APPENDICES

Appendix A

MATERIALS SUBSTITUTABILITY

A. INTRODUCTION

The possibilities for and potential consequences of substitution are important to all who are concerned with materials supplies and usage. In situations where normal supplies of a material are threatened or constrained, one of the first questions asked is: What is a suitable substitute?

Experience with problems of materials availability, most recently stemming from the shortages of 1973-74. has encouraged users to examine alternative materials and designs. Impacts of those shortages on the national economy have led Government policy makers to inquire about the prospects and effects of substitution as a means of alleviating or avoiding future serious consequences from shortages of essential materials.

For these reasons, the technology assessment examined the information and data requirements of substitution analyses, with a view toward assessing how this capability might be incorporated in a new integrated materials information system. The study examined the following aspects:

- The meaning of the term "materials substitution";
- The information/data required by various classes of decisionmakers for materials substitution decisions;
- The present sources of information/data to make such decisions;
- The gaps in such information and data; and
- The costs involved and the time required for developing the essential system capabilities for substitution analyses.

For purposes of this study the term "materials" is defined very broadly. It includes all substances used by mankind, except food and drugs. Materials are classified in two ways, (1) in accordance with their intended use, and (2) relative to their state of manufacture. The first of these classifications includes the following categories:

- Physical/Structural materials include all substances in raw, semifinished and finished form used in the manufacture of goods, which remain in identifiable form during a period of use. They include: metallic minerals, metals, construction minerals, wood, paper, cotton, wool, plastics, and ceramics.
- Reagents and Intermediates include all substances which are used in the manufacture of a finished product but do not remain as part of it. Such substances generally include chemicals, fertilizers, abrasives, solvents, and industrial gases.
- Energy/Fuels materials include the various mineral fuels and products refined from them, They include: petroleum, coal, natural gas, natural gasoline, and liquified petroleum gases.

The second way to classify materials is according to state of manufacture; major categories include:

- Raw, semifinished, and finished materials includes ores, concentrates, and basic metals and alloys. Also included are agricultural and wood products.
- Components/applications include all parts of consumer and industrial durables. Also included are pesticides, pharmaceuticals and household cleaners, as well as finished grades of petroleum products,
- Systems include all finished household and industrial durables. The term "systems", as applied to energy/fuels and reagents and intermediates, usually refers to the method by which these classes of materials are used.

Table A-1 is a three-by-three matrix using both classification schemes as axes. The argument for classifying materials in these two ways is to consider the possibility that materials substitution may vary among materials classes.

The term "substitution" also needs definition, From the examples given in table A-1, it is clear that the concept of substitution cannot be limited simply to replacing one material with another. Substitution also involves replacing one process with another or changing the functional characteristics of a material or part. Further, these three classes of substitution—material, process, and function-can occur at any of the various stages in the resource, processing, and manufacturing cycle, from raw materials through primary products, parts manufacture, and components to final system design and assembly. Examples of these three classes of substitution are given in table A-z.

Table A–1.-Examples of Substitution Involving Various Classes of Materials

Category of Material, by State of Manufacture	CLASS OF MATERIAL-BY USE		
	Physical/Structural	Reagents and Intermediatedes	En.rgy/Fuels
Raw, Semifinished, and Finished Materials	Alunite for bauxite	Recovered sulfur for Frasch sulfur	Western coal for Eastern coal
	Raw polyester for raw cotton	Natural brines for rock salt	Gasified coal for natural gas
	Alcoa's chloride aluminum reduction process for the Hall process	Mining of natural soda ash for Solvay process soda ash	Fuel oii for natural gas
	Basic oxygen furnaces for open hearth steel-making	Phosphoric acid from furnace phosphorus for wet process acid	Formed coke for metallurgical coke
Components/Applications	New copper alloy for present alloy in auto radiator	Hydrochloric acid pickling for sulfuric acid pickling	Lead-free gasoline for regular
	Aluminum alloy for copper alloy in auto radiator	Direct application to soil of anhydrous ammonia for liquid application of ammonium salts	Propane for fuel oil
Systems	Air-cooled auto engine for water-cooled engine	Not applicable	Geothermal for coal-fired steam boiler
	Mass Transit for automobiles		Solar heating system for natural gas system
	Video phone communications for business transportation		

