one cannot make an *a priori* judgment, as Utterback has done [8], that the literature is more accessible than is contact with others. The availability of particular information sources clearly varies with each situation. It should be emphasised that the problem-solver can and in practice frequently does, solve, or more appropriately resolve the problem by redefining it in accord with the information he possesses.

Secondly, information which contributed to the resolution of nontechnical problems was specifically excluded. This is not intended to indicate that non-technical problems are not important, or even critical in certain innovations. However, in order to carry out the detailed examination of information characteristics necessary to achieve the goals of this study, only information contributing to the resolution of technical problems was included. Also, to this end, 'on-going' or very recently completed technological developments were selected for study. This feature served also to minimize most of the usual problems associated with historical case studies such as rational reconstruction and even tracing of relevant personnel.

Thirdly, the investigation was restricted to those innovations leading to new products. Process innovations are, of course, important, but their inclusion would have added another variable to be controlled. Thus the study was focused on the process of innovation leading to new products.

Research Methods

The sample was generated from the 'New Product' feature of the most recent issue of the total set of British technical journals on 1st August 1972.[1] A technical journal was defined as one containing articles of a technical nature, advertisements of products and processes and general news of relevance to one or a related range of industry. In practice this definition sufficed to distinguish these periodicals clearly from scientific literature on the one hand, and from trade literature such as news-sheets and catalogs distributed by individual companies on the other.

This approach provided a representative sample of the sort of innovation which is the "bread and butter" of much industrial activity. Too many studies of innovation have been concentrated on the spectacular, neglecting the fact that "technical change is to a significant extent, based on the cumulative effect of small incremental innovations." [9] One consequence of this sampling procedure was that no single innovation had a total development time of more than thirty months.

The initial sample of 1317 innovations was reduced to 178

[1]At this date there were 343 technical journals published in the U.K. which contained a feature describing new products relevant to the journal's interests about to be released onto the market [4].

by excluding those that did not meet the criteria of being a recent development by an industrial firm in the U.K. of a product that contained an element of technical novelty (at least to the company). A final sample of thirty innovations was randomly selected.

Data concerning the innovations were obtained by face-to-face interviews using a focused interview technique, with all the personnel directly involved with the technical development. The confidence of the respondents was obtained by assurances of such confidentiality as required, by preparation such that the authors were fully acquainted with the details of the company and the technology associated with their line of business, and by devoting sufficient time to each interview to ensure that informal as well as formal contact occurred. The fact that the innovations were of rather a small scale, as mentioned above, may have assisted in overcoming problems of secrecy. By a combination of detailed, convergent and iterative interviewing, an agreed list of the technical problems encountered during the process of each innovation, and the information which played a role in resolving these problems, was constructed. These raw data were then transformed into measures of fifty variables developed during pilot studies.[2] The variables fall into four major classes, describing characteristics of the organization, the innovations, the problem-solver himself, and the information which contributed to the resolution of problems arising during innovation.

In order to be able to classify and correlate the characteristics of the information, it was necessary to isolate approximately uniform "units" of information. It is quite apparent that there does not exist any absolute standard for such a division. Nevertheless, it was found in practice to be possible to subdivide information units on the basis of a general coherence in terms of content and source. This process can perhaps be best illustrated by an example.

During the development of a new solvent system for degreasing steel components, the chief chemist on the project read a report from a U.S. company that the kind of system they had developed had a dermatitic effect [1]. In order to determine the dermaticity of their own product, the chemist first scanned a range of technical literature, from which he obtained general indications of test procedures [2] and then telephoned a microbiologist at the university, who was able to direct him to a handbook [3] where the correct procedures for testing were contained [4]. Using this information he carried out patch tests and discovered that the product was highly dermatitic [5]. From his experience the chemist recognized that the monomeric amine was responsible for the dermatitis [6], and set a subordinate to search through the trade catalogs to find a non-dermatitic substitute [7]. One was found, tested for general performance [8] and incorporated in the product. Thus, by the approach used in this study, eight distinct units of information contributed to solving this technical problem.

[2]A much larger number of variables drawn from the literature was used during the pilot studies, but reduced to the fifty according to criteria of importance and relevance to this study.

These divisions are to some extent arbitrary and, as a consequence, the absolute numbers obtained have no particular significance. However, they have been consistently applied throughout the study and it is contended that any other criteria of distinction would have produced comparable results.

