A feasibility study of a system for computer-aided selection of materials for industrial production

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A FEASIBILITY STUDY OF A SYSTEM FOR COMPUTER-AIDED SELECTION OF MATERIALS FOR INDUSTRIAL PRODUCTION

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A FEASIBILITY STUDY
OF A SYSTEM FOR COMPUTER-AIDED
SELECTION OF MATERIALS FOR INDUSTRIAL PRODUCTION

A Dissertation

Submitted in Partial Fulfillment

of the Requirements for the Degree

Doctor of Industrial Technology

Approved:

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December, 1981

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ABSTRACT

This study was a comparative analysis of two methods of selecting materials for industrial production. The specific objectives were to find out if (a) a computer-aided materials selection system would select materials which were not significantly different from materials chosen by practicing professional engineers; and (b) the time required by the computer system to select materials would be significantly less than the time required by the engineers.

The criterion measures were (a) the closeness of fit of properties to design specifications for each material selected; and (b) the amount of time consumed by each subject in the selection of each material.

The research design selected was a pre-experimental Static Group Comparison with repeated (time series) observations. Five plastics selection engineers were identified from throughout Eastern Iowa, and three selection problems were submitted to each of the five engineers and to the computer selection system. The resultant data were analyzed using a Friedman Two-Way Analysis of Variance and the Mann-Whitney *U* test.

The data supported the hypothesis of no difference in the materials selected ($p = .7872$). However, the time required to select materials was significantly less ($p = .0355$) for the computer than for the five engineers. On the basis of the analysis, it was concluded that the computer selected materials which were not significantly different from those selected by the five engineers, but that the computer took significantly less time to make the selections.

The implications of the results of this study are that, for the field of materials selection, computer technology seems to offer a real alternative to manual searches of selection data. Further research is recommended to develop larger and more complete data bases, and to develop better modeling techniques to allow the computer to do a better job of selecting the individual materials.

CHAPTER I

Introduction

Background

Selection of a material from which to make a product or part is a task of the industrial designer and the product engineer. The selection is normally guided by a list of properties and characteristics. In order to adequately specify required materials characteristics such as mechanical and physical properties, the overall design must first be established (Sharp, 1966, p. 20). The importance of the materials selection process itself, however, must not be underestimated. Poor selections can result from inadequate data, inappropriate methods, or insufficient time spent in the process. They can lead to unnecessary costs in materials or production, problems in processing, and/or early failure in service.

Today, materials selection has become a major focus of attention in industry in part due to the increased scarcity and cost associated with various materials and the serious problems of product liability (Special Outlook Report, 1974, p. 21; Mock, 1973, p. 74). Premature failure of a part or product can result from too little concern, effort, or knowledge at any of several steps in design and production.

This study will focus on the steps taken by the designer selecting a material from which to make a product or part.

Unfortunately, the design engineer cannot be expected to keep abreast of all information related to new materials. The quantity of new materials being introduced each year has been steadily increasing. The volume of data describing materials has become so great that no one person can aspire to be conversant with a significant part of it (Lindop, 1973, p. 40). Recent studies have shown, in fact, that in most cases designers do not even try to choose materials with regard to their scarcity, recyclability, energy requirements, or process optimization. In addition, most newer materials do not find general use until many years after they are introduced (Mesker & Stedfeld, 1978, p. 38).

The advent of the computer has made it possible to handle large quantities of data quickly and accurately. The computer has already become a familiar and useful tool in industry for computer aided design (CAD), machine control and process optimization (Computer Aided Manufacturing, or CAM), quality assurance, and production planning and inventory maintenance. In computer aided design, the engineer uses the computer, via a cathode ray terminal (CRT), to retrieve and review old design, correct weaknesses found through production or consumer feedback, and to help develop new designs (Ezzat, Note 1).

The selection system. The object of this research effort is to test a computer system developed to assist the engineer in making better material selection decisions. The system incorporates consideration of parameters, such as engineering specifications, energy and cost requirements for processing, and recyclability. The system attempts to maximize the matching of predetermined property specifications with the properties of the selected material. The system tries to solve the problem of being able to deal with all data describing new or unfamiliar materials.

This problem has been approached in a limited fashion by several commercial suppliers of materials, for example, General Electric's "Plastic" system (Materials Information Sources, 1975, p. 21). A generally available system which is not prejudiced toward the products of one supplier and which allows for detailed specification of properties, however, has not yet been developed.

Statement of the Problem

The research problem associated with this study is to determine whether a Computer Aided Materials Selection System would provide better, faster solutions to materials selection problems.

Significance of the Problem

Using computer analysis for materials selection offers potential benefits to industries through the reduction of production costs. The documentation such analysis provides will improve the stance of industry with relation to product liability claims. The optimization of product design and performance realized through the materials selection process may reduce the number of liability claims.

The use of such systems makes possible reduction of a company's dependence on scarce and strategic materials. Conservation of both scarce materials and process energy consumption is also encouraged.

Limitations of the Research

The total number of commercially available engineering materials may be as high as 75,000, and this number is growing continuously (Lindop, 1973, p. 40). The compilation of data for all of these materials in a computer system may be expected to require many more years of work, and to occupy ever-increasing amounts of computer space. Before such an investment of time and equipment is undertaken, research is required to determine the feasibility of such systems. In this research effort, a limited databank of approximately 100 materials with 50 properties and characteristics per material will be used. In addition, the system tested will include only polymeric materials.

Definition of Terms

Definitions are provided only for terms which have meanings specific to this research different from or more narrow than their meanings in general usage.

Materials: Unless otherwise noted, refers to all raw or partially processed materials from which parts or products might be manufactured.

System: When used independently, refers to the software and data files used by the computer to select materials according to engineering input.

CHAPTER II

Review of the Literature

Industrial Product Engineering

Due to concerns with product liability and the rate of return on investment, manufacturing industries are becoming increasingly concerned with the productivity of materials, processes, and labor (Mock, 1973; "The New Trade-offs," 1976). The industrial product or design engineer is in a position to address problems relating to materials and processes during the product design and prototyping stages of product development. Careful selection of materials can result in increasing corporate profits by reducing the costs of materials and processing. In addition, careful materials selection, and documentation of it, helps a company's legal stance with regard to product liability claims (Mock, 1973; Pye, Note 10).

The most direct approach to increasing profits is by keeping materials acquisition and inventory costs to a minimum. This task involves finding the least expensive of all the suitable materials, and assuring that any material already in stock is considered before bringing in others (Pye, Note 10; Boardman, Note 5). Waste in production is another aspect of materials costs which can be minimized both by selecting materials which are easily and profitably reclaimed, and by choosing processes which minimize scrap (Beatson, 1974; Mesker & Stedfeld, 1978; "Special Outlook Report," 1974).

In addition to the design of original parts or products, substitution of more appropriate materials in established product lines can be very profitable. Industries are frequently finding that they can substitute materials which consume less energy, tooling, and time in processing. Production processes can also be reviewed, as an alternative material might permit the use of a different, less expensive process (Mesker & Stedfeld, 1978; Ezzat, Note 1).

These examples seem to reflect the development of an increasing need for a holistic approach in the design area, where the needs of both the consumer and producer are integrated in the design. Established production processes and materials must also be frequently compared to alternatives to assure maximum productivity and product life at lowest cost (Sharp, 1966, pp. 15-16).

Traditional Methods of Selection

The selection of materials is not easy, nor has it been since the earliest days of mass production. The first automobiles, for example, used very few materials. In those days, materials science was not as highly developed as it is today, so that overengineering was often the best way to assure product success. Today's cars may use as many as 10,000 different materials; overengineering is now too costly to be feasible (DuMond, 1980).