Table A–2.—Examples of Three Broad Classes of Substitution

One Material for Another	
	Aluminum for Copper in a Bus Bar
	No. 2 Yellow Pine for No. 1 in Woodwork for Home
	Mica-Based for Asbestos-Based Insulation
	Polyester Fabric for Cotton
	Painted Plain Carbon Steel for Stainless Steel
	Aluminum Building Wall Studs for Wooden
	Graphite Golf Club Shafts for Steel/Hickory
One Process for Another	
	Friction Welding of Metal Parts for Butt Welding
	Rolled Threads on Screws for Cut Ones
	Castings for Forgings
	Float Glass for Ground Plate Glass
	Continuous Melt Extraction of Wire for Drawing
One Function or Level of Function for Another	
	Bulk Distribution of Oil Products in Place of Unit Containers
	Elimination of Chrome on Automobiles
	Air-Cooled Engine as a Substitute for Radiators in Water-Cooled Engines

Clearly there is interaction between the three alternatives; replacement of basic material may well dictate process changes throughout the system; process changes may affect the design; design changes certainly lead to new material requirements. But each choice is a separate issue, with its own requirements for information and data. A system providing information and data for substitution analyses must consider each alternative and its needs,

B. DECISIONS AND DECISIONMAKERS

Having defined the kinds of substitution that take place at various levels, from processing of materials to design of final products, it is appropriate to ask: Who makes decisions regarding substitution and why do they consider substitutes?

It is difficult to identify anyone in a free economy who is not involved in the process of making decisions regarding materials substitution, The consumer directly or indirectly dictates most of the choices.

In the chain of decisionmakers who respond in different ways to their perceptions of consumers' choices are two broad classes, Both are potential users of information and data on materials substitution. As shown in table A–3, the first class is Materials Users.

Table A–3.—Potential Users of Information on Substitution

Materials Users	National Policymakers
R&D Personnel	Government Administrators
Designers/Engineers	Congress/Executive Branch
Management/Entrepreneurs	Public Interest Groups
	ab

Everyone in the chain—from raw material producer on-can be considered a Materials User. At the raw materials level, even producers are users of materials in a less refined state, e.g., the alumina producers are users of bauxite. The second class of user consists of public officials and those who influence public policy.

The shortages that developed in the period 1973-74 have tended to overemphasize the need for substitution to overcome shortages, Substitution is continuously taking place to increase the performance and reduce the cost of goods and services,

Four considerations of national interest encourage the development and use of substitute materials:[1]

1. Environmental and safety controls, which have introduced a whole new set of social specifications. creating a need to deal with shortages resulting from prohibited facilities, materials, and processes:

[1]Mineral Resources and the Environment, Appendix to Section 1, Report of Panel on Materials Conservation Through Technology, National Research Council, PB-239580. February 1975.

2. Government intervention in the industrial system to overcome large dislocations such as the combined shortage of electric power and petroleum fuels;

3 Future prospects of dislocations in the flow of materials from sources in developing countries and unstable sources; and

4. The need to reduce reliance on materials of rising cost from foreign sources to balance U.S. payments abroad and control inflation at home,

These and several other examples of motivations for considering substitution are listed in table A-4, They make it clear that substitution is but a special case of materials selection. Materials selection takes place with a particular set of criteria and when another set of criteria is imposed, another selection takes place—the latter being called substitution.