RESULTS

Sources of Information Used in Technical Problem-Solving

1) General Source: One factor which has been examined in most studies of the role of communications in innovation is the source from which the information is obtained, particular interest being shown in whether the information originates inside or outside the innovating company. Because in this study the problem-solver was chosen as the central focus for information reception and processing, three empirically distinct categories of the general source of the information were utilized. The first distinction depends on whether the problem-solver had to seek the information himself, for example, by examining the published literature or through personal contact, or whether he actually possessed the knowledge prior to the commencement of the innovation. This latter category, labeled "personal," was typically a product of the problem-solver's education or experience. The information which had to be sought was further divided according to whether the information was acquired from outside the company (external) or from sources within the company (internal).

Literature published outside the company was included in the external category, regardless of where the problem-solver located it, whereas company reports or manuals were classed as internal. Likewise, contacts with people not employed by the company were included in the former category. It should be noted that the general source is that from which the problem-solver directly obtained the information, and not the original producer of the information. This avoids the difficulties of attempting to trace all the information to an ultimate source.

Using these criteria the total of 887 information units contributing to the resolution of technical problems arising during the development of the thirty innovations (an average of 29.6 information units per innovation with a standard deviation of 8.7) were categorized according to their general source (Table I). Overall, the three general sources were used

TABLE I
General Source of Information Units

	This study		Langrish et al (10)			Myers & Marquis (9)	
General Source	No.	%	No.	%		No.	%
External	300	34	57.5	36	)	133	32
Internal	267	30	56	35	)		
Personal	320	36	44.5	29		281	68
Total	887	100	158	100		414	100

Note: Throughout this paper comparisons are made with data from what the authors consider to be key studies. No attempt has been made to include all possible relevant data.

approximately equally, though in particular innovations one source was used more than another. Translation of the data of Langrish *et al.* [10] into a similar form reveals that their results are broadly comparable.

Only one third of all information used in resolving technical problems was obtained from outside the company. Utterback [8] similarly found that during the problem-solving stages of an innovation, internal sources are more heavily used. It should be noted further that, in accord with the findings of Myers and Marquis [9] and of Allen [11], almost 80% of the information used in resolving technical problems arising during innovation was widely available, though perhaps only to specialists with the appropriate education or experience.

While the extensive data of Myers and Marquis [9] are not strictly comparable with the others in Table I, they found that in more than two thirds of the cases the major information contributing to the resolution of a problem already being worked on was derived form education and experience. The discrepancy between these data and those of the British studies will be discussed more fully below.

2) Specific Source: In order to make a more detailed study of the role of communication in innovation, information units were further classified according to the immediate specific source for the problem-solver. This produced a large number of classifications for each of the three categories of general source (Table II). While it was possible in the cases of the external and internal information to identify single sources, the determination of the specific source of personal information was more difficult and respondents usually cited a combination of sources (an average of 2.4 per information unit). In certain cases, a particular piece of personal information could be traced to a relatively specific source such as the reading of technical literature, but more often it could not be attributed to anything more specific than education and experience. The large number of categories illustrates the wide range of sources from which information was drawn but also limits the analysis which can be made.

Of the information obtained from outside the firm, that contained in various forms of literature provided as many inputs to the solution of technical problems arising during innovations as did that from various personal contacts. This finding suggests that the conventional wisdom of the critical role of personal contact in information transfer may be overemphasised. However, contact with individuals in both university and industry did contribute significantly to the innovation process. The vast majority of information from internal sources was a product of R&D activity, i.e., experimentation, analysis and calculation in the innovating firm.

The relatively high reliance on scientific literature and the low use of vendors concurs with the results of Shotwell [12] but not with those of Allen [13]. The significance of the relative contributions of scientific and technical information to the resolution of technical problems have been discussed extensively elsewhere [14].

In order to examine further the relative contribution of information obtained from printed materials as compared with personal contact, the data concerning the specific source of external and internal information have been aggregated into broader categories (Table III). It can be seen that personal contacts do in fact provide the largest amount of information, though not a great deal more than the other two categories. These results differ somewhat from those of Myers and Marquis [9] and of Utterback [8] who found a greater reliance on information obtained from personal contacts compared with other external and internal sources.