Tools used in the selection process usually include engineering materials handbooks (Notes 3-6). Some of these are the Handbook of Engineering Materials (1963) by Brady, the Encyclopedia of Materials and Processes (1963) by Clauser, and Metals Handbook (volume one) by A. S. M. Several materials-oriented magazines and journals put out special selection issues each year, among them the Materials Selector (Stedfeld, 1980) and the Modern Plastics Encyclopedia (Agranoff, 1980). Many less well known texts are also used, and a strong influence has always been enjoyed by advertising flyers from materials producers and suppliers (Kusy, Note 3).

Other tools are also offered by trade journals, some of which have been named above. These consist of articles offering simplified, relative ratings of a small group or family of materials (Miska, 1978; Mock, 1976; Weymuller, 1971).

Because engineers tend to use materials and processes which are already familiar to them (Sharp, 1966, p. 13), designers have often settled for such simplified ratings of materials rather than using detailed properties data (Pye, Note 10). This approach, however, is becoming increasingly untenable ("Systems Analysis," 1979, p. 84).

More sophisticated approaches to materials selection have been developed by several companies and organizations. Examples of such efforts are detailed by J. T. Wimber (1976). Exploratory work in computerizing data searches for metals selection is presently being conducted at the John Deere Technical Center at Moline, Illinois, under the direction of T. J. Bulat and B. Boardman (Mock, 1976, p. 28; Note 5).

The most elaborate manual approach to materials selection found in the literature was developed in England within the last few years (Lindop, 1973). The Fulmer Research Institute has assembled a comprehensive four volume system designed to deal with all aspects of the selection process, from establishment of specification criteria to location of vendors for the materials. This system, the Fulmer Materials Optimizer (Pye, 1979), represents the product of three years of work by a team of 25 specialists. The quantity of labor required to assemble this system provides ample testimony both to the problems involved in the selection process, and to the importance given materials selection by modern industries ("Materials System," 1974; Lindop, 1973).

Selection Systems for Polymers

Significant work has been done by the research staff at the John Deere Technical Center relating to selection of materials for agricultural equipment parts. The work has been comprehensive, dealing with both metals and nonmetals. It has resulted in the development of systems for defining the application problem and the nature of the part to be made, and for evaluating the physical and mechanical properties which will be required of it.

Manual screening of generic (broad) families of materials is included in these methods (Boardman, Note 5; Graham, Note 6; Kusy, Note 3). Wimber's system (1976) is an example which applies to all types of materials. An example of a system specific to one family of materials is that developed for polymer selection by P. Kusy (1976).

Final selection in these methods is normally manual, using the results of the screening process to narrow the field of data to be processed (Kusy, Note 3; Wimber 1976). Recent work, however, has resulted in the development of computer systems for the final data processing as well (see below, Computer-Aided Materials Selection).

Alone among the commercial databanks provided by trade journals, the Modern Plastics Encyclopedia (Agranoff, 1980, pp. 475-531) provides designers with a design guide to the selection of plastics for engineering applications. This guide is updated each year, and includes information on designing with the newer plastics. It provides a systematic approach to the selection process, then follows with design tools for assessing specific mechanical and physical property requirements.

Computer-Aided Materials Selection

A review of the literature revealed few published writings related to the use of computers in material selection. Although a great deal of work has been done in the general area of selecting materials for specific production and design problems, it appears that little has been done to bring computers into the field. The accuracy of this impression is corroberated by writings of experts in the field (DuMond, 1980; Kusy, Note 3; Carter, Note 8). The work that has been done, however, has been very promising (DuMond, 1980; Miller, 1975; Schaefer, Note 7).

Computer modeling and simulation. When using a computer to select materials, the computer programmer is very concerned with duplicating the methods of the product engineer in comparing each material to his specifications. Considerations relating to acquisition and inventory costs, waste, reclaiming, and processing must all be included, if possible (Hanley & Hobson, 1973; "Ten Most Critical Issues," 1980).

Because the program cannot be altered during its execution, solutions to all these considerations must be provided in the program. Otherwise, it is quite conceivable that one might select a very inexpensive material which costs a great deal to process or one that is easily processed, but very expensive (Pye, Note 10; Kusy, Note 3).

Simulation of the selection methods used by an engineer is accomplished by a mathematical model that is developed into an algorithm. Two modeling techniques for use in computer algorithms are offered by Drs. Hanley and Hobson (1973). Their contribution to the literature is the only one offering details of programming algorithms. The two models are (a) assigning weight factors to each property, an algebraic model and (b) assigning weighting factors to actual design objectives, a geometric model.

Rather than simply providing materials specifications, the authors felt that it was necessary to give the computer a certain amount of flexibility so that it could select materials which exceed or, in some cases, do not attain specified property values. Another variation is to be able to assign weights to each property so that the computer can be more demanding with critical properties and more flexible with less critical ones.

The mathematical algorithm used to accomplish such goals is described for the algebraic case:

Where X_i is one of several properties of a material and Y_i is the specification for each property, the equation

$$Z = \sum_{i=1}^{n} |(X_i/Y_i) - 1|$$

is minimized as 'i' varies from 1 to 'n'. X_i is found in the data files, Y_i is provided as input by the system user. Minimizing the value of Z gives the materials whose properties offer the smallest total deviation from the specified values.

Pye has proposed an algorithm for use in manual selection which involves both weighting factors and cost. The evaluation in Pye's (Note 10) model is strictly relative. Where M_i is the relative merit rating for the 'i'th characteristic, W_i is the relative importance of that characteristic to the product function and C is the cost of the material after processing, the equation

$$Q = \sum_{i=1}^{n} M_i * W_i/C$$

is maximized. Materials with the highest Q value would be likely candidates for selection.

Although the value for M_i is not defined, a likely algorithm for determining an appropriate value would be

$$M_i = X_i - Y_i/Y_i$$

or the fractional deviation of the candidate's characteristic value from the input specification (Kusy, Note 3).

This final idea has been adopted in the system used in this study, and requires having the designer specify not only a target value for each property, but also an importance factor. Values above and below the specification may then be assessed. A value for thermal expansion, for example, might not be acceptable if it deviated at all from the specification. Other values, such as tensile strength, might be permitted to exceed specifications by a factor of as much as two (Henley & Hobson, 1973). A detailed report on the development of the computer system used in this study has been included in Appendix IV.

Interactive computing methods. The approaches of Hanley and Hobson (1973) and of Pye (Note 10) represent attempts to deal with the fact that the product engineer is normally more critical about some selection criteria than others. But because most engineers expend little effort in assuring that materials selection is optimized (Mesker & Stedfeld, 1978, p. 37), ease of use must be a prime consideration in the design of a computer system to aid in the selection process. Requiring that one choose importance factors as well as a more complete listing of specifications than one is accustomed to may render the use of the computer less attractive (Boardman, Note 5;

Graham, Note 3; Kusy, Note 6).

With interactive programming, however, this factor could be arrived at conversationally, and with a minimum of effort. For example, the computer might ask, "Do you feel this property is (a) critical, (b) moderately important, or (c) only of low importance?" The response can be recorded by the computer and converted into a factor for use in the evaluation algorithm for that property. Other numbers can indicate when a value may deviate above or below the specification (Davis, 1978).

Other systems. The earliest work found in the literature in the development of applications software for materials selection is that of H. Laurie Miller of Canada (1975). Miller describes several systems considered for materials selection. Among these was a slotted card technique, in which pins inserted in the cards allowed valid choices to drop from the deck. A transparent overlay sheet for comparison purposes was also used. Both of these systems were rejected because they could not deal with the quantitites of data required for a general search of polymers.

Another commercial system has been developed by General Electric for the use of their customers. The system, "Plastic," is oriented toward polymer selection, and can be accessed by customers either by phone, by letter, or by terminal/modem phone line connection. Examples of the program operation and output may be found in an article on materials information sources (also see Appendix V) in Materials Engineering magazine (1975).