Table A-4.—Examples of Motivations for Substitution

Material Shortage/Potential Shortage
Price/Cost Advantage—Uncertain Future Cost
Higher/Better Performance
Increased Reliability/Decreased Maintenance/Increased Life
Increased Marketability
Skilled Labor Shortages
Fabrication/Production Facility Shortages
Poor Performance of Present Material
Regulatory Actions
Development of Self-Sufficiency
Elimination of Single Source Dependency
Use of Internal Materials
Risk Minimization
Political Advantages
Protection of Domestic Industries
Follow the Competition
Energy Reduction

C. THE PROCESS OF SUBSTITUTION ANALYSIS

DELTA charts[2] have been prepared to show more specifically the information requirements for both materials users and national policy makers. In each chart, information and data needs have been keyed to the various steps in the decisionmaking process.

1. Materials Users

Figure A–1 shows the information requirements for substitution analysis by Materials Users. This DELTA chart shows the logic of a designer/user in one of the manufacturing industries.[3] Rather than explain Figure A–1 in the abstract, the chart will be described by using two current examples—with numbered paragraphs referring to the numbered symbols in the chart.

a. Rear Deck of an Automobile

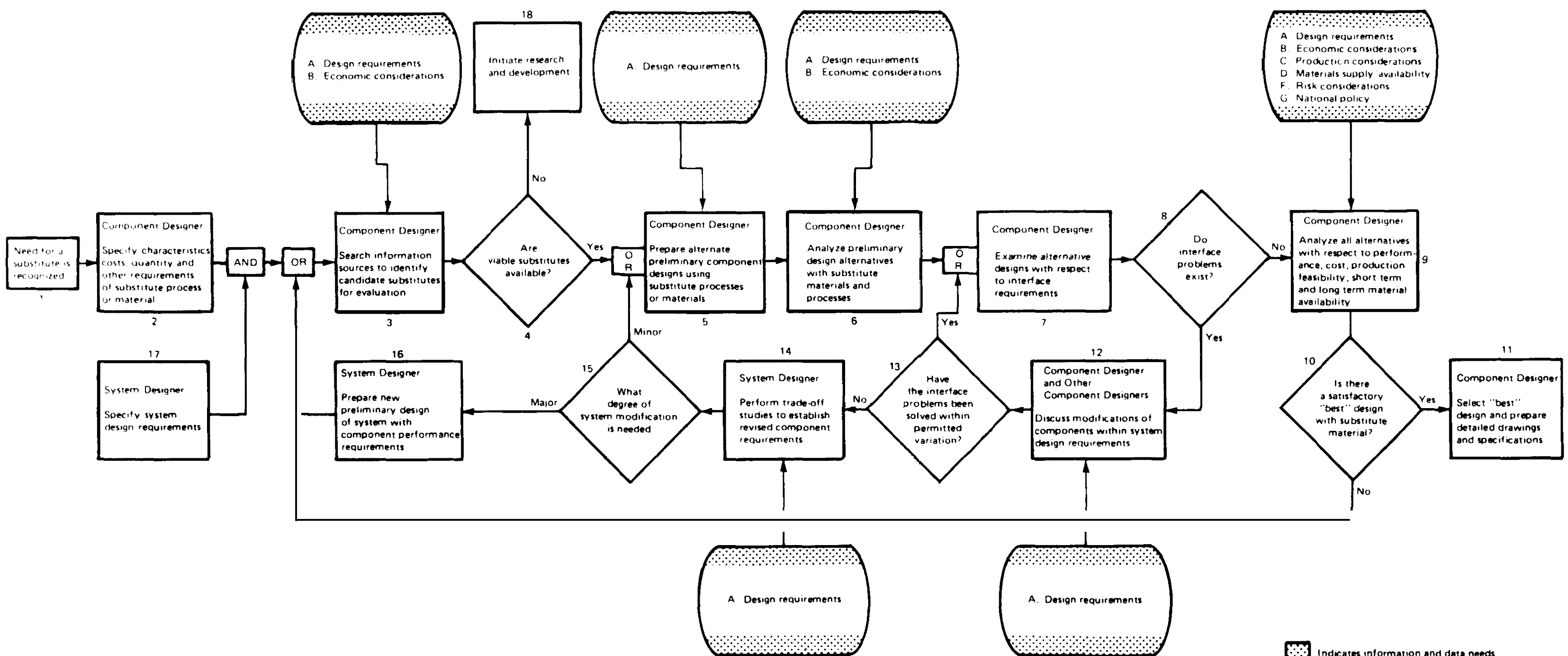
(1) Because supplies of petroleum will be limited and more costly, automobiles will have to be more efficient in their energy usage. One way to reduce the energy used in an automobile is to reduce its weight, It is recognized that the rear deck of an automobile now made of steel might be produced from a substitute material to effect weight reduction,