TABLE II

Specific Source of Information

External	No.	%	Internal	No.	%	Personal	No.	%
Literature			R&D activity	183	69	Company experience	255	34
Trade	43	14	Personal contact in section	42	15	Outside experience	58	8
Technical	22	7	Personal contact elsewhere in Company	24	9	Education	150	20
Scientific	36	12	Company Literature	15	6	Personal contact in company	24	3
Textbooks & Handbooks	28	9				Industry	62	8
Total	129	42				Literature		
Industry						Trade	84	11
Reps and Customers	20	7				Technical	84	11
Supplier Cos.	39	13				Scientific	20	2
Consultants	12	4				Total	188	24
Total	71	24						
Universities	30	10						
Government Agencies	11	4						
Research Associations	24	8						
Overall Total	265	88		264	99		737	97

Note: As the categories are numerous, some of the numerically less frequent ones such as conferences, exhibitions and patents have been omitted from this table. This accounts for the percentages listed not totaling 100%.

TABLE III

Summary of Sources of Information

Source	This study[a] No.	%	Myers and Marquis (9)[b] No.	%	Utterback(8)[c] No.	%
Printed Materials	165	29	31	7	36	13
Personal Contact	211	37	94	23	111	38
R&D Activity	191	34	35	8	107	37
Total	567	100	160	38	254	88

[a] The data from this study are based on all categories of external and internal information, including those not shown in Table II.

[b] Myers and Marquis include a category "education and experience" amounting to 51% of the total inputs, which in this study are classed as personal information; the extra 11% is attributed to "multiple sources."

[c] Utterback's other categories are "experience" (7%) and "other" (5%).

There are a number of possible explanations for the discrepancy between the results of this and other British studies and those of Myers and Marquis [9]. It may simply be a product of a different use of terminology, or of the fact that Myers and Marquis examined only one major information input per innovation. A further and potentially more significant explanation may lie in differing levels of expertise in British and American firms; in the former information has to be sought outside the firm whereas in the latter the information is available within the firm.

The organizational source of the external information has also been examined in a number of studies of the role of communications in innovation. In order to compare the

TABLE IV

Organizational Source of External Information

Sources	This study %	Langrish et al.(10) %	SAPPHO(15) %	TRACES(16) %	Myers and Marquis (9) %
Industry	54	64	41	83)	60
University	27	10	19	7)	
Government	11	21	22)		3
Research Association	8	0	4)	10	
Other	0	7	4	0	37

present data, all the literature sources had to be traced back to their institutional origin. The results along with data from a number of other studies are shown in Table IV.

As for the other studies, industry forms the major organizational source of external information, although it does not predominate to the same extent as found in the studies of Langrish *et al.* [10] and TRACES [16]. In contrast, however, this study indicates a greater reliance on information produced by universities than do the others. The data here do not support the hypothesis of Rothwell and Robertson [2] that firms in the U.K. rely more heavily on government agencies for problem solving information than do firms in the U.S.

THE RELATION BETWEEN INFORMATION SOURCE AND CONTENT

While detailed information on the distribution of use of the various general and specific sources provides some insight into the role played by information in the innovation process, it does little to explain why these sources should be so used, or whether more efficient use patterns might be established. One obvious possibility is that different types of information are obtained from different sources. In order to examine the relationship between content and source, all information units were categorized according to a number of classes developed from the work of Myers and Marquis [9] (Table V).

Information describing the properties, composition or characteristics of materials or components forms the largest class of information by content. This corresponds with the results of Myers and Marquis [9] who found that more than half of the significant information inputs described design or performance characteristics. Information of all other classes of content, except for the small class relating to the existence and/or location of specialist facilities and services, was used approximately equally over the whole range of the thirty innovations.

However, examination of the relationship between content and general source (Table V) shows that information of each particular class of content was obtained predominantly from one general source.[3] Thus, information describing the existence or availability of equipment or materials with particular properties, general laws and theories, and the existence of specialist facilities or services was acquired mostly from sources outside the company during the innovation. Similarly information from within the company was dominant in the

[3]All categories displayed a significant variation at the $p=0.01$ level, excepting theories and laws at $p=0.05$.