Under the direction of Paul Kusy, the staff at the John Deere Technical Center has developed a sophisticated batch oriented system for computer aided selection of polymeric materials. The system (CMSS, or Computerized Materials Selection System) requires a trained operator. It has proven useful in encouraging the successful use of polymers in that company's products, as polymers are not well understood by most design and product engineers. In recent months, they have been experimenting with interactive systems, in the hope that they may find more users than have batch versions (Boardman, Note 5; Kusy, Note 3).

Not all of the industrial applications of computers for materials selection are using programs tailored specifically for this task. Roy Oberholtzer of Rockwell International's Advanced Technology and Engineering group has found that sophisticated database management systems (DBMS) can do the same job without requiring specialized programming. In this approach, the DBMS queries the database according to specific inquiry parameters supplied by the operator.

Although this type of approach requires more understanding of the way in which the selection is conducted by the computer, it also offers specific advantages. Among these is the ability to vary the algorithm with each selection problem. This is not provided by any of the specialized software that has been reviewed in the literature or in the field. The primary disadvantage of this approach is that the operator must understand both the format of the engineering properties database and the operation of the DBMS before effective use of the approach is possible (Oberholtzer, Note 9).

One of the greatest problems encountered by all of the selection experts interviewed is that design engineers do not normally provide adequate specifications. Without this information, the computer cannot always perform an adequate selection. At Rockwell, this problem is avoided by the use of a special form which must be filled out when requesting the services of the plastics selection expert (Appendix VI).

Summary

The area of materials selection is critical to both industry and the consumer. Cost reductions, as well as longer and more satisfactory product performance may be achieved from optimized selection. Attempts to systematize the selection process have so far been limited. Very few efforts to use computers in this process have been discovered in the literature, although some unreported work is going on in private industry and government agencies.

No work has been discovered which attempts to evaluate the commercial viability of computer systems such as those described here. Where pilot systems are in use, it should be noted that users profess their value (Kusy, Note 3; Oberholtzer, Note 9). Still, experimental studies may provide an understanding of the commercial feasibility of such systems before additional work is done (Mosteller & Rourke, 1973).

If the full benefits of this approach are to be realized by American industries of all sizes, more activity is needed, with more exposure to peer review (Boardman, Note 3). Suitable goals for such activities would be to reduce the cost of the selection process itself, to improve the matching of materials properties to specifications, to use polymers and other novel materials, and to develop modeling to span more than one materials family, for example, polymers, metals, and ceramics (Gray, 1980).

Other goals, which are more difficult to test for, but are equally valid in terms of social need, include: increasing product life, reducing the number of successful product liability claims, reducing the total costs of production per part, increasing the efficiency of production in terms of material waste, and reducing the energy consumed in the production process (Pearsall, 1979; Kelly, 1980; "Ten Most Critical Issues," 1980).

Research Hypotheses

The basic hypothesis of the study was that the use of the computer-aided materials selection system would yield more appropriate and faster solutions to materials selection problems. The research hypotheses for this study are stated in the null form:

1. There is no significant difference in the closeness of fit of a material's properties to specifications between materials selected by engineers and those selected by the computer.

2. There is no significant difference in the amount of time required to solve materials selection problems by the computer and by engineers.

CHAPTER III

Methodology

The Research Design

The pre-experimental research design for the evaluation of the computer system approach to materials selection was a Static Group Comparison Design with repeated (time series) observations (Campbell & Stanley, 1963, p. 12). There were six subjects: five materials selections engineers and the computer. The design used is shown in Table 1.

Table 1

The Research Design

X_1	0_1	0_2	0_3
X_2	0_1	0_2	0_3
X_3	0_1	0_2	0_3
X_4	0_1	0_2	0_3
X_5	0_1	0_2	0_3
X_c	0_1	0_2	0_3

Note: X_1 through X_5 were engineers, X_c was the computer, the observations refer to the results of each selection as measured by a criterion variable Z. Solid lines indicate an assumption that the subjects were equal, and the dashed lines indicates an assumption that the subjects were not equal.

Method. For the purposes of the study, drawings of three parts were selected. Stresses and working conditions for the parts were determined by the researcher. The drawings and associated property requirements were given to each subject. They were each also given a list of materials (an equivalent list to that in the computer databank), and asked to select the most appropriate material for the conditions stated. Identical property requirements were input to the computer.

Since the study was not concerned with the operation of the computer program, the computer was operated by the researcher, who developed the system. An expert level of familiarity with the computer system was therefore assumed. The subjects were asked to work on the problem until it was solved to their satisfaction. If no suitable material was found by a subject, that response was considered to be his solution.

The computer proceeded through as many iterations as the operator felt was necessary to arrive at a suitable solution. Appendices VII, VIII, and IX are copies of the selection problems as delivered to the subjects, with the requested response format. Appendices I, II, and III reflect the properties specified, the subjective scales used to rate certain characteristics, and the materials included in the databank, respectively.

Target Population and Sampling Design

The target population of the research effort was all design engineers in industries producing commercial products. Due to geographic and financial considerations, this population was not available for random sampling. For this reason, five materials engineers from moderate-to-large sized industries in eastern Iowa were selected for the study. These individuals are each independently and solely responsible for the selection of polymers for their company's products. They were also volunteers for the study, and as such their performances were expected to be higher than the means of both the target population and the research population of design engineers responsible for materials selection in eastern Iowa.

The five engineers represent three different domains of commercial products: agricultural transportation equipment, household appliances, and electronic guidance and control systems. The applications for polymer usage in each company vary significantly, and represent a broad spectrum of considerations in terms of materials usage.

Statistical Analysis

The object of the analysis was to determine whether a significant difference existed among the six "subjects" on the basis of the criterion variables. As this population is relatively small, with rather specialized characteristics, it was considered reasonable to assume that values for the criterion measures would not be normally distributed. The scores resulting from the three problems over the six subjects were also expected to be dependent as they are affected by some of the same factors.

The primary test statistic selected for the data analysis was the Friedman Two-Way Analysis of Variance. This is a nonparametric equivalent of the parametric one-way ANOVA for dependent data (Popham & Sirotnik, 1973, p. 298). The Friedman test is suitable for determining differences between nonparametric matched samples. In this design, matched samples of the three problems were taken from each of the six subjects.

The subjects and scores were organized as presented in Table 2.

In Table 2, subjects I-V represent the engineers, and (subject) C represents the computer. The cells in the table will contain the deviation values (Z) for each problem, for each subject. The values were summed vertically to give the ranked R values R_I through R_C. The test statistic Xr^2 was then computed according to the formula:

$$Xr^2 = \frac{12}{Nk(k + 1)} \sum (Rj)^2 - 3N(k + 1)$$

where N = number of rows, k = number of columns, and $(Rj)^2$

represents the sum of the squared column ($R_1 - R_N$, C) values. In our design, Xr^2 would be computed to be:

$$Xr^2 = \frac{12}{3(6)(6+1)} \sum (Rj)^2 - 3(3)(6+1)$$

The probability of Xr^2 was determined by use of the standard Chi square table with df equal to (k - 1) (Popham & Sirotnik, 1973).

Table 2

Selection Results Matrix

Subjects	I	II	III	IV	V	C
Problem A						
Problem B						
Problem C						
	R_I	R_{II}	R_{III}	R_{IV}	R_V	R_C

Note: Cells in the matrix contained the rank within each problem of Z scores for each material selected. Ties were broken so as to reduce differences in column totals (R).

Dependent variables. The three responses for each subject included the material selected for each problem and the time required to make each selection.

Criterion variables. The responses were evaluated on the basis of the value of the total of all deviations in percentage from the specifications, and on the amount of time required to reach the solution. The summed deviations were calculated with the equation

$$Z = \sum_{i=1}^{n} |X(i)/Y(i) - 1|$$

where X(i) is one of several properties of a material, and Y(i) is the specification for each property.

Z was minimized as 'i' varied from 1 to 'n'. X(i) was drawn from the data files, and Y(i) was provided as input by the system user. Minimizing the value of Z provided materials whose properties offered the smallest total deviation from the specified values.

The secondary test statistic selected for use in this study was the Mann-Whitney U (Popham & Sirotnik, 1973, pp. 276, 295). In the event that the Friedman ANOVA provided a significant result, the Mann-Whitney U would be employed to assess differences between the individual subjects, specifically between the performance of the computer as compared to one or more of the engineers (Huck, Courmier, & Bounds, 1974, p. 215). This procedure is analogous to the post-hoc Scheffe's procedure utilized in conjunction with the parametric one-way ANOVA method (SPSS, 1975, p. 428; Huck et al., 1974, p. 68).

Threats to Validity

Two factors were of particular concern to this research situation, as both constituted threats to the external validity of the research. The first of these was the possibility of a Hawthorne effect; that is, the effect of the research observations on the performance of the subjects (Huck et al., 1974,p. 265). To the extent that subjects knew their performance was reviewed, this potential effect was unavoidable. The effect might be expected to produce performance values somewhat smaller than the true deviations among the target populations.

The second factor was the sampling design. To the extent that volunteers were used, the observed performances were again expected to deviate from the true values for the population involved.

In both of these cases, the reductions in the deviations of the sample values only served to make the study more rigorous in terms of comparing the results achieved by the engineers with those of the computer. This reduced the probability of Type I error, but increased the probability of Type II error. From a research standpoint, these were uncontrolled variables, and they increased the overall uncertainty of the experimental results. No other independent variables or threats of validity were considered to have important consequences to the analysis.

CHAPTER IV

Analysis of the Data

The materials selected by the respondents in the study are presented in Table 3. These responses were converted into Z values. The resultant values are presented in Table 4.

Table 3

Results of Selection Problems

Subject	Material Selected	Time Required
	Problem I - Gear	
1	Nylon 6/6 30% Glass Reinforced	30 min.
2	Acetal Standard Homopolymer	10 min.
3	Nylon 6/6 30% Glass Reinforced	30 min.
4	Nylon 6/6 30% Glass Reinforced	15 min.
5	Phenolic - Mineral Filled	10 min.
Computer	Phenolic - Glass Reinforced (V.H.S.)	2.5 min.

Table 3 (continued)

Subject	Material Selected	Time Required
	Problem II - Cam	
1	Epoxy - Glass Fiber Filled	25 min.
2	Acetal - Teflon Filled	10 min.
3	Polyphenyl Sulfone Glass Reinforced	60 min.
4	Phenolic - Glass Reinforced	5 min.
5	Phenolic - Glass Reinforced	10 min.
Computer	Phenolic - Glass Reinforced	3.5 min.
	Problem III - Valve Sheath	
1	ECTFE Flouropolymer - Glass Reinforced	45 min.
2	Polyproplylene - Glass Filled	10 min.
3	ECTFE Flouropolymer - Glass Reinforced	15 min.
4	Epoxy Standard Molding Grade	15 min.
5	Acetal - 25% Glass Reinforced	5 min.
Computer	ECTFE Flouropolymer - Glass Reinforced	2.1 min.

Note: Subjects 1 through 5 were the engineers and "Computer" indicates the materials selected by the computer. The time indicates how long it took for each respondent to select each material.

Table 4

Selection Response Z Scores

Subjects	I	II	III	IV	V	C
Problem A	7.8	6.4	7.8	7.8	9.0	5.7
Problem B	0.2	4.1	5.8	3.3	3.3	3.3
Problem C	1.9	3.0	1.9	2.6	2.8	1.9

Note: Cells contain the Z scores for each material selected (see text). Subjects I through V were the engineers and subject C was the computer.

The data in the cells were then ranked within each set of problem responses (Table 5). Ties in rows were broken so as to reduce differences in column totals, a conservative approach recommended by Hays (1973, p. 786).

Table 5

Ranked Response Scores

Subjects	I	II	III	IV	V	C
Problem A	5	2	3	4	6	1
Problem B	1	5	6	3	2	4
Problem C	2	6	1	4	5	3
R	8	13	10	11	13	8
R^2	64	169	100	121	169	64

Note: Cells contain the rank of Z score for each problem. Ties were broken so as to reduce column totals "R."

This procedure was repeated for the results corresponding to the time required for each subject to select each material. The data for time are presented in Tables 6 and 7.

Table 6

Response Times*

Subjects	I	II	III	IV	V	C
Problem A	30	10	30	15	10	2.5
Problem B	25	10	60	5	10	3.5
Problem C	45	10	15	15	5	2.1

*In minutes.

Table 7

Ranked Response Times

Subjects	I	II	III	IV	V	C
Problem A	5	2	6	4	3	1
Problem B	5	3	6	2	4	1
Problem C	6	3	4	5	2	1
R	16	8	16	11	9	3
R^2	256	64	256	121	81	9

Statistical Calculations

Xr^2 was calculated from the data on materials selected to have a value of 2.4285. With 5 degrees of freedom, this represents a probability level of .7872. Any difference in the Z scores of the responses, therefore, has a negligible probability of being significant.

Since no significant differences were found at this stage, the application of the Mann-Whitney U test statistic to the Z scores was not conducted. A multiple comparisons procedure is not appropriate in those cases where an overall Xr^2 value is not found to be significant (Huck, Courmier, & Bounds, 1974, p. 215).

The time values obtained were significantly different. The same table was employed for determining rank values and in breaking ties to reduce differences between column totals.

The resultant value of Xr^2 with five degrees of freedom was 11.95. This value corresponds to a probability of .0355. That is, the probability of this difference existing in a homogeneous population of respondents due to chance is 3.55 percent.

Given that the value of Xr^2 for the time values was significant, the Mann-Whitney U test was conducted in order to determine whether or not significant difference existed between the computer's time values and the time values related to the engineers' responses. The data were ranked as in Table 8.

The values of the ranks for each group were subsequently summed and the value of *U* was calculated. The formula used for the Mann-Whitney *U* Test was as provided by Hays (1973, p. 778):

$$U = (Na)(Nb) + \frac{Na(Na + 1)}{2} - Ta$$

U was thus computed to be equal to zero (0.0). With Na = 15 and Nb = 3, a *U* of 0 was found to be significant at a probability level of .01 ($p < .01$) (Guilford & Fruchter, 1978, p. 534).

Summary

The statistical analyses showed the selection made by the six participants to be statistically equal in terms of relative deviation from the specifications for the problems. In essence, the choices of the computer and respondents were not significantly different based upon the criterion measure.

The time required by the computer to select materials for the three problems, however, was significantly ($p < .0356$) lower than the time required by the five engineers. The Mann-Whitney *U* test showed that the computer took significantly ($p < .01$) less time to select materials than did the five engineers.

Table 8

Selection Times Ranked for the Mann-Whitney U Test

Time	Rank	Group
60	18	A
45	17	A
30	16	A
30	15	A
25	14	A
15	13	A
15	12	A
15	11	A
10	10	A
10	9	A
10	8	A
10	7	A
10	6	A
5	5	A
5	4	A
3.5	3	B
2.5	2	B
2.1	1	B

Note: As all ties occur in Group A, how they are broken is not important.

CHAPTER V

Summary and Conclusions

Interpretation of the Data

The purposes of this study were to determine (a) whether any significant difference could be found between materials selected by professional engineers and those selected with a computer selection system, and (b) whether the time required to make such selections would be significantly different for the computer and the five engineers. The data used for the study came from five practicing engineers from eastern Iowa, and from a computer selection system. This system was designed by the researcher following principles discovered through a review of the literature and through personal interviews with eleven individuals professionally involved in materials selection. The data were analyzed to test the two research hypotheses:

1. There is no significant difference in the closeness of fit of a material's properties to specifications between materials selected by engineers and those selected by the computer.

2. There is no significant difference in the amount of time required to solve materials selection problems by

the computer and by engineers.

The interpretation of the test statistics is straightforward. There is no significant difference ($p = .7872$) between the materials selected by the five engineers and those selected by the computer as measured by the summed deviations from specifications, Z. The research statistic Xr^2 suggests that the six responses come from a homogenous population of materials selectors.

There is a significant difference between the time required by the computer to reach solutions for the problems and that taken by the five engineers. Simply stated, the computer takes less time to arrive at essentially the same solution. The probability of this time difference's existing in a homogenous population due to chance is .0355 for this study.

Conclusions

In the study, performance in the quality of materials selected is equivalent when employing the computer and when selection is done by engineers. It would seem practical, therefore, to use that selection approach which provides results in the shortest possible time. This time savings is provided by the computer approach.

Observations Related to the Research Design and Instrument

The research instrument was designed in part from information used in a form provided by Roy Oberholtzer (Appendix VI, Note 9). The responses to the research instrument provided useful information for improvement of the selection system, as well as insights into the methods used by engineers to select materials. In three cases, the participants returned detailed comments with their responses to each of the problems.

One respondent expressed concern that, in his opinion, the information provided in the problems was not adequate to make an intelligent choice of materials. Information which this respondent felt would have been useful, but which was not provided by the researcher, included mode or type of fatigue stress, lubrication information, and permissible cost. In spite of his concerns, this respondent submitted solutions to all three problems.

Two other respondents indicated that it was customary for them to be involved more deeply in the design of the product. It was not typical for them to receive a request such as this from a design department without the opportunity to propose changes in the design as dictated by the mechanical or processing behavior of the material. At the same time, conversations with the respondents indicated that most requests for materials selections were accompanied by much less information than were the selection problems in this study.

It is possible that the research design employed, requiring one problem/solution decision cycle, may have caused some fluctuation in the data provided by the respondents in the sample. In at least two cases, this approach would not represent their normal work processes. The researcher attempted to incorporate this factor by evaluating the responses in strict accordance to the goodness of fit (Z) of each material to the design specifications. It was accepted that this may not be the only, or even the best, approach to evaluating materials for specific applications.

It was recognized from the outset that the research design created a clinical situation which was not a duplicate of the conditions normally prevailing when an engineer selects materials. Simulation of the iterative, or feedback, approach usually used in industry could not have been accomplished without the results of the selection being influenced. For example, the engineers were told specifically not to use any computer selection system to which they might have access.

The researcher also was concerned with the limited number of materials from which selections were allowed, in spite of the fact that the engineers shared this handicap with the computer. This proved to be no handicap in the present design, however, as the computer performed well. More important, none of the respondents indicated that the list of materials was too limited to make an adequate choice.

It remains a subject of interest how the computer would compare in a study in which the number of polymers from which selections could be made was in the hundreds or thousands, instead of ninety.

Suggestions for Further Research

All of the respondents showed considerable interest in the study and expressed a desire to see the results of the research. In addition, some indicated a desire to follow up the study with a comparison of several computer selection systems used by Iowa industries.

The conclusions of the present study place the use of computer-aided materials selection systems in a very favorable light. With the increasing costs of materials and processing and considering the rapidly decreasing cost of computer technology, further study in the area of materials selection systems such as the one used in this study seems essential.

This work should include the development of larger databanks, selection algorithms which improve upon the analysis of the data over current methods, and feasibility studies into commercial access databanks and data procurement centers.

Another area which the researcher perceives as urgently needing attention is the development of uniform methods for reporting properties. The use of four different hardness scales and three different impact scales, unavailable data such as stress cracking and environmental behavior, and unscaled nonspecific fatigue data renders the comparisons of polymers very difficult in many cases. When conventional English measurement units are then combined in a single databank with Systeme International (SI) units, the problem is compounded several times.

Solutions to some of these problems, especially the use of uniform (SI) units, will not be difficult to achieve. Others, such as hardness and fatigue data, require the agreement of experts on the most universal and appropriate method of characterizing and reporting each property.

The results of this study suggest that materials technologists might reasonably begin to contemplate the development of a universal materials selection system. Such a system would deal not only with one family of materials, such as polymers, but also with metals, ceramics, and composites: the entire range of structural engineering materials.

The problems in developing such a system are admittedly great, but the potential rewards in the form of materials substitution and conservation, are greater still. Materials selectors cannot hope to select adequately from one family of materials, much less from all materials. The use of proven computer aids to selection will greatly improve our capability in using materials which are mechanically and environmentally adequate, as inexpensive as possible, and plentifully available whenever possible.

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APPENDIX I

Material Characteristics Listed in Databank

Material family and group code	
Tensile strength	psi
Elastic modulus (tension)	psi
Yield strength	psi
Elongation at rupture	%
Compression strength	psi
Flexural strength	psi
Elastic modulus (flexure)	psi
Impact strength, Izod	ft-lbs
Fatigue strength	psi/10**8 cycles
Brinell Hardness	3000 kg
Hardenability	(1 - 5)
Cost/cc (relative)	cents
Cost/psi tensile strength	cents
Specific gravity	
Handling danger rating	(1 - 5)
Recyclability	(1 - 5)
Filler used (zero = none)	%
Water absorption/24 hours	%
Refractive index	(0 = opaque)
Melting point	°F
Deflection temperature	(264 psi)
Thermal conductivity	Btu/hr/sqft/°F/ft
Coefficient of thermal expansion	in/in/°F
Electrical resistance	microohm-cm
Dielectric strength	v/mil
Dielectric constant	60 Hz
Weatherability, general	(1 - 5)
Corrosion resistance	(1 - 5)
Acid (weak) resistance	(1 - 5)
Solvent resistance	(1 - 5)
Machinability	(1 - 3)
Weldability	(1 - 3)
Cold workability	(1 - 3)
Forgability	(1 - 3)
Castability, gravity	(1 - 3)
Castability, slush	(1 - 3)
Injection	(1 - 3)
Extrusion	(1 - 3)
Pultrusion	(1 - 3)

Compression molding	(1 - 3)
Thermoforming	(1 - 3)
Transfer molding	(1 - 3)
Rotational	(1 - 3)
Reaction	(1 - 3)
Blow molding	(1 - 3)
Coating	(1 - 3)
Lamination or lay-up	(1 - 3)

APPENDIX II

Subjective Scales Used to Rate Materials

Property	Scale
Handling danger	1 = No danger 5 = Danger in most situations
Recyclability	1 = Not recyclable 5 = Totally recyclable at profit
Weatherability	1 = Poor resistance to ultra-violet and humidity changes 5 = Excellent outdoor performance
Corrosion resistance	1 = No resistance 5 = Highly resistant
Acid resistance	Refers to weak acid solutions 1 = No resistance 5 = Very high resistance
Solvent resistance	Refers to solubility in conventional hydrocarbon solvents 1 = Extremely soluble 5 = No known solvents
Processability	1 = Not possible or not done 2 = Possible, but not preferred 3 = Process yields good results

APPENDIX III

List of Materials

ABS Medium Impact		Grade 6.3
ABS High Impact		Grade 4.5
ABS Heat Resistant		Grade 7
ABS Transparent		Grade 5.6
ACETAL Standard		Grade 10
ACETAL 20% Glass Reinforced		Grade 8.5
ACETAL 22% TFE Filled		Grade 6.9
ACETAL Standard Copolymer		
ACETAL 25% Glass Reinforced		Grade 16
ACRYLIC General Purpose	Type 1	Grade 6
ACRYLIC General Purpose	Type 2	Grade 8
ACRYLIC High Impact		Grade 5.5
ACRYLIC Modified XT		Grade 7
ALLYL DIGLYCEROL CARBONATE		Grade 5
ALKYD Putty		Grade 4
ALKYD Rope		Grade 7
ALKYD Granulated		Grade 3
ALKYD Glass-Reinforced		Grade 5
ABS/POLYCARBONATE		
ABS/PVC Rigid		
ACRYLIC/PVC		
ABS/POLYSULFONE		
CELLULOSE ACETATE	Type 44	Grade 6.4
CELLULOSE ACETATE	Type S2	Grade 3
CELLULOSE ACETATE BUTYRATE	Type H4	Grade 7
CELLULOSE ACETATE PROPIONATE	Type H2	Grade 4
EPOXY Standard Casting		Grade 9.5
EPOXY CYCLIC ALIPHATIC		Grade 10
PTFE		Grade 2.5
PTFE Ceramic Reinforced		Grade .75
PVF		Grade 7.2

ECTFE Glass Reinforced	Grade 12
NYLON 6 General Purpose	Grade 9.5
NYLON 6 Glass Reinforced	Grade 21
NYLON 12	Grade 7.1
NYLON Transparent	
NYLON 6/6 General Purpose	Grade 11.8
NYLON 6/6 Glass Reinforced	Grade 25
NYLON 6/6 High Impact	Grade 7.8
NYLON 6/12	Grade 8.8
PHENOLIC General Purpose Filled	Grade 5
PHENOLIC Glass Reinforced	Grade 5
PHENOLIC Mineral Reinforced	Grade 6
PHENOLIC RUBBER/ABS	Grade 4
POLYPHENYLENE SULFIDE	
POLYSULFONE Standard	
POLYSULFONE Glass Reinforced	
NORYL SE 100	
NORYL Glass Reinforced	
POLYCARBONATE Standard	Grade 8.5
POLYCARBONATE Glass Reinforced	Grade 23
POLYESTER Cast	Grade 4
POLYESTER Molding Glass Reinforced	Grade 5
POLYESTER Pultrusion	Grade 100
POLYESTER General Purpose	Grade 8
POLYESTER Glass Reinforced	Grade 19.5
POLYESTER Glass Reinforced Fire Resistant	Grade 16
POLYETHYLENE T1	Grade 1.4
POLYETHYLENE T2	Grade 3.3
POLYETHYLENE T3	Grade 3.4
POLYETHYLENE High Molecular Weight	Grade 5
POLYPROPYLENE General Purpose	Grade 5
POLYPROPYLENE High Impact	
POLYPROPLYENE Glass Reinforced	
POLYSTYRENE General Purpose	Grade 5
POLYSTYRENE High Impact	Grade 3.3
POLYSTYRENE Glass Reinforced	Grade 14
PVC General Purpose	Grade 1
PVC Rigid	Grade 5

APPENDIX IV

Development Report

General Objectives

Interviews with personnel at Hinson Industries and John Deere Company, Waterloo, Iowa, have revealed three issues of overwhelming concern to the design engineer and materials specifier. First, materials chosen and the process of choosing them must incur minimal costs in terms of time and capital. One implication of this idea is that a material should be used even if it is not the best choice, if it is in inventoried stock and its cost is not higher than the net cost of bringing another material to the plant.

Second, convention is a very strong factor in materials usage. Design engineers like and tend to use materials with which they are familiar. This is partly because they already know the general properties of such materials, partly because such materials come to mind without the difficult task of selection, and partly because they are either on-hand or easy to obtain.

Third, industries producing most types of consumer items must be certain that the strength and other properties of materials used in production conform to laws and standards set for each type of product. This concern adds fuel to the second issue; engineers associate familiar materials with the ability to meet critical standards for their product line.

The success of a computer-assisted selection system will be strongly influenced by its ability to address these issues. For example, the time required for selection must be reduced so that the cost of labor and computer time is minimized. The materials selected must include options which represent reductions in cost below costs of familiar materials. The system must indicate and favor materials which are in inventory. It must be easy to use, and interact favorably with the user so that engineers will be willing to set aside convention and use it. It would be desirable eventually to provide listings of suppliers of selected materials so a user could tell where to get them. It might also be helpful to provide a guide or format through the computer to help the user through a well thought out process of specifying properties so as to derive maximum benefit from the system.

A list of suppliers will not be included in the pilot system, nor will the ability of materials to meet certain product standard. Yet, if use of the system is easy enough, and if it proves to be advantageous for the user to specify acceptable limits which conform to appropriate standards, the system can be expected to sell itself.

In the final evaluation, this concern overrides all others: if the system is used, then it is at least a partial success. How much of a success, and in what ways, must be determined through a carefully planned field test.

Specific Objectives and Goals

Use of the system must be as easy as possible. The user must be able to obtain from a terminal or printer:

1. A general description of the system.
2. Guidelines for establishing a list of specifications*
3. Notes on how to use specifications so as to realize the full benefits of the computer approach*
4. A list of all materials which meet the specifications
5. An indication of which material conforms best to specs
6. A list of specifications for any material in the file*
7. A list of all materials in the file*
8. A list of all the properties used in the selection process

9. A clarification of any subjective or nonstandard scales.

*These are not required, but are desirable enhancements of such a system.

The properties chosen and the way in which each value is assessed must, so far as possible, be consistent with the way they would be assessed in a manual selection process, unless this interferes with the efficiency and benefits of the computer approach. Complete development of algorithms for this goal will be postponed for the full-scale versions of the system due to the complexity of the mathematical modeling involved. The experimental version will include several alternate ways of assessing data in an attempt to provide some simulation of manual selection procedures.

List of Materials

Attempts to find out from local industries (John Deere, Chamberlain Manufacturing Corporation, and Hinson Industries) what materials are most commonly used or kept on hand have been unsuccessful. The annual Materials Selector issues of Materials Engineering magazine (1979, 1980, 1981) have been used as sources from which to select materials for the pilot version of the system. Materials can be added easily to the databank. This publication is designed for use by industrial designers, product engineers, materials procurers, quality control engineers, and others. For the pilot version, 70 polymers have been chosen for inclusion in the databank.

List of Properties

Readings in Materials Engineering (Mock, 1976; Miska, 1978) and in Engineering Materials (Sharpe, 1966) have augmented personal experience in the selection of materials and provided the basis for a list of properties important and useful enough for inclusion in the databank. The list adopted is intended for the pilot system and, it is expected that it will need changing and extending later.

One of the greatest problems in implementing the system has been the fact that certain properties of different materials are often characterized differently for the various types of materials (thermoplastics, thermosets, elastomers, etc.). Sometimes this is due to inherent differences in the materials or their applications; other times it is due to convention. Several such properties have been scaled by the author for subjective ratings of the materials.

Programming Language Considerations

Important considerations in the selection of a programming language for the system are:

1. The ability to interact conversationally with the user.

2. The ability to perform complex manipulations of data at high speed.

3. The ability to address, sort, and evaluate large quantities of data at high speed.

Considerations which are of special importance to the pilot version are:

1. Local availability of computer terminals and disk storage space.

2. Ease of editing the selection and manipulation routines.

The only language which satisfies these last two criteria on the campus of the University of Northern Iowa is H. P. Access BASIC, which runs on the University's Hewlett-Packard 2000 minicomputer. This computer may be accessed by terminal or by phone.

