creases rapidly as the fragment types increase in size—have been shown to apply to the Common Date Base. The analysis results reflect the differing natures of the two files with respect to less common elements, especially sulfur, which might be expected to be more prominent in a collection containing substances of biomedical interest. The preponderance of carbon, oxygen, and nitrogen in the CDB means that, as for the random sample file, fragments to serve as screens for substructure search containing these elements must be treated in more detail than other fragments. In this respect, the files are similar.

The differences in the results show that a more flexible screen generation program than that previously employed for screen generation with the random sample file[4] may be advantageous. This has now been developed for augmented atoms, octuplets, and four-atom fragments, where the screens are selected on the basis of fragment incidences in the files being used. Thus, the screens set may be different for files of different characteristics, and the changes can be made automatically without the systems operator being aware which fragments are being used. Details of this work will be reported shortly.

ACKNOWLEDGMENT

We thank the Office for Scientific and Technical Information, London, for financial support for this work, and Chemical Abstracts Service for the provision of the two files in machine-readable form. Conversion of the CDB file into a form which could be handled on the ICL 1907 computer at Sheffield was carried out by J. M. Harrison in cooperation with UKCIS Research Unit, University of Nottingham. This work is gratefully acknowledged.

LITERATURE CITED

(1) Crowe, J. E., Lynch, M. F., and Town, W. G., "Analysis of Structural Characteristics of Chemical Compounds in a Large Computer-Based File. Part I. Non-cyclic Fragments," *J. Chem. Soc. (C)*, **1970**, 990.
(2) Adamson, G. W., Lynch, M. F., and Town, W. G., "Part II. Atom-Centered Fragments," *J. Chem. Soc. (C)*, **1971**, 3702.
(3) Adamson, G. W., Cowell, J., Lynch, M. F., Town, W. G., and Yapp, A. M., "Part IV. Cyclic Fragments," *J. Chem. Soc. Perkin I*, in press.
(4) Adamson, G. W., Cowell, J., Lynch, M. F., McLure, A. H. W., Town, W. G., and Yapp, A. M., "Strategic Considerations in the Design of a Screening System for Substructure Searches of Chemical Structure Files, *J. Chem. Doc.* **13**, 153-7 (1973).

Technological Forecasting—an Experiment Relating to the Pulp and Paper Industry*

D. J. FLOTO, R. A. HAGSTROM, T. L. HEYING, R. E. MAIZELL,** and W. J. MAYER
Olin Corp., New Haven, Conn. 06504

Received April 30, 1973

The methodology of a technological forecast, integrating consultant, industrial, and academic input from three successive Delphi rounds, is presented. Questions gleaned from information sources and from panel suggestions made during the progress of the study were answered anonymously. Each respondent indicated his personal familiarity with the development or event, his estimate of the stated event's impact, and his estimate of the year in which there is a 50% chance of occurrence. Part of the study's success is determined by convergence and degree of helpfulness. The point is made that a TIS Department can play a leadership role in studies of this kind.

The chemical industry executive has at his disposal a large tool kit for helping him arrive at decisions. These include market research, econometrics, committee meetings, educated intuition, laboratory and pilot plant work, and consultants, to name a few. One of the newer additions to this tool kit is the technique of technological forecasting.

This paper will show how a technical information services department can make use of the Delphi technique as a technological forecasting tool and thereby provide a basis for chemical industry executive decision making.

Our experiment dealt with the future of the pulp and paper industry, and the probable impact of that future on the chemical industry, in particular on the Chemicals Group at Olin.

TECHNOLOGICAL FORECASTING—GENERAL REMARKS

Technological forecasting is 10 to 15 years old, but is still regarded as one of the newer techniques to help in the executive decision-making process. Interest in the field has developed sufficiently for formation of at least one major professional society—the World Future Society—and for publication of a number of professional journals,

* Presented before the Division of Chemical Literature, Middle Atlantic Regional Meeting, ACS, Washington, D. C., January 16, 1973.
** To whom correspondence should be addressed.

including: *The Futurist, Technological Forecasting and Social Change, Futures: The Journal of Forecasting and Planning,* and *Long Range Planning.* In addition, there are a number of excellent texts and other books in the field, of which perhaps the best known are those by Erich Jantsch,[7] James Bright,[2,3] now at the University of Texas, Joseph Martino[9] of the U.S.A.F., and Marvin Centron,[4,5] formerly of the Defense Department. Norman Dalkey's recent book, *Studies in the Quality of Life,* summarizes his own and other selected early studies on the subject and is a good collection of the underlying assumptions and validity of the Delphi method.[6] On the more popular side, most of us are familiar with Toffler's *Future Shock*[10] and with the efforts of science fiction writers to predict the future.

Delphi is one of several tools available to accomplish technological forecasting. Some other tools include: trend extrapolation, scenario methods, cross-impact methods, and evaluative monitoring (which means following the literature on a current basis and critically evaluating it for major trends). The reader is referred to the books cited above for details of these techniques and to the article by Kiefer.[8]

DELPHI TECHNIQUE

The Delphi technique was first used at the Rand Corporation in the 1960's. Since then, several chemical companies, other industries, and government have used it to determine prospective technological and potential social changes. The textbooks and journals mentioned previously give details of this technique, but a brief review of some of its features might be of interest.

In a nutshell, the Delphi technique is a method for obtaining and refining the judgments of groups. The rationale for the procedure is essentially the age-old adage that two heads are better than one. Delphi is particularly applicable where one is looking at futures about which exact or precise knowledge is not available.

In the Delphi technique, there is anonymous response to a formal, written questionnaire. The members of the group do not know who the other members are, nor are individual responses ever divulged. The purpose of this is to help avoid the domination of meetings by articulate, assertive personalities, high-ranking executives, and group pressure toward conformity. This kind of domination can result in reluctance, or even fear, by knowledgeable people to express their ideas candidly.

Another feature is iteration. Results from successive questionnaires are fed back to participants in a summarized, statistical, anonymous form, so that each member of the group can study the responses of the group as a whole and the reasons for answers which vary from the median. Each member is then given the option of revising his own estimate or judgment.

A third feature of the technique is that results are presented in the form of a statistical group response. Very simply, a typical result might be the median year by which the group thinks a specific event is likely to occur. Again, the purpose is to help minimize the possible bias of dominant personalities.

The principal strengths of the technique derive from its anonymity and orderliness. Its principal limitations are lack of susceptibility to intensive statistical evaluation and lack of knowledge regarding the rationale, or assumptions which serve as a basis for panel members' judgments.

So the steps are, very briefly, (1) selection of a group of specialists who will participate; (2) submission of a questionnaire to these specialists; and (3) iteration or feeding back of judgments several times. The process differs sharply from the run-of-the mill committee meeting in that Delphi is an orderly, systematic method in which there is an equal chance for all to be heard without restraint of any kind. In addition, there is complete documentation of all answers for further reference.

The people constituting our group of participants are primarily from within Olin. Their responsibilities include such diverse functions as research and development, product management, sales, technical service, public affairs, and marketing economics. Another indication of the panel's make-up would be by discipline; they are chemists, paper specialists, chemical engineers, toxicologists, economists, public affairs specialists, and others.

Forecasting, as we said at the outset, is an addition to the executive took kit for decision making. It is by no means the only tool and, in fact, we would hope executive decisions would not be made using Delphi as the only input.

ROLE OF THE TECHNICAL INFORMATION SERVICES DEPARTMENT

One of the main points to be emphasized in this paper is that our TIS Department was able to play an important role throughout the entire experiment. Based on a review of the literature and other information sources, TIS staff selected many of the events on which our group was asked to express their judgments as to when (if ever) the event had at least a 50% chance of occurring. Guided by management, we prepared the questionnaires, tabulated the results, and conducted the project from start to finish in cooperation with the participants. It is our conviction that a qualified TIS Department can successfully achieve a leadership position in technological forecasting in any chemical or other industrial company.

In the pulp and paper industry we were fortunate in that published clues to possible future events are available. These include the following examples:

1. The American Paper Institute, which provides primarily economic and statistical information and data on the pulp and paper industry.
2. The *Institute of Paper Chemistry Abstract Bulletin* and other publications.
3. Technical and trade journals, which give excellent reports on research in progress—e.g., (a) *Tappi,* (b) *Paper Trade Journal,* especially their forecasting issue of 1972 (May 27), (c) the *Pulp and Paper Magazine of Canada,* (d) *Svensk Pappers Tidning,* and (e) *Pulp and Paper.*
4. U. S. and foreign patents.
5. The Wall Street Journal, an excellent source of forecasting data.
6. *U. S. Industrial Outlook 1972 with Projections to 1980,*[11] issued annually.
7. Notices of Research in Progress from the Science Information Exchange of the Smithsonian Institution.
8. The various reports of the Institute for the Future at Menlo Park, Calif. We especially note their study on the future of newsprint, sponsored by MacMillan Bloedel Ltd.[12]
9. Reports of other private consulting organizations. In this vein, a major source is the SCOUT service of Futures Group, a private consulting organization in Glastonbury, Conn. A compilation of forecasts, based on various sources regularly scanned by Futures Group personnel, can be especially designed for the client's needs and remain proprietary to him if so desired.

In our evaluation of the literature, we looked particularly for indications that pulp and paper technology was either changing or apparently remaining the same. To the chemical manufacturer, the various developments could

mean one or more of the following:

1. The use of more chemicals
2. The use of less chemicals
3. No change in the use of chemicals
4. The use of different chemicals
5. The use of the same chemicals in different ways
6. Development of nonchemical products and processes

The situations indicated from our literature and personal sources were phrased into statements of events to be submitted to our group of specialists for their estimate of the probable year of occurrence.

What are some possible future developments and technologies which might influence the growth of the pulp and paper industry in coming years? Our survey shows, for example, such factors as the following:

1. Pulp and paper technology
2. "Paperless technology"
   - A. Cathode ray tube
   - B. Microfilm and microfiche
   - C. Color TV and video cassettes
   - D. Facsimile, Picturephone, and related devices
3. Timber supply
4. Environmental and energy considerations
5. Population and economic growth
6. Plastics
   - A. Synthetic paper
   - B. Packaging
7. Exports and imports
8. Continuing education and reading programs

As would be expected, trends in pulp and paper based on environmental considerations are of great interest and are heavily reported in the literature. For example, the pulp and paper companies have used relatively large quantities of water in their processes and these companies have spent, and are spending, large sums on pollution control.

We can't report our findings on these and other points because they are regarded as proprietary, but you may wish to draw your own conclusions.

METHODOLOGY DETAILS

The first questionnaire (of three) was sent out with an introduction providing an elementary description of pulping and bleaching, the basic assumptions, a projected timetable for the study, and the symbols to be used in filling out the questionnaire.

For each of 49 events, grouped by subject category, the respondent was asked to indicate his familiarity with the event, the event's importance both to Olin and the pulp and paper industry, and the year by which there is at least a 50% chance that the event will have occurred. ("Already" and "never" are acceptable answers.) Those unfamiliar with the event were advised to skip the entry. All, however, were encouraged to elaborate on their reactions to an event in the "comments" column provided with each question. Two further events were phrased to require "yes" or "no" answers.

The persistence of current methods of pulping was evaluated by requesting an estimate for 1982 of the proportion of pulp produced by each of these processes (1969 market shares indicated). In the last question, 17 chemicals used in pulp and paper processes were listed for an estimate of their 1982 outlook. Finally, important events not contemplated by the original questionnaire could be entered separately for inclusion in the next rounds of questioning.

As each questionnaire was returned, it was numbered in order of receipt, so that names were not recorded. One worksheet per question was used to summarize replies. Since most questions were asked in similar form, a master could be appropriately ruled, typed, and photocopied.

To maintain the projected time schedule, all replies received after the deadline were ignored. The first questionnaire was sent to 31; 23 of these were returned on time.

It was quite simple to total the entries and find percentages. Space permitted the entry of years of occurrence from 1972 through 1995, plus "later" and "never". The median point of the year of occurrence could be determined visually. The 25th and 75th percentiles could also be visualized and entered on the worksheet. Where appropriate, percentages were entered from previously prepared tables.

On the second questionnaire, three percentiles [25th, median, and 75th (years)], the respondent's first answer (year), and representative reasons given by panel members for early and late dates were listed. The respondent's and the panel's first answers on the importance of the event to Olin and the pulp and paper industry were also given. The respondent was then asked for reassessment of his answers, a description of the nature of impact on P&P and on Olin if the event occurs, and the nature of action Olin should consider.

A new series of 20 events suggested by respondents on the first questionnaire was added and handled in the same way as questions in round 1. Additional important events were again requested.

Twenty-three responses were received. Percentages and percentiles were calculated as in round 1.

For round 3, 14 of the original events were eliminated, chiefly for lack of impact on Olin. The panel consensus from questionnaire 2 for the median year of occurrence and the event's impact on Olin was listed. Actions Olin should consider were also listed. Ranging from one to 14 per question, each recommendation was evaluated by the respondent as to when action should be initiated and how helpful it would be. Nineteen of the 20 additional events from round 2 were resubmitted in round 3 for reassessment in the manner of round 2. Finally, each respondent was asked how helpful the experiment was, how much time was spent on it, and how willing he would be to participate again.

All questionnaires, in addition to being tabulated in a routine manner, were carefully scanned by personnel qualified to note patentable ideas and other unique comments. Areas of unfamiliarity are of special interest to those concerned with current awareness or continuing education programs.

PRESENTATION OF RESULTS

In our formal report to management, we presented our results in two sets. First, we presented a series of events ranked chronologically (with the earliest date first) in the order in which our group thought there was a 50% likelihood that they would occur.

Second, we presented those actions which our group felt Olin should take in response to these events. Our group of specialists was productive; they presented almost 200 specific actions they thought Olin should take, together with a time frame within which each of these actions should be taken. These events and actions are significant in that they offer one basis for executive decision-making.

SOME MEASURES OF SUCCESS

One measure of success for Delphi forecasts is the respondents' reactions to the experiment. In our case, 71%

thought the experiment was very helpful or helpful. They stated they had each spent a total of 11 hours, which is quite reasonable. Further, all of the group answering the question said they would be willing to participate in another technological forecasting experiment. We regard this as quite favorable.

Another measure of success for a Delphi study is what is technically called degree of convergence. This means the extent to which the participants tend to move toward consensus, measured by decrease in the interquartile range in successive rounds of questioning. Convergence in 69% of the judgments was found. This is also regarded as favorable.

CONCLUDING REMARKS—FUTURE PLANS

As we looked at the results, we were amazed, even shocked. In certain critical areas, we found that P&P developments were moving along rapidly, much more rapidly than we had expected. Many of these related either directly or indirectly to P&P industry responses to environmental pressures. If the pace of these developments were going to accelerate, then we had not been doing nearly enough research and development to keep us competitive. We found that there was need for us to take specific actions now if we were to retain the desired position in this field. To remain static would be inviting disaster. This is frank talk, but it illustrates in a most dramatic way the results that can stem from a forecasting study.

We plan to consider very carefully all of the recommendations made by our group of specialists to see whether these should be implemented by R/D, manufacturing, or marketing.

In addition, we plan to apply the cross-impact method to the results of this study to help management arrive at policy decisions.

Additional forecasting studies are planned in other fields, especially since initial response within the Company has been favorable.

LITERATURE CITED

(1) Baran, Paul, "The Future of Newsprint, 1970–2000," Report R-16, Institute for the Future, Menlo Park, Calif., December 1971.

(2) Bright, J. R., ed., "Technological Forecasting for Industry and Government; Methods and Applications," Prentice-Hall, Englewood Cliffs, N. J., 1968.

(3) Bright, J. R., and Schoeman, M. E., eds., "Guide to Practical Technology Forecasting", reference edition, Prentice-Hall, Englewood Cliffs, N. J., 1973.

(4) Cetron, M. J., "Technological Forecasting; a Practical Approach," Gordon and Breach, Technology Forecasting Institute, New York, 1969.

(5) Cetron, M. J., and Ralph, C. A., "Industrial Applications of Technological Forecasting; its Utilization in R&D Management," Wiley Interscience, New York, 1971.

(6) Dalkey, N. C., Rourke, D. L., Lewis, Ralph, and Snyder, David, "Studies in the Quality of Life; Delphi and Decision-Making," Lexington Books, D. C. Heath and Co., Lexington, Mass., 1972.

(7) Jantsch, Erich, "Technological Forecasting in Perspective; a Framework for Technological Forecasting; its Techniques and Organisation; a Description of Activities and Annotated Bibliography," Organisation for Economic Co-operation and Development, Paris, 1967.

(8) Kiefer, D. M., "Industry Maps Tomorrow's Technology," *Chem. & Eng. News* **50**(9) 11, 12, 17, 19 (1972).

(9) Martino, J. P., "Technological Forecasting for Decision-Making," American Elsevier Publishing Co., New York, 1972.

(10) Toffler, Alvin, "Future Shock," Random House, New York, 1970.

(11) U. S. Department of Commerce, Bureau of Domestic Commerce, "U.S. Industrial Outlook 1972 with Projections to 1980," U. S. Government Printing Office, Washington, D. C., 1972 (issued annually).