TABLE V

Content of Information for the Three General Sources of Information

Content	General Source of Information (Units)							
	External		Internal		Personal		Total	
	No.	%	No.	%	No.	%	No.	%
Existence or availability of equipment or materials with particular properties	65	22	11	4	47	15	123	14
Properties, composition, characteristics of materials or components	88	29	142	53	58	18	288	32
Test procedures and techniques	27	9	17	6	45	14	89	10
Operating principles or rules, required specifications, technical limitations	13	4	29	11	46	14	88	10
Location of information	20	7	8	3	50	16	78	9
Theories, laws, general principles	35	12	16	6	20	6	71	8
Design-based information	33	11	40	15	50	16	123	14
Existence of specialist facilities or services	19	6	4	2	4	1	27	3
Total	300	100	267	100	320	100	887	100

provision of data on the properties, composition or characteristics of materials. Personal information was used about equally to obtain all types of information but was still the major source of test procedures and techniques, operating principles and technical limitations, and of the location of information.

Hence we have clear evidence that, as might be expected, a problem-solver uses the knowledge he possesses whenever he can, but when this is insufficient he usually approaches a particular general source to obtain a particular type of information.

Although the resolution of technical problems requires a wide range of different types of information obtained from different sources, such a one-dimensional analysis of the origins of information is clearly an insufficient basis for making general prescriptions about the role of information in the innovation process and means of improving it. Different types of innovation will produce problems requiring a different mix of information to solve them and hence display a different source usage pattern.

THE CONTRIBUTION OF INFORMATION TO TECHNICAL PROBLEM-SOLVING

While the frequency of use of a particular type or source of information may be a rough measure of importance, such a correlation is based on the unrealistic assumption that all units of information contribute equally to the solution of technical problems. It was felt that a better indicator of the relative importance of each unit of information to the problem-solution process should be sought. Accordingly, respondents were asked to assess each unit of information for its impact on the resolution of the problem according to the categories shown in Table VI.

Very little of the information actually evoked the basic idea to solve a problem not previously formulated. Most information provided or directly assisted in the solution of a problem. With regard to the impact of different general sources, it can

TABLE VI

Impact of Information from General Sources

Impact	General Source					
	External		Internal		Personal	
	No.	%	No.	%	No.	%
Evoked basic idea	5	2	1	1	0	0
Provided or directly led to solution of problem being worked on	106	35	64	24	88	28
Stimulated action leading to the solution but was not itself incorporated	53	18	61	23	39	12
Narrowed area of solution of demonstrated feasibility	56	19	69	26	43	13
Defined base parameters to problem	20	6	37	13	51	16
Enabled test of proposed solution to be carried out	52	17	30	11	88	28
Contributed to unsatisfactory solution	8	3	5	2	11	3
Total	300	100	267	100	320	100

Note: The categories of impact are arranged in decreasing degree of contribution to the resolution of technical problems arising during innovation.

be seen that information obtained from outside the company contributed significantly more in providing the solution to technical problems than did the other categories. While sources outside the company contributed only about one third of the information, they were by far the most important in resolving technical problems arising during innovation. Internal information had the greatest impact by stimulating action leading to a solution in which the information itself was not contained and by narrowing the possible area of solution, i.e., information from within the company played the role of assisting the solution but did not provide the actual solution. Personal sources were used significantly more to obtain information which enabled the test of a proposed solution to be carried out, or defined the base parameters of a problem. Thus it appears that the greater the "cognitive distance" between the problem-solver and the information he acquires, the more likely it is to contribute in a major way to the resolution of technical problems. While all sources of information are important, it is that information with which the problem-solver is least familiar and which is least readily accessible to him at the commencement of the innovation that in practice provides the greatest contribution to solving the technical problems—a clear indication of the value of close links to sources of information outside the firm.

Turning to the relationship between content and impact, it can be seen that in general only two types provided or directly led to the solution of a problem being worked on (Table VII): information describing either the existence or availability of material with particular properties if design-based information, i.e., information relating to the design of materials or equipment. What is particularly significant is that the most frequently used type of information—that describing the characteristics of materials of components—does not contribute most to the innovation. This provides confirmation that examining information in terms of source only does not provide a very sound basis for assessing its role in the innovation process. This is most apparent with regard to the theories and laws which comprised only 8% of the total information

TABLE VII

Impact of Information of Different Types

Content	Provided solution		Stimulated solution		Narrowed area		Defined problem		Enabled test	
	No.	%	No.	%	No.	%	No.	%	No.	%
Existence of materials with particular properties	72	62	11	9	19	16	11	9	4	4
Properties etc. of materials	49	17	84	30	95	34	44	16	8	3
Test procedures	9	10	3	3	7	8	0	0	71	79
Required specifications	16	19	13	15	16	19	40	47	0	0
Location of information	1	1	11	14	2	3	0	0	63	82
Theories	28	42	18	27	9	14	8	12	3	5
Design basis	82	71	8	7	18	16	5	4	2	2
Specialist facilities	1	4	5	20	2	8	0	0	17	68

Note: Data from the three general sources are aggregated; only the five major categories of impact have been included.

TABLE VIII

Impact of Information from Various Sources

	Impact									
	Provided Solution		Stimulated Solution		Narrowed area		Defined problem		Enabled test	
	No.	%	No.	%	No.	%	No	%	No.	%
Source summary										
Printed Materials	62	40	31	20	30	19	13	8	21	13
Personal Contacts	66	32	35	17	32	16	18	8	55	27
Organisational Source										
Industry	73	45	26	16	30	19	12	7	21	13
University	29	36	20	25	13	16	2	3	17	20
Government	3	10	6	20	9	30	0	0	12	40
Research Assoc.	5	22	10	42	3	12	3	12	3	12

contributed directly to the resolution of problems; 42% of theories and laws had this impact.

The fact that the source or type of information which made the greatest contribution to problem resolution is not the most frequently used does not necessarily indicate, as Allen has suggested [17], that this source is being used insufficiently. As we have previously shown, different sources provide different types of information, and a wide range of these is required to resolve the technical problems arising during innovation.

The relationship between source and impact is confirmed by the summary (Table VIII) which shows that information from printed materials and personal contacts contribute approximately equally to technical problem resolution. A slightly greater percentage of information from printed materials provided the solution, whereas personal contacts assisted more by enabling tests to be carried out. Apart from the different degree of reliance of organizational sources (Table IV), there was no significant variation in the impact of the information from these different sources. Industry provided slightly more direct solutions whereas the other three organizational sources played a more supportive role.

CHARACTERISTICS OF THE ORGANIZATIONS

Up to this stage we have been examining the various characteristics of the information used in resolving technical problems arising during innovation on the implicit assumption that all the innovations could be treated equally. However, it might be expected that innovations developed in different types of organizations would produce a different range of technical problems and draw on different sources to obtain the information required for problem resolution.

This factor has been the focus of surprisingly little attention, though Myers and Marquis [9] did find that the "patterns of characteristics of innovations in the five industries revealed more similarities than differences." Other studies, notably by Woodward [18] and Burns and Stalker [19], have demonstrated the different forms of management which are required by different forms of technology.

It might be expected that the "science-based" industries would develop a different type of product than those of the craft industries and hence be faced with a different set of technical problems. In order to examine this, the OECD "research intensity" classification [20] of industries as high, medium or low, according to the level of their annual expenditure on R&D as a percentage of their total net output, was adopted. The use of the three general sources does not vary significantly from a random distribution for the high and medium research intensity industries (Table IX), but the industries of low research intensity (the traditional craft industries) relied far more heavily (p=0.01) on external sources than on internal and personal sources. There does appear to be a general trend from reliance on personal sources in high research intensity industries to reliance on external sources in the low research intensity industries. The science-based industries, having a highly developed R&D capability, are, or at least consider themselves to be, self-sufficient in expertise such that they rely to a considerable extent on their own resources. The craft industries, having a small R&D capability, are forced to rely more on external sources of information in order to carry through an innovation. These results correspond with Allen's findings in his study of 7 parallel R&D contracts involving 15 R&D groups [13] that "better performing groups rely more than the poorer performers upon sources within the laboratory." The explanation was based on the lack of acquired technical competence within the laboratories of poor performers.

TABLE IX
Comparison of Source Usage with Research Intensity of the Innovating Industry

Source		Research Intensity	
	High	Medium	Low
General Source			
External	9.1	10.6	12.6
Internal	8.7	10.6	7.4
Personal	11.6	10.7	7.4
Total	29.4	31.9	27.4
Source Summary			
Printed Materials	5.6	5.4	5.0
Personal Contacts	5.9	8.9	8.6
Total	11.5	14.3	13.6

Note: Because of the uneven distribution of innovations in each research intensity class (high:medium:low = 18:7:5), the data are presented as the average per innovation.

It is personal contacts rather than printed materials that problem-solvers in the lower research intensity industries rely on for obtaining this information (Table IX). Lacking the R&D expertise, it is not surprising that they are not in a position to draw on impersonal and abstract sources such as the literature, but rather approach individuals for assistance with specific problems. In the science-based industries, literature and personal contacts were used equally. These findings are supported by an examination of the external sources used by low research intensity industries which suggests a distinct bias towards the use of trade contacts such as sales representatives and customers, consultants, and the research associations, though the sample is insufficiently large to provide these conclusions with statistical validity.

THE ROLE OF INDIVIDUALS

No support was found for Allen's claim for the key role played by the "technological gate-keeper;" each individual associated with a project appeared to have at least some contacts or sources of information which he regarded as his own. The fact that the study focused only on those actively engaged in the innovation of interest, or that the innovations were of relatively small-scale, may have precluded detection of this phenomenon. However, in the data relating to use of internal sources no "star" [11] type of information network was detected in any innovation.

No measure of the relative performance of individuals was attempted, but a significant difference in patterns of information use was found for problem solvers with different educational backgrounds. While all of them contributed an approximately equal amount of information, those with a university education relied much more on external sources of information while those with a part-time or less formal education depended on personal information. It appears that the university educated problem-solver is better equipped to develop large scale innovations and to extend his resources by seeking information outside the company [14]. Education was the only characteristic of the individual which was found to affect patterns of information flow during the innovation process.

CONCLUSIONS

This study has provided a number of insights into the characteristics of information usage during the resolution of technical problems arising in the course of innovation. It is by no means an exhaustive study of the role of information flow and communication patterns in innovation. In particular, specifically excluded has been an examination of the relationship between information usage and successful innovation. Nevertheless, there have emerged a number of important consequences, particularly for researchers in this area, but also of interest to managers concerned with technical change. Some of the conclusions may appear obvious to practioners, but even a cursory examination of the literature on this subject would indicate that they have not always appeared so to researchers. Moreover, one of the functions of research is to examine hidden assumptions which, once displayed in the light of day, may appear obviously false.

Overall, it has been shown that information contributing to the innovation process is obtained equally from printed matter and by personal contact. There is no strong tendency to rely on personal contact. However, it is apparent that different types of information are obtained from different sources. The problem-solver uses personal contact to obtain the sort of information which by its very nature is not contained in printed form, such as the availability of particular areas of service or expertise, or the requirements of the actual or potential customer. Information which is characteristically found in literature, such as the properties of products in trade catalogs, experimental techniques in manuals or theories in textbooks, is primarily sought in that location.

The innovation process was most efficient in terms of development time and of the number of unsuccessful approaches when these two general sources were combined into a mutually supportive relationship; in particular this occured when personal contacts were used for locating relevant information in printed material, and subsequently for translating this information into a form appropriate for the problem-solver. It is important to note that this relationship was not merely additive; the use of the two general sources in tandem led to new and relevant information which would have been very difficult to obtain in any other way.

Another finding is that there is no direct relationship between frequency of use of a particular source or type of information and the contribution it makes to the innovation. What is important is the ability to recognize, locate and use a wide variety of sources of information to the appropriate extent, the appropriateness depending on the nature of the innovation.

These findings suggest important directions for subsequent research. In particular it is apparent that simplistic linear models of information flow are completely inadequate in describing the innovation process. For, as has been shown, the critical role of the information is often not that of completing an unfilled chain, but rather suggesting completely different approaches to the problem at hand, i.e., it plays an active rather than a passive role.

Management concerned with the stimulation and direction of technological development can also gain some useful insight from these findings. The importance of a wide range of information in successful innovation has been clearly demonstrated. Hence, the manager should promote diversity and flexibility to ensure access to as wide a range of information as possible; narrowly prescribed information retrieval systems are unlikely to provide this range. Given the synergistic interaction that is possible between personal and printed sources of information, formal and informal retrieval systems need to be coordinated. The efficiency of each is markedly increased by engagement with the other.

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