It should be noted that BASIC is not as fast a language for manipulation of data as some other languages. For a full-scale memory bank with 1,000 or more materials and perhaps 50 properties, the time required for search execution might be too long for an interactive user in BASIC. A version translated into FORTRAN or Pascal might be more suitable. Either of these two languages would satisfy the first three requirements above, if implemented on an appropriate computer.

Algorithms

Algorithms are models of a procedure for solving a problem. In the present system, the problem of concern is whether or not to consider a databank property value as satisfying the needs of the application. The algorithms used in the pilot system have been revised several times, with each revision an attempt to improve the quality or the speed with which selection decisions are made.

It is not adequate to simply see whether a file value is equal to the specification for that property and to reject it if it is not (see Specific Objectives and Goals, p. 52). The chances of any fits given such an algorithm are very nearly zero, and in any case such an approach may be more irrelevant than stringent. Rather, for any given property and application, an engineer may want the selected material to have either at least the specified property value, not more than the value, or perhaps a value that does not differ from the specifications by more than a certain percentage.

The earliest selection algorithms developed provided for all three of these options, and offered five, ten, and twenty percent variations above or below the specified value for the third option. Refinements of these algorithms involved variations in the way that deviations from the original specifications were calculated and accumulated. Another algorithm was introduced allowing for variations in (a) the total of the summed deviations of all properties from input specifications, and (b) the number of specified properties which would be allowed to deviate from specs, for each material evaluated. The latest versions of the selection program are both faster and more responsive to the user's personal ideas on these questions than were earlier versions.

Go/no-go properties. Depending on the application, an engineer may feel that certain properties must be conformed to, where others might be less critical. In conventional selection procedures, this gives rise to "go/no-go" criteria, which must be met before any further consideration is given to a material. In the latest and most important development of the selection algorithms, this option has been added.

The importance of this capability can be seen by looking at the way it works. If the user identifies a go/no-go property, the computer will search the entire databank for conformance to that one property, setting a "flag" for each material to "1" indicate compliance, or to "0" for noncomplicance. If a second go/no-go property is identified, the computer need only check those materials for which the flag is set to "1." In a very short time, users can set the flags for 70 or even 1,000 materials according to three or four go/no-go criteria. When the other search algorithms are applied, they need only be applied to materials still flagged with "1's." In time test runs of the go/no-go augmented system and the earlier version, the selection time for 70 materials was reduced from three minutes to 55 seconds through the use of one go/no-go property.

APPENDIX V

Selection of Plastics Materials by Computer Analysis

General Electic Company's Corporate Consulting Service, located in Schenectady, New York, has recently established a computerized Plastics Materials Data Bank, by means of which it hopes to simplify and improve its necessary plastics materials functions worldwide. General Electric is one of the largest producers and converters of plastics materials in the United States. Because its diversified manufacturing and service components are widely scattered over the country, management has recognized the considerable problems associated with materials selection, purchasing, inventory, and utilization.

The plight of persons responsible for selection of plastics materials has been rapidly approaching the desperation point. This is an unfortunate, though natural, result of the extremely rapid growth which has occurred in the plastics industry over the past two decades. With amazing regularity, whenever a need for new properties or processing capabilities has been defined and voiced by designers or manufacturers of plastics products, polymer scientists and technologists have responded promptly with one or several brand new materials.

At the present time, there are approximately 50 different classes of polymeric materials useful in plastics manufacturing, and commercially available. For each of these classes of materials, the standard offerings of vendors range, with various degrees of sophistication, from a single compound to well over 250 distinct compounds or formulations with unique property combinations.

When faced with a materials choice problem in plastics, engineers find themselves almost totally dependent upon (a) their own previous experience with a very few specific compounds, (b) advice from vendors who logically can only promote their own offerings, or (c) vague generalizations found in various trade journals or the advertising media. While several compilations of properties data for plastics by chemical types have been made (for example, in Modern Plastics Encyclopedia), these are generally broad range values encompassing the extremes to be found in each category. Valuable as they are, such data are only the beginning for a design or manufacturing engineer who must locate a real material with a specific combination of properties, including processing characteristics, for a given application. Nor do the available property compilations help him locate the best dollar value in materials. Without computer assistance, this requires a tedious search and comparison process which, actually, seldom gets done.

Access to the computerized information bank on plastics materials is via G. E.'s well established Mark III timesharing network. Teletype terminals for the time-sharing system are in place in nearly all operating components of the company, and several times as many are in use by non-G. E. people, both in the U.S. and abroad. The Data Bank may be accessed by all network users. The continuing costs of updating and expanding the files are covered by surcharges applied to the normal billing for computer costs from Information Services Business Division. Special user numbers are issued to allow access to the program PLASTIC and to provide for the necessary accounting procedures.

Two separate, but related, information files are available. The first describes plastics materials simply according to their generic types with various degrees of subgrouping (eg., ABS, Plating Grade). Processing and properties information contained in this file is in terms of ranges of values to be expected for typical products included in the particular category. About 50 major chemical types and 175 subgroups are presently included.

The second, more extensive file concerns actual commercial products available in the U.S. marketplace. At the present time, this vendor materials data bank contains information on the offerings of approximately 75 U.S. companies, with a total of about 2,500 individually identified products. Each product is described first by a file number which not only defines its basic chemical type and subgroup, but also provides an identifier for internal search routines. In addition, each listing shows the vendor name, the product trade name and/or number, the principal modifiers and fillers, if any, and the most important distinguishing features. Then follows an extensive listing of processing information and material property values totaling up to 71 items, and including such categories as recommended processing techniques and parameters; physical, mechanical, thermal, optical, electrical, and environmental properties; and prices. A separate file of unclassified notes is also drawn on automatically to describe further certain products where necessary.

One important feature of the G. E. information retrieval method is that all interaction with users is direct, on-line at the teletype terminal, and requires no knowledge of any particular computer language. Most of the input required from the user is prompted by the program itself. While a printed user's manual is supplied, programs have been designed to minimize the need for reference to the manual. The latter is useful for a detailed description of the various capabilities of the program and for identifying codes required in certain operating modes. The only equipment required at the user's location is a teletype terminal and a standard electronic interface to a telephone line. Both of these are often leased from the telephone company.

In the initial teletype dialogue with the computer, the user is given the choice of receiving brief instructions explaining the various modes of operation of the program. Similar, but more detailed, information is also contained in the user's manual. Someone with prior experience with the Data Bank program normally does not require the teletype instructions and can proceed directly into one of the six operating modes.

Following the selection of mode of operating, the program continues with the user making various decisions, as described for three of the six modes in the following paragraphs.

Mode 1--Finding Vendors for Material

Frequently, the kind of plastic material has already been determined, and the program user seeks vendors and vendor compound identification for such materials. This mode of operation may sometimes follow the receipt of information from Mode 5, regarding generic types suitable for a certain application. It is also used where the engineer knows he must employ a particular material type, but wishes to explore the marketplace in some detail.

Modes 2, 3, and 4--Listing of Property Values

This is where the computer can help the user compare various potentially satisfactory materials, property by property, in a fraction of the time it would normally take him. Data listings for up to nine individual vendor products, or up to nine generic types, are printed out side by side.

Mode 2 provides the complete properties list, containing a total of 71 possible items for vendor compounds (68 possible items for generic material types) as well as the identifying information for the materials requested. The printout format is designed to allow convenient comparison of all listings by cutting the teletype paper and placing the sections adjacent to each other.

In Modes 3 and 4, the user also has the option of electing to see only those kinds of properties data of particular interest to him out of the total bank of 71 properties. This can greatly reduce teletype printout time and computer-terminal connect time charges to the user.

Modes 5 and 6--Matching Materials to Requirements

The entire data bank of plastics materials can be scanned to find out which ones have the processing and properties characteristics to match a set of criteria formulated by the user. The answers to this matching game can be in the form of either chemical classes of plastics, referred to in the program as "generic types," or individual commercial products called "vendor materials" by the program. The user determines this by selecting either Mode 5 or Mode 6, respectively, when asked by the computer.

From the user's standpoint, the computerized plastics databank and its access programs are designed to offer help in a variety of ways. They can:

1. Assist him in selecting materials which meet his requirements at lowest cost

2. Save him time in searching for technical data

3. Make him aware of materials with which he is not familiar

4. Force him to identify his real needs, thus allowing better match between product requirements and material utilization

5. Give him a logical basis for material selection rather than reliance on his personal experience alone

6. Indicate materials which could improve his product at no increase in cost

7. Indicate certain materials which are rejected for the application and the reasons why

8. List alternate qualifying materials to enable better selection and cost comparison

9. Help him consider measures of processability in selecting materials.

Obviously an important requirement of any data bank is that the information be kept current. To accomplish this, the primary file-building programs have been designed with the capability of adding new products or new information on already filed products, or for changing or deleting any or all information on a product. An on-going effort associated with the operation of the program service is continual updating of the files.

Numerous possibilities for future extensions of the computerized services are under consideration. For example, G. E. thinks a similar system to help in the selection of plastics processing equipment would be useful. Interest has also been aroused among users of other kinds of materials, such as metal alloys, where compositional variations are very great and considerable amounts of standardized test data are available in scattered reference sources. It is anticipated that this kind of data retrieval technique will have a profound, beneficial effect upon many engineering and design functions in industry.

D. L. Hollinger, Senior Engineer
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Schenectady, New York

APPENDIX VI

Plastic Material Selection Form

Material Constraints Required

for

Project _____________

NAME ______________________ EXT. ______________________

EP ___________ DATE ______________________

PART NO. _____ CONVERSION PROCESS ______________________

Material Class: Check one

Thermoplastic ____ Thermoset ____

Property values required; insert value in appropriate column.

Property Class	Property	= to	≤ than	≥ than
Mechanical	GEN.NAME			
	SPEC. NO.			
	TRADE.NAME			
	MANUFACT			
	IDENT			
	A.C.			
	FILLER			
	AMOUNT			
	SPEC.GRAV			
	TENSL			
	TENSL.MOD			
	TENSL.BREAK			
	FLEX.MOD			
	IZOD.IMP.NOTCH			
	IZOD.IMP.UNNOT			
	HARD.SCALE			
	HARD.LEVEL			

Property Class	Property	= to	≤ than	≥ than
Thermal	THERM.COND			
	COFF.LIN.EXPAN			
	U.L.TEMP.INDEX			
	DEFL.TEMP.264			
	DEFL.TEMP.66			
Optical	REFRC.INDEX			
	TRANSM			
Flammability UL94	FLAM			
	AT.THICK			
Electrical	DIEL.STREN			
	DIEL.CONS.HHZ			
	DIEL.CONS.KHZ			
	DIEL.CONS.MHZ			
	DISS.FACT.HHZ			
	DISS.FACT.KHZ			
	DISS.FACT.MHZ			
$16	COST			

Note:

1. It is suggested you consider more than one submission; the second page would be reducing or eliminating those constraints that you would like to have but aren't absolutely essential. Use an (A) after page number for second submission, etc.

2. U.L. Temp. Index: This is the temperature above which a property or properties will degrade with time according to U.L.

3. Flam is flammability rating for U.L. Bulletin 94. After flame source is removed from sample:

   V0 Specimen will cease burning in 5 seconds
   V1 Specimen will cease burning in 25 seconds
   V2 Specimen will cease burning in 25 seconds, but will drip flaming material which will shortly extinguish
   HB Material will continue to burn but not exceed a rate of
   3 in/min for thickness < .120"
   1.5 in/min for thicknesses of .120" through .500"

Environmental Requirements

Exposure to Ultraviolet radiation for	< 25% __ of part life
	> 25% __ of part life
	< 50% __ of part life
	> 50% __ of part life

Temperatures: Min _____°F. Max _____°F

APPENDIX VII

The Research Problems

Letter of Introduction

Seth P. Bates
Materials Technology Laboratory
Industrial Technology Center
University of Northern Iowa
Cedar Falls, Iowa 50614
319 268 1900/319 273 2561

Dear Sir:

You have generously agreed to help me with the research that I am conducting on materials selection processes. My proposal for the research is finally finished, and I am ready to proceed with the data collection. This is where you come in.

Enclosed with this letter you will find three materials selection problems, each consisting of a specifications sheet and a part sketch or drawing. Also enclosed is a list of materials which our hypothetical company has in stock or which may easily be acquired through established vendors. Most of the families of polymers are represented. The task which I set before you is to select one polymer from this list from which to make each part. We are making prototypes of the parts, and the eventual production runs will be of 10,000 units each.

As you work through the criteria, feel free to comment on a separate sheet, but please adhere to the requirements in the selection. The selection should be manually done, and the time required to find each solution should be recorded somewhere on the corresponding problem sheet. Please do not spend more time on any problem than you believe the production situation warrants.

If you have access to a computer selection system, please feel free to put the requirements through the computer system when you are done with the manual selection. I would be most interested in seeing the results of such a search. However, it is essential to the present study that the solutions entered on the problem sheets be manually selected.

I will be away from my desk from May 21st until June 10th, and time is of the essence. Please fill out the problems as soon as you can find the time, return them, and let me know of any problems or questions by note or by phone after June 10th.

You will be sent a complete copy of the dissertation as soon as it is completed. I will be conducting the analysis of the solutions between June 10th and June 30th, and would be happy to share that process with you by phone or note.

Thank you very much for all your help, both in this and in our earlier consultations.

Sincerely,

Seth P. Bates

Problem I

Part name: GEAR

General dimension:	OD + 6.500"	Depth = 1.500" at OD
	ID = 0.876"	Depth = 2.125" at hub
	Keyway = 0.125" x 0.250"	

Application: Cam driver

Environment: Agricultural. Exposure to dust, dirt, chaff, and water. Gear housing open to atmosphere. Maximum 200 rpm.

Minimum property requirements:

Compression Strength	15,000 psi
Flexural Modulus	2,000,000 psi
Brinell Hardness	9 or higher
Fatigue Strength	4 ksi at 10**8 cycles
Temperature Range	-30 to 200°F
Weather Resistance	fair to good
Processability	injection or compression molding

Material of Choice: ______________________________

Problem II

Part name: CAM, Single Lobe

General dimensions: Max. dia. = 4.5" Thickness = 1.000"
Min. dia. = 3.25" ID = 2.125"
Keyway = 0.125" x 0.250"

Application: Cutting blade pushrod driver
Driven by keyed shaft.

Environment: Agricultural. Exposure to dust, dirt, chaff, and water. Gear housing open to atmosphere. Maximum 200 rpm.

Minimum property requirements:

Compression Strength	15,000 psi
Flexural Strength	20,000 psi
Flexural Modulus	4,000,000 psi
Brinell Hardness	20 or higher
Fatigue Strength	2,500 psi
Temperature Range	-30 to 200°F
Weather Resistance	good to excellent
Processability	injection or compression molding

Material of Choice: ______________________________

Problem III

Part name: VALVE GATE

General dimensions: Max. dia. = Height =

Min. dia. = 1.000"

Application: Liquid fertilizer flow valve

Environment: Agricultural. Liquid solutions of mild acidity or basicity.

Minimum property requirements:

Tensile Strength	10,000 psi
Tensile Yield	6,000 psi
Compression Strength	25,000 psi
Brinell Hardness	5 to 20
Temperature Range	-30 to 200°F
Acid Resistance	good to excellent
Processability	injection molding

Material of Choice: ______________________________