(2) and (7) The rear deck designer in cooperation with the automobile systems

[2] DELTA charts incorporate a logical network of Decisions, Events, Logic, Time sequence, and Activity. This kind of flow chart shows the major steps in a decision-making process.

[3] A similar chart could be prepared to show the logic of a user/producer in the process industries, for example, a copper company. Such a company looks for another ore body and alternative processes as its current properties are being depleted. Or aluminum companies, in cooperation with the Bureau of Mines, investigate the feasibility of using alunite and other high alumina clays in the production of alumina. Such a diagram would show essentially the logic of raw materials and process selection. The data and information requirements would differ in detail, but the principles used in laying out the decision logic and information requirements would be the same.

Figure A–1. Information Requirements for Substitution Analysis by Materials Users



designer specifies the design requirements for all components, including a lighter weight rear deck. They also specify other desirable characteristics or requirements for the new rear deck. For example, the new material should be formed by equipment in existing production lines with a minimum of modification and the cost should not exceed the cost of a conventional rear deck fabricated from steel,

(3) The rear deck designer next searches for information that will lead him to identify candidate substitute materials, In this search, he wants to specify design requirements and economic constraints, From that input, he would like an information system to identify for him specific kinds and grades of material that meet his requirements, If the component designer specifies only a few of the more important technical performance requirements, he may have a list of candidate materials including aluminum, magnesium, reinforced plastics fiber composites—among others. The components designer on the other hand may specify a large number of technical and economic requirements resulting in no candidate substitutes,

(4) Depending upon how strictly he applies his performance requirements, the rear deck designer either has a long list of substitutes, a few, or none. In this case, we would expect him to have a leading candidate substitute mat erial—alu m in u m,

(5) The rear deck designer then prepares alternative preliminary designs of a rear deck using aluminum, Some of the problems he faces are inherent in the chemical, mechanical, and physical properties of aluminum as compared with steel, His major information need is for design requirements including properties of materials.

(7) The rear deck designer then examines his alternative designs with respect to the interface requirements of his rear deck and the other components of the automobile that interact with it. For example, if the weight of the rear deck is substantially different when fabricated with aluminum as compared with steel, this may change the suspension characteristics,

(8) He then decides whether or not interface problems exist. In this case, they probably will exist and he must reconcile them.

(12) The rear deck designer and the other component designers get together to discuss the designs of their several components attempting to identify ways in which slight modifications will result in overall compatibility. The information required here is a more detailed analysis of the design requirements as they impinge on the technical performance of each of the components and the whole automobile as a system,

(13) A decision has to be made. Have the interface problems been solved within permitted variation ? If the answer is “yes”, the rear deck designer goes on with his design within the agreed-upon limits,

(14) If the answer is “no”, the problem must be referred to the systems designer who performs trade-off studies to establish revised requirements for rear deck, suspension and other components. He may ask the designer working on the suspension system to modify his design to adapt to the weight of an aluminum rear deck,

(15) At this point, either a major redesign or minor one is initiated. If a major design modification is needed, the automotive systems designer must prepare new preliminary designs for the entire automobile with the performance requirements for each component re-established. On the other hand, if the system modification is relatively minor, the several component designers go back to their drawing boards and work within the newly established variances,

(5) through **(8)** After having reviewed the new interface requirements, the rear deck designer decides that his design is compatible with the other components,

(9) The rear deck designer then analyzes all of his alternative designs—all of which use

alum in urn—with respect to performance, cost, production feasibility, short-term and long-term materials availability, and all other criteria that will ultimately guide a final decision. The information requirements at this point in the analysis are substantial. They include all design requirements and economic considerations guiding the design, They include all information on producibility, labor skills, the availability and use of existing facilities and labor, and energy requirements. They also include forecasts of materials supply and competitive uses for those materials. Such information includes data on production capacities, stockpile levels (where applicable), export-imports, the various forms in which the material will be available, and the delivery time or lead time required.

At this point, the designer will also need information on risks, He will need to assess the legal liability and other risks that he, or his company, might undertake if this design is accepted. Further information related to national policy considerations is needed. Data on the environmental, health, or energy aspects of processing aluminum into a finished rear deck would be applicable,

After all of this information is pulled together and assessed, the designer recognizes a potential limitation on the availability of aluminum. The rear deck represents a substantial increase in the pounds of aluminum per automobile. Forecasts of the availability of aluminum for the automobile industry indicate only marginal availability, which could force a price increase.

(10) When the designer asks, is there a satisfactory "best" design with a substitute?, he may have to answer "no". The supply of aluminum is not assured—in which case, the search for a substitute starts again at Box No. 3. If, on the other hand, an arrangement can be made with an aluminum supplier to assure supplies, the answer may be "yes", In this case, the rear deck designer proceeds with the final selection of the best design and prepares detailed drawings and specifications as indicated in Box No. 11.

b. Coating for an Appliance Part

(1) The need for a substitute is recognized. Rule **66** has been established by the City of Los Angeles and other cities forbidding the use of certain solvents which, in dilute concentrations in air, form eye irritants by photosynthesis.

(2) The component designer specifies the characteristics of a desired coating, its costs, the quantity requirements, and other performance requirements.

(3) The component designer then searches for information that will guide him in the identification of candidate substitute coatings. In this search, he specifies the performance criteria that will be used. He would like to identify coating systems that avoid use of solvents that have been banned. From his information on coating systems, he can identify four alternatives:

(a) Replace the banned solvents with a combination of new solvents that work with existing coating compositions;

(b) Replace the solvent coating by a powder coating;

(c) Replace the solvent coating with a water-dispersed coating system; or

(d) Replace the solvent coating with a radiation-cured coating, wherein the liquid portion becomes a part of the coating film.

(4) It is obvious that there are several viable substitutes available,

(5) The component designer seeks additional information on coating systems performance and costs. Also, he may prepare a number of alternative formulations. He may test one or more of his alternatives in the laboratory to substantiate the data that he obtained from his information system.

(6) The component designer then analyzes in a preliminary way the alternative coating systems, based on information available on design requirements and economics.

(7) The component designer next examines alternative coatings with respect to interface requirements —in this case, incompatibility y with adjacent materials.

(8) The question then has to be asked, do interface problems exist, and if the answer is "no", the component designer can analyze his various coating systems with respect to performance, cost, production feasibility, short-run and long-term material availability. In this analysis, he requires a substantial amount of information. It includes design requirements, economic considerations, production considerations, materials supply/availability considerations, risk considerations and even national policy.

(10) He then asks the question, is there a satisfactory "best" design with the substitute coating system included? From the many types of substitution formulations in each of the four options, he undoubtedly can find a satisfactory coating.

2. National Policymakers

Figure A–z presents a DELTA chart showing the information requirements for substitution analysis by National Policy makers. Information requirements for National Policy makers can best be explained by using two current examples of substitution issues at the national level, with numbered paragraphs referring to the numbered symbols in figure A-2.

a. Bauxite

(1) Bauxite is the principal source of alumina from which aluminum metal is produced. In recent years, Jamaