The Flow of Technological Innovation in an R&D Department

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The flow of technological innovation in an R&D department

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The flow of technological information, in particular the type of sources and transfer channels for technological information has been a focus of research interest since the very first studies concerning management of research and development. However, the results of these empirical studies, although encouraging and useful to managers, leave several questions unanswered, and even worse, contain some contradictions.

In this paper we will try to explain some of these contradictions using the technology characteristics as a contingency factor. The model, which we will present has been tested in a twofold way: questionnaires were used to provide insight into the importance of some sources, while interviews on the basis of standardized problems led us to a better insight into sources and channels.

1. Sources and channels of information in the R & D process

The importance of good communication and optimal information flows has been stressed throughout the whole history of the study of management of the innovation process. Already in one of the first analyses in the field, Carter and Williams [9] came to the conclusion that of the 24 factors they were able to identify as characteristics of a “technologically progressive company”, the six most important factors (such as high quality of incoming information, willingness to share knowledge...) had something to do with the information flow. Other landmark studies such as the Myers and Marquis study [20], the Langrish et al. study of Queen’s Award winning innovations [18], or the second SAPPHO study (Rothwell et al. [23]) reached similar conclusions. The SAPPHO researchers summarized it as follows: “Not only must management ensure that information flows smoothly throughout its own organization, but also that the firm is aware of developments outside its own environs, particularly in the specific area concerned with innovation, including the behavior of the competitors”.

If one accepts this conclusion, it becomes of utmost importance to the management of innovation to study ways of improving the information flow, and the studies concerning this topic are numerous. The results of empirical
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studies concerning the information flow in an R&D environment can generally be classified into four categories: sources of information messages, channels through which information is acquired, the role of individuals or gatekeepers in the information flow, and the influence of organization and architecture upon the communication.

However, given the importance of communication, the results of these empirical studies provides the innovation manager with hardly any rules of thumb to steer the information flow. As an example in table 1 the results of some studies about sources of information have been summarized (after some transformation to obtain comparable data). The comparison of those studies is in itself already a difficult problem. The studies involved vary quite considerably in sample size, and selection method and quality. Most of them were clearly linked to particular industries (Myers and Marquis [20]; Allen [3]; Utterback [28]), some of them used small samples, etc. However, the least that can be concluded from these studies is that an unambiguous answer to the question “which are the most important sources” is not available. The number of externally generated ideas ranges from 11 to 65 percent of the total number of information messages. For those cases where sufficient data is available, the personal experience as a source of information ranges from 8 to 66 percent of the total number of messages.

Table 1: Sources of information during the innovation process (in % of the total number of sources)

<table>
<thead>
<tr>
<th>Sources of Information</th>
<th>Personal</th>
<th>Internal in the company</th>
<th>External to the company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baker et al [7]</td>
<td>64</td>
<td>25</td>
<td>11</td>
</tr>
<tr>
<td>Myers and Marquis [20]</td>
<td>66</td>
<td>12</td>
<td>22</td>
</tr>
<tr>
<td>Utterback [28]</td>
<td>7</td>
<td>47</td>
<td>46</td>
</tr>
<tr>
<td>Langrish et al. [18]</td>
<td>--</td>
<td>35</td>
<td>65</td>
</tr>
<tr>
<td>Gibbons and Johnston [14]</td>
<td>36</td>
<td>30</td>
<td>34</td>
</tr>
<tr>
<td>Allen [3]</td>
<td>8</td>
<td>42</td>
<td>50</td>
</tr>
<tr>
<td>Sounder and Chakrabarti [26]</td>
<td>--</td>
<td>84</td>
<td>16</td>
</tr>
<tr>
<td>Nystrom [21]</td>
<td>--</td>
<td>62</td>
<td>38</td>
</tr>
</tbody>
</table>

Regarding the transfer channels for technological information, the picture is hardly clearer. From the comparison of twin projects Allen [3] concludes that the better performing engineer does not make more use of literature than the less performing, but the first one uses literature in a more balanced way over the time span of the project. Moreover, Allen finds that literature is not that important. The best source of information appears to be an organizational colleague who is nonetheless outside the project group to which he belongs. Shotwell [25] presents on the basis of a study of only one laboratory some dissenting conclusions: he found that literature, in particular the formal scientific literature, is the best source of ideas. And in contradiction to Allen’s result that the better
performing engineer makes an equally balanced use of all sorts of sources, one can cite the results of Ettlie [12], who asserts that all the various information channels are equally important, but are differently used over time.

Concerning the role of individuals (in particular the technological gatekeeper) here too results are again somewhat divergent. The technological gatekeeper is, as the classical definition runs, “an individual who maintains consistent, ongoing contact outside the organization, who understands the way in which outsiders differ in their perspective from their organizational colleagues, and who is able to translate between the two systems” (Allen et al. [4]). The existence of these gatekeepers has been shown in the US, (Allen [2]; Taylor [27]), and in British organizations, as well as in Sweden (Allen and De Meyer [5]) but regarding their characteristics, one discovers opinions which differ clearly. Whereas Allen and Taylor consider the technological gatekeeper to be a spontaneous phenomenon (he is usually to be found at the lowest levels of the hierarchy), to Frost and Whitley [13] gatekeepers are a result of their administrative position (“a first-line supervisor’s job brings ex officio extensive external contact with it”) and to Hall and Ritchie [17] the gatekeeper function is a result of the organizational structure.

Myers [19] develops the concept of “specialized gatekeepers”, or gatekeepers who are communication facilitators for specific categories of information. He distinguishes between information related to the managerial aspects of the project, information about a scientific field or discipline, and information concerning the performance of different kinds of laboratory techniques. His results, based on one medium-sized laboratory, do not refute the concept that for each of the three kinds of information, gatekeepers are characterised by a different set of descriptors. A qualitative interpretation of his results suggests that the gatekeepers for managerial information are organizationally determined, while the gatekeepers for the second kind of information are more explicitly associated with informal relations.

On the basis of methods similar to the ones used by Allen and applied to six firms in three industries, Brown and Utterback [6] relate the proportion of gatekeepers and consequently the origin of gatekeepers, to perceived environmental uncertainty: the higher the perceived environmental uncertainty, the higher the proportion. They conclude also that in firms with lower levels of perceived environmental uncertainty, gatekeepers will more often occupy formally defined roles, that is be supervisors or group leaders.

Once again the differences in results can be due to several factors. The American studies were mainly limited to smaller samples from the aircraft and aerospace-related industries, and the Swedish study of the metallurgical industry, whereas the British studies were mainly through case-studies. Differences in industry, in research methods etc., might have caused the differences in results.
A main conclusion of these studies is consequently that up to now, one cannot define an optimal portfolio of sources, or channels through which information reaches the R&D department. Apart from the fact that the empirical studies cannot always be compared easily, due to the ambiguous definitions of an information unit or an innovation project, the differences in results do not refute the hypothesis that there might be contingency factors which influence the optimal portfolio of sources and channels.

The studies of Olsen [22], Yon Hippel [31] and Vanderwerf [32] suggest that the source of innovation might be dependent on the (sub)industry. Olsen concludes for example that in the textile industry the suppliers play an important role in initiating the innovation process. Vanderwerf [32] suggests that innovation in wire termination is mainly due to the machine suppliers. To Von Hippel, the bulk of the ideas will come from those outside parties, (suppliers), manufacturers, users etc.) who may benefit most from the innovation. This again is dependent on the type of industry. The weakness of such an approach is that it assumes that within an industry, innovation is characterized by common characteristics. Apart from the fact that quite a few large sample studies (Van Lommel et al. [30]) doubt the fact that companies belonging to the same industry share common economic characteristics, this assumption is in conflict with the assertion that innovation in an industry is often stimulated by “new boys”, or companies who do not belong to the industry. (Goodman and Abernathy [16]). This suggests that sources of information for real innovative projects would not precisely be determined by the characteristics of the industry.

Other authors make a distinction between initiation of the innovation project and the problem-solving phase (Myers and Marquis [20]; Utterback [28]), between product and process innovation or between small and large companies (Rothwell and Robertson [24]). Though each of these factors clearly has some influence, none of them seem to provide a clear answer to the question of how the information flow in an R&D department should be organized.

The model presented in the following sections is based on the assertion that the structure of the information flow can be related to the characteristics of the technological life-cycle. It is hypothesized that neither industry, size nor any other factor except technology is the major contingency factor which influences the information flow during the process of technological innovation.

2. The technological life-cycle

To explain the differences in results concerning the flow of technological innovation, it is our opinion that one should not rely primarily upon an external contingency factor, but rather that one should explore the characteristics of the technology itself. The model which has been developed by Utterback and Abernathy [29] and which describes the evolution of a productive unit appears to be the best empirically supported model to describe the evolution of process technology. This productive unit is defined as “an integral production process
that is located under a common management to produce a particular product line”. The essential idea of a productive unit is, as the classical formulation runs, that it “tends to evolve and change over time in a consistent manner.” (Abernathy [1, p.48])

The evolution over time of such a productive unit is characterized by a shift in the emphasis on the kind of innovation activities, the degree of flexibility, the vertical integration of the production process, and the degree of standardization of the products.

Briefly, one can distinguish three phases (see Abernathy [1] for a more detailed description):

(1) A “product” phase or fluid state, characterized by:
   - a product-performance-maximalizing attitude and competition on the basis of product characteristics;
   - a high frequency of product innovations, mostly based on expectations about developing and expanding user needs, rather than detailed market research;
   - generally a large variation in the number of competitors, because the “entry-fee” (investments in know-how and capital goods) can be relatively low at this stage of the technological life-cycle;
   - an entrepreneurial approach of management and an organic organization;
   - a non-coordinated, flexible, non-standardized production process, built around general purpose equipment.

(2) A “transitional” phase characterised by:
   - the gradual emergence of one or more dominant product designs;
   - emphasis on product variation rather than product innovations;
   - a segmented production process in which automated sections exist besides manual operations;
   - a gradual increase in task specialization and formal procedures.

(3) A “process” phase or specific state, in which:
   - competition is based mainly on price, which, consequently leads to an emphasis on cost reductions and streamlining of the production process;
   - process innovation is strongly emphasised;
   - products become more and more standarized;
   - efficiency, scaling up and vertical integration are emphasised as strategic objectives.

(4) Finally one can add a fourth stage in which the productive unit reaches a state of maturity, in which neither product nor process innovation is of primary strategic importance.

Far from touching upon the question what the mechanisms are, due to which productive units evolve along this technological life-cycle, or which difficulties have to be overcome to go from the third to the second or first state, we will use here these four stages as classes, or groups in which productive units can be categorized, based on their behaviour concerning innovation.

One of the most important consequences of the technological life-cycle concept, is that to whatever class a productive unit belongs, the nature of its product and process innovation, and the characteristics of the manufacturing process and organizational flexibility should be tuned to each other.
The central hypothesis we want to develop here is that the characteristics of the information flow are influenced by the stage of the technological life-cycle in which the productive unit can be classified.

3. A theoretical model for the flow of technological information

The core of the model presented here, implies that the most important sources of technological information and the dominant element of the information network are related to the class or group to which a productive unit (PU) belongs, with respect to its innovation behaviour. This model is described schematically in Fig. 1.

Fig 1. Relation between information flow in an industrial innovation department and the group to which a PU belongs based on its innovation behaviour.

<table>
<thead>
<tr>
<th></th>
<th>Product phase</th>
<th>Transition phase</th>
<th>Process phase</th>
<th>Mature phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant source of</td>
<td>Scientific and</td>
<td>Users</td>
<td>Suppliers</td>
<td>Other markets</td>
</tr>
<tr>
<td>information</td>
<td>technological research</td>
<td>Competition</td>
<td>Production department</td>
<td>Scientific research</td>
</tr>
<tr>
<td>Users/customers</td>
<td></td>
<td>Suppliers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant information</td>
<td>Hiring of new</td>
<td>Non-hierarchical</td>
<td>Hierarchical</td>
<td>Manpower flow</td>
</tr>
<tr>
<td>network element</td>
<td>engineers</td>
<td>technological gatekeepers</td>
<td>technological gatekeepers</td>
<td></td>
</tr>
<tr>
<td>Disperse contacts</td>
<td></td>
<td>Gatekeepers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gatekeepers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.1. Group 1: The product stage

In PU’s of the first group, ideas emerge from the fusion of the results of recent scientific and technological research and the (rising) market demand or the first crystallization of the user needs. The most important sources are located among the users on the one hand, and the sources of recent scientific and technological results on the other hand. The last ones are situated in universities and science-orientated research institutes, some competitors who act as technological forerunners, in some industries in the component suppliers who put research into practice at the front of technological knowledge (e.g. the producers of electronical components), or in companies who are active in markets which differ completely. On the market side it is not that important, given the vague definition of the market needs, to discover the user requirements with traditional market research techniques. It is better to try detecting the gradual emergence and definition of these needs using a close relationship with the users or even try to influence the product definition.
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PU’s of this kind are, by definition, characterized by a flexible and unstructured organization. Information about the state-of-the-art of the technology will flow into the organization through flexible and unstructured transfer channels. More intensively than in other groups, the technologists from these PU’s will develop their own external contacts to keep in touch personally with the evolution in technology and on the market. Due to the uncertainty about needs, product definition and technology, these external contacts will be unstructured, rather ad hoc than lasting, and highly variable in time. The number of persons who will be contacted externally is probably high, but they hardly form a stable network. Technologists in such a PU cannot rely on a clearly defined group of external experts, of whom they know the capacities and potential.

Information will flow into the organization due to the hiring of new employees, though this is not an explicit policy of this kind of PU to internalize this PU is confronted with, lead automatically to a higher rotation of employees and/or the growth of the total number of employees and/or the growth of the total number of employees.

Internally the network of oral contacts reflect the orientation towards the technology. The number of contacts within the company with other departments is lower than for PU’s of other groups. The contacts are rather orientated towards their own innovation department. Written sources, in particular those which reflect the recent scientific and technological advances, for example scientific journals, professional journals and reports, rather than business journals or textbooks, will form a major part of the information portfolio of the technologist.

3.2. Group 2: The transition stage

However, as soon as the dominant design emerges and the transition stage starts, the attention of the technologist will gradually shift from the front of technological and scientific progress to competition and suppliers.

The gradually emerging dominant design results in a decreasing need for radical product innovations, for which one would have to consult sources of technology and science. The competitors, on the contrary, are the key figures in the definition of the dominant design. They supply an abundance of information about the parameters of the dominant design, and are consequently a source of ideas for incremental product innovation.

The start of the first cost-reduction programs and process innovations, the design of the first islands of automation, the need to supplement the know-how about the product with company-owned knowledge about the production process, forces technologists of these PU’s to look for information to suppliers and specialized service companies.

This is a group where contacts with universities decrease strongly for two reasons. On the one hand one does not need more to pursue radical product innovations, on the other hand highly specialized research institutes will not yet be consulted to resolve the typical technical problems which can arise when one tries to exploit a production
process optimally (e.g. the behaviour of materials in extreme conditions of heat, velocity,-or the avoidance of the influences or consequences of inertia forces, etc.).

The typical process problems which one can encounter at this stage can be solved with information and ideas from suppliers and engineering companies.

The market remains an important, if not the single most important source of information. Customers of PU’s in this group, are offered a product of which the basic characteristics are defined, which satisfies the needs, but on which quite a lot of incremental product variations and improvements are conceivable. Once the basic design has become clear, it is far easier for them to formulate their wishes and requests in a clear way, and these requirements constitute a major source of information to the technologist whilst refining his product design.

This second group, which is somewhere in the middle of a flexible, organic organization, characteristic of the first group, and the well-structured, mechanistic organization of the third group, surrenders some of its slack and flexibility for an increase in productivity and a more opaque structure. This is reflected in the streamlining of the channels through which information flows into the organization.

The second group is the group where the presence of the spontaneous technological gatekeeper is indispensable. The gradual reduction in slack results in more highly structure contacts with the environment. Oral information will flow through those people who prove to be most effective in handling information. One of the causes of the appearance of technological gatekeepers may be some kind of darwinistic process in which the more talented information gatherers and diffusers are assigned the task of gatekeeping in a natural way. Since on the other hand this tendency to efficiency and slack free structure is still very young, the PU’s of this group are characterized by non-hierarchical technological gatekeepers, or gatekeepers one may find on the lowest hierarchical level, or as first level supervisors.

3.3. Group 3: The process stage
Group 3 is, in contrast to the first two groups, characterized by a well-defined organizational structure, an emphasis on process innovation and incremental product innovations, and a lower perceived environmental uncertainty.

The required technical information is concerned mainly with the implementation of process improvements, and is sought for internally, with suppliers and with specialized research institutes and laboratories performing research on the optimization of production processes. Given the fact that process know-how is pre-eminently company-specific information, the internal sources, in particular the production department, becomes more important than in the first two groups.
The customer requests remain important to realize incremental product improvements. These needs are easy to formulate and can be discovered with the traditional market research techniques. To the technologists it is not that important any more to conceive a product together with the users, but rather to know their requests as accurately as possible. This data can easily be supplied by the commercial department, a market research department, or a technical support department. The informal contacts with the customers can consequently be replaced by formal channels (e.g. internal written reports, or memos originating in the commercial department).

The formalization of the information channels is not limited to information about the market. Given the reduced uncertainty about product definition, market needs and technological evolution, the hierarchy will be able to provide the necessary information to the technologist in a planned way. While designing the organizational structure one will explicitly take into account the flows of information. Technological gatekeepers, as translators of externally available information, will be active in this third group, but since it regards a more predictable and less uncertain task, the function of the technological gatekeeper can be explicitly recognized by the organization, or even performed by the hierarchy. PU’s of the third kind are organizations characterized by hierarchical technological gatekeepers, or gatekeepers who are explicitly recognized as such in the organization chart or who have apart from their technical duties, important managerial or administrative tasks.

The technologists who maintain external contacts are able, due to reduced environmental uncertainty and the stabilization of the technology, to rely on a better defined and stable network of contacts: though the total number of contacts might be somewhat lower, the frequency with which each individual is contacted is higher due to the clearer definition of the target group of information sources.

The wide gap between the technological needs of this group and the related scientific supply results in the fact that science-oriented journals become unimportant. Supplier brochures and journals of professional organizations become more important in the portfolio of literature relevant to the technologist. Complementary to the formalization of channels and the growing tendency to consult internal sources, internal reports become more important to the technologist in the PU’s of this group.

3.4. Group 4: The mature phase

PU’s from the fourth group do not consider innovation as a priority as all. The proper technologies, regarding the product as well as the process, have become more stabilized and R&D is limited to a kind of “maintenance” of the technologies in use. It is however of utmost importance to these PU’s to recognize and evaluate the potential of new technologies which could render their core technologies obsolete. To realize this, there should exist technological antennae, able to receive continuously signals about technological evolutions, and one should develop the ability to internalize these potentially threatening technologies.
These antennae should be tuned to a variety of “broadcasting sources” located in scientific and technological research. This has something to do with the statement above that at the origin of a new technology, the symbiosis between academic and industrial research is intense. Moreover these antennae will have to be orientated towards unknown markets for the PU.

The existing channels, even more than in group 3, are aimed at the own company. They are consequently, completely incapable of internalizing information about technologies and markets. To get this kind of information inside the PU one has to open “destructive” channels, for example the hiring of new employees for key positions in the company, or the creation of research teams with universities, which can be located at the boundary or even outside the PU.

3.5. Conclusions
Reviewing the model one can assert some hypotheses:

(1) Concerning the technological gatekeepers:

   \( H_1 \): In R&D departments of “phase 1” productive units there will be no gatekeepers or the gatekeeping function will be performed by non hierarchical gatekeepers.

   \( H_2 \): In R&D departments of “phase 3” productive units the gatekeeping function will be performed by hierarchical gatekeepers.

(2) Concerning the use of literature:

   \( H_3 \): The absolute of literature will be higher for technologists of “phase 1” productive units.

(3) Concerning the sources of information:

   \( H_4 \): Customer information is important in all phases but will come to the technologists through more formalized channels in later phases of the technological life-cycle.

   \( H_5 \): Competitor’s information becomes more important in phase 3 or 4 than in phase 1 or 2 of the technological life-cycle.

   \( H_6 \): Universities as sources of scientific state-of-the-art knowledge will be most important in phase 1.

   \( H_7 \): Research institutes organized on an industry basis and performing process research will be more important in phase 2 and 3 as a source of information than in phase 1.

   \( H_8 \): Production departments will be more important as a source of information when in phase 3 than in phase 1.

   \( H_9 \): Suppliers will be more important as a source of information to the technologist in phase 3 than in phase 1.
4. Methodology

The model described above has been empirically tested in two ways. In 22 companies or company units which could be clearly identified with a productive unit as defined by Abernathy [1], a questionnaire was distributed among technologists. These 22 companies come from a variety of industries: electronics (6), mechanical construction and metallurgy (11), biochemistry (1) and bioengineering (1), software development (2), and chemistry (1). They are all located in the northern part of Belgium and would all, by international standards, be classified as small or medium-sized enterprises. The number of employees in R&D and Engineering departments varied from 4 to 100. With one exception they have all existed for more than 10 years and are all considered to be healthy companies with a good profit record. Technologists are defined as those people who spend at least 50 percent of their company time on technical problem-solving related to innovative activities. Draughtsmen and technicians who perform a purely operational task are not included in this group. Most of them are engineers of some sort, but some of them are scientists, medical doctors or other professionals.

The goal of the questionnaire was to get a picture of the internal and external information network, as well as of the use of a selected number of information sources. This questionnaire was distributed through a contact person, in the majority of cases the R&D manager. A total of 202 technologists out of 406 who were approached answered the questionnaire.

In nine of these companies or company units 36 technologists were interviewed on the basis of eight standardized problems typical of those encountered during a project of technological innovation. These standardized problems are short cases of a half to a page long, drawn from a previous study (De Meyer [10]). The described problems are for example technical problems arising during the transfer from R&D to production, the need to come up with new ideas, etc.

During the interviews the technologists were asked to describe how they would react to the problem, to whom they would turn for help, where they would look for information, and how they would proceed to solve the problem. The advantage of the method is that in this way one obtains comparable information from interviews with people from a variety of backgrounds, who are put into the same situation. One gets almost a proxy of a laboratory experiment.

The productive unit had of course to be classified into four groups to verify the model. This classification exercise was performed by a panel of five experts with different technical backgrounds, but generally accepted to be well acquainted with innovation and with a knowledge of Belgian industry. One of them is the research director of one of the largest industrial companies in the country, two are technological advisers in para-governmental institutes,
one expert comes from academe, and one is the top manager of an institute stimulating and subsidizing scientific research in universities and industry.

The classification was based on the information the experts had themselves about the companies and the answers to a questionnaire about the company or company unit’s emphasis on process or product innovation, the degree or flexibility of the production planning, the degree of customization of the product, the importance of cost and/or product characteristics as a competitive weapons, the perceived uncertainty in the environment, the time span between two consecutive introductions of new products as well as the evolution of that time span and the appearance of new technologies.

This questionnaire was filled out by a senior manager of the companies in the sample. Though the sample has never been stratified, the classification resulted in seven “phase 1”, five “phase 2”, six “phase Y”, and four “phase 4” productive units.

5. Results of the questionnaire

In a first part of the questionnaire, technologists were asked to indicate whom they would contact inside and outside the company in case of a technical problem and with which frequency this happens per month. This allowed us to study gatekeeper activities. To define the gatekeepers we used a classical definition: he or she is a technologist who has a higher number of outside contacts than his organizational colleagues, and who is consulted more by his colleagues than one would expect. In other words he is an external as well as an internal communication “star”. This results in three operational requirements:

(1) The distinction of the number of times a person who was consulted had to be positively skewed to accept the existence of internal communication stars with the productive unit;

(2) To consider a person as an internal communication star, the frequency with which he is consulted by his colleagues should at least be equal to the average for the productive unit, plus one standard deviation;

(3) To consider a person as an external communication star, he should contact more outside persons and/or read more than his average colleague.

Given these requirements, and limiting ourselves to the productive units of the first three groups, there were 2 productive units without technological gatekeepers, and 14 with technological gatekeepers. In two cases there were an insufficient number of observations to apply the three rules mentioned above and to obtain an unambiguous result.
To operationalize the distinction between hierarchical and non-hierarchical gatekeepers we defined the last group as those gatekeepers whose task is limited to technological problems, for example the lowest levels of engineers and first-line supervisors with very limited management responsibilities (functional supervisors or sub-project leaders). The group of the hierarchical gatekeepers consists of those people who belong to the management of the productive unit or who have a job description which clearly includes the gatekeeping function.

One only finds companies without gatekeepers in “phase 1” companies or company units (table 2). In the “phase 1” companies only nonhierarchical gatekeepers can be found, while in the process group hierarchical gatekeepers outnumber the non-hierarchical ones.

**Table 2: Cross tabulation of companies by group and types of gatekeeper**

<table>
<thead>
<tr>
<th>Incidence of gatekeeper</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>No gatekeepers</td>
<td>2</td>
</tr>
<tr>
<td>Non-hierarchical gatekeepers</td>
<td>5</td>
</tr>
<tr>
<td>Hierarchical gatekeepers</td>
<td>0</td>
</tr>
</tbody>
</table>

This table is clearly not suited to traditional statistical analysis. We had to rely on a small sample technique (log-linear models) to be able to assert something about this table. Moreover there is the additional problem that one of the cells contains a zero. Goodman [15] suggests in this case to add to each cell a small number such as 0.5. He argues that this is a conservative procedure which tends to underestimate the confidence level.

Applied to table 3 the log-linear procedure provides a model which tries to explain the results, considering only the main effects (group and type of gatekeeper) and a model which considers the interaction effect between the main effects as well. Consideration of the interaction effect improves the goodness of fit significantly ($\chi^2$-square tests, $p < 2.9\%$).

**Table 3: Number of hierarchical and non-hierarchical gatekeepers**

<table>
<thead>
<tr>
<th>Types of gatekeeper</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Non-hierarchical gatekeepers</td>
<td>8</td>
</tr>
<tr>
<td>Hierarchical gatekeepers</td>
<td>--</td>
</tr>
</tbody>
</table>
Though this may not be conclusive, these results support the hypotheses 1 and 2 about the evolution from non-hierarchical to hierarchical gatekeepers along the technological life-cycle.

A second part of the questionnaire provides some insight into the use of literature as a carrier of problem-solving information. In the questionnaire, the respondents could indicate, on a scale of never, once a year, once a month, once a week or once a day, whether they consulted certain types of formal written sources for their job. This is of course not a very good reflection of how much the technologists actually read. But assuming that there are 220 working days a year, 12 months and 48 weeks, one can get an estimate of how frequently they consult written sources. On the basis of this rough calculation one finds (table 4) that technologists of “phase 1” productive units would consult written sources more often than their colleagues of other groups. This supports the third hypothesis.

Table 4: Frequency of literature consultation

<table>
<thead>
<tr>
<th>Productive units of</th>
<th>Frequency of literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>293</td>
</tr>
<tr>
<td>Phase 2</td>
<td>184</td>
</tr>
<tr>
<td>Phase 3</td>
<td>251</td>
</tr>
<tr>
<td>Phase 4</td>
<td>234</td>
</tr>
</tbody>
</table>

\[ F = 2.97; p < 0.05 \]

To the test the sensitivity of this result, the same calculation was performed by replacing the higher number mentioned of 220, 48, and 12 by half or double. The 16 cases one gets this way provided similar results.

To verify the hypothesis about the sources we can first rely on a question in which the technologists asked to indicate whether they considered a particular source of information to be important to their job (table 5). Customers are important for every phase, even more so in the second one of the third group than in the first or the fourth group. This fits the model, because it supports the idea that productive units in phase 2 or 3 work with a dominant design, and indeed rely on customers to get ideas for product improvements. In phase 1 or 4 where one focuses on technologies which have not yet convinced all customers and of which customers are unaware, one can rely somewhat less on them as a good source of problem-solving information. The commercial department as a source shows a clear pattern: less important in phase 1 and 2, very important towards the end of the technological life-cycle. Contacts with customers are important, but a lot of market information comes in phase 3 or 4 through the more formalized channel of a commercial department. One could raise the question of whether this is not related to the size of the company. We could find no correlation, significantly different from zero, between size and the importance of the commercial department as a source of information.
The flow of technological innovation in an R&D department

Table 5. Percentage of technologist that considers a source to be important or very important

<table>
<thead>
<tr>
<th>Source</th>
<th>Total (N = 202)</th>
<th>Phase 1 (n = 85)</th>
<th>Phase 2 (n = 60)</th>
<th>Phase 3 (n = 40)</th>
<th>Phase 4 (n = 17)</th>
<th>p a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers</td>
<td>50.0</td>
<td>45.9</td>
<td>56.7</td>
<td>53.8</td>
<td>41.2</td>
<td>3.8</td>
</tr>
<tr>
<td>Commercial department</td>
<td>28.2</td>
<td>20.0</td>
<td>26.7</td>
<td>42.5</td>
<td>41.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Competitors</td>
<td>40.6</td>
<td>37.6</td>
<td>36.7</td>
<td>45.0</td>
<td>58.8</td>
<td>NS</td>
</tr>
<tr>
<td>Universities</td>
<td>14.9</td>
<td>11.8</td>
<td>10.0</td>
<td>23.0</td>
<td>29.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Industry-based research institutes</td>
<td>9.4</td>
<td>4.7</td>
<td>6.7</td>
<td>22.5</td>
<td>11.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Production department</td>
<td>45.5</td>
<td>42.4</td>
<td>36.7</td>
<td>55.0</td>
<td>52.9</td>
<td>NS</td>
</tr>
<tr>
<td>Suppliers</td>
<td>41.6</td>
<td>41.1</td>
<td>33.3</td>
<td>48.7</td>
<td>58.8</td>
<td>4.5</td>
</tr>
</tbody>
</table>

a Significance level of the χ²-test on the distribution in %

Competitors as a source of information are once again important, but there is no significant influence on the degree of importance of the classification in groups. On the basis of this result hypothesis 5 has to be rejected.

Both universities and research institutes become more important when one moves from phase 1 to phase 4. The result concerning the research institute supports our hypotheses. Indeed, these industry-based research institutes are created in Belgium for well-established industries (metallurgy, mechanical construction, welding, agro-industry, etc.) and perform mainly process-optimization research. One expects indeed technologists from “phase Y’ or “phase 4” companies or company units to turn towards these research institutes for technological support.

Concerning the role of the production department as a source of information, there is no significant bias in the perceived importance of the production department according to initial classification in groups, contrary to what the hypothesis suggests. If one groups together the company units of, on the one hand, phase 3 and 4 and on the other of phase 1 and 2, there is a statistically significant difference between the proportions of technologists in these two new groups who consider the production department to be an important source of information. There is moreover some qualitative information to support this. As mentioned earlier, technologists were asked whom they would contact in the case of technical problems. An analysis of these names and the departments to which they belong shows that the proportion of the people mentioned who were from a production department is significantly higher in the “phase Y’ companies than in “phase 1” companies.

Suppliers form a seventh source of information. They are more important in “phase 3” or “phase 4” companies or company units than in “phase 1” or “phase 2” companies or company units. This supports hypothesis 9.
6. Results of the interviews

As already mentioned, 36 technologists out of nine companies (who were classified in the first three groups) were interviewed on the basis of standard problems. These problems resulted from a previous pilot study (De Meyer [10]) and were considered to be typical to the R&D environment.

The decoding of the interviews consisted of checking the frequency of the channels the interviewees suggested they would consult or use to solve the problem. We are aware of the fact that by doing so, some of the richness of the answers was lost, in particular the intensity with which the sources would be consulted. Interpreting this intensity would probably introduce too much bias.

Although these frequencies (table 6) of the intended use of source and channels allow us to get some insight into the preferred sources and channels, interpretation is difficult given the large number of sources and the uneven number of interviewees in each group. Therefore we relied on a variant of factor analysis which is pre-eminently fitted for a multivariate analysis of nominal variables (Benzecri [8]). Since there are only three groups, one is able to position these groups perfectly in a two-dimensional space. The first dimension for the sources (fig 2) which explains 68 percent of the variation in the data, reflects the controversy: personal experience and personal contact with customers versus engineering firms, suppliers and other companies. The second dimension opposes universities and competition with the commercial department; in other words technology versus formal market sources. The location of phase 1, 2 and 3 companies or company units is precisely as one would expect it to be. The position of phase 1 companies is close to that of universities and the R&D department. The position of phase 2 companies is determined by the first dimension and is close to the market. Phase 3 companies are positioned as well by first dimension, and close to suppliers and other companies.
Table 6: Number of times a type of source was mentioned during the interviews

<table>
<thead>
<tr>
<th>Sources</th>
<th>Respondents of companies classified in</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Product phase</td>
<td>Transition phase</td>
</tr>
<tr>
<td>Commercial department</td>
<td>21</td>
<td>8</td>
</tr>
<tr>
<td>R&amp;D department</td>
<td>68</td>
<td>6</td>
</tr>
<tr>
<td>Production department</td>
<td>45</td>
<td>8</td>
</tr>
<tr>
<td>Other departments</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Personal experience</td>
<td>62</td>
<td>13</td>
</tr>
<tr>
<td>Technology or product itself</td>
<td>50</td>
<td>8</td>
</tr>
<tr>
<td>Customers</td>
<td>34</td>
<td>8</td>
</tr>
<tr>
<td>Suppliers</td>
<td>27</td>
<td>3</td>
</tr>
<tr>
<td>Universities or research institutes</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>Competition</td>
<td>23</td>
<td>3</td>
</tr>
<tr>
<td>Other (non-competitive) companies</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>Specialized service or engineering companies</td>
<td>27</td>
<td>3</td>
</tr>
<tr>
<td>Market</td>
<td>15</td>
<td>9</td>
</tr>
</tbody>
</table>

Channels

<table>
<thead>
<tr>
<th>Sources</th>
<th>Product phase</th>
<th>Transition phase</th>
<th>Process phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Text and analysis</td>
<td>47</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Formal procedures</td>
<td>56</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>Literature and internal reports</td>
<td>45</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>Oral communication</td>
<td>38</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>Group procedures</td>
<td>39</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>New employees</td>
<td>16</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Formal training or conferences</td>
<td>17</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

Figure 2. Sources and groups
It is remarkable that the production department is neutral (in the origin of the space), which is somewhat consistent with the results derived from the questionnaire on the importance of the production department, but not with the hypothesis, from which one would expect it to be important, especially for the third group.

With respect to the channels (fig. 3) the first dimension, which explains 51 percent of the variation, contrast new employees with literature, and to a lesser extent with group efforts in problem solving. The second dimension contrasts oral communication with literature. “Phase 1” companies clearly form the most literature-oriented group, “phase 2” companies believe in oral communication, while “phase 3” companies have the most formal approach. The hiring of new employees seems to be important only for group 3 respondents.

The results are, in our opinion, consistent with most of our hypotheses, except for the one about the production department.

Figure 3. Channels and groups
7. Conclusions

In this paper we have presented a model which tries to explain some of the inconsistencies which exist in empirical studies about the flow of technological information in an R&D department. We suggest that the underlying factor which explains the inconsistencies is the technology, in particular its characteristics as described by the technological life-cycle.

Though the empirical data supports, to a large extent, the proposed model, we are aware of the limitations of the evidence presented, which is based on sample of 22 companies, mainly producing assembled industrial products.

The main result of the study remains however the fact that a relation between the nature of the sources and the way in which they are consulted by the technologist on the one hand, the phase to which a productive unit belongs on the basis of its innovation activities on the other hand, cannot be denied.

What does this mean for the management of technological innovation, or more particularly, for R&D? A first statement that one can make seems to be that there exists an optimal portfolio of sources and channels for each productive unit. This does not imply that each company and company unit in the same phase along the technological life-cycle will have an identical information portfolio. Factors such as industry, size, specific technology, etc., will certainly have a secondary influence. But a deliberate analysis of the optimal portfolio of sources and channels of problem-solving information based on an understanding of the position of the productive unit along the life-cycle, can be a useful exercise to the R&D manager.

A second managerial conclusion relates to the evolution of the productive unit along the technological life-cycle. The evolution of sources and channels from highly informal user and science-orientated sources to more formalized contacts with customers and sources located with production and suppliers, a shift from non-hierarchical to hierarchical gatekeepers may seem a rather natural evolution. As productive units grow and mature, their organization will become formal, their technology will become more specific, even parochial or very characteristic for the productive unit, and they will become more inward-looking even for problem-solving information. The reverse is however far from natural. Those productive units which are confronted by threatening new technologies, or whose set of technologies goes through a rejuvenation, will preferably be urged to adapt their technological information system and leave some room for spontaneous contacts and highly informal information transfer instead of the well-organized systematic information review of the traditionally interesting literature, the regular reviewer meetings with the traditional suppliers, etc. It might even require the drastic destruction of some of the procedures which are perceived as productive for providing information. The model presented here suggests that this will be necessary if the productive segment wants to adapt to its new situation.
A third conclusion one can draw from this model goes a step further and should probably be formulated as a hypothesis. The present day managerial scene is quite influenced by mergers and collaborative agreements for strategic, marketing as well as development reasons. Although the answer to the question “with whom one should negotiate collaborative agreements” is of course dependent on a number of reasons related to, among other things, the business strategy of the productive unit, it is asserted here that in that choice the information framework presented here can be of help. When one of the main considerations in pursuing a collaborative agreement is the creation of a stronger development team, the perspective partner has of course to fit in with the information needs of the other partner. As stated in the beginning, innovation is often mainly creative information processing. If one wants to improve this process through collaborative agreements, one of the aims of this cooperation should be the improvement of the access to the sources of appropriate information. Consequently if one is on the look-out for a partner, and the productive unit concerned works with a technology with the characteristics of phase 1, a partner which is at the same time a user or who provides access to centres of scientific excellence should be favoured. If on the other hand the searching partner works with a technology with the characteristics of phase 3, an agreement with a supplier or a production specialist might rather be indicated. The fact that a number of companies working with a very mature technology, try to get, through acquisitions of young entrepreneurial companies, a window on technological development is a symptom of behavior one would expect from a “phase 4” productive unit.

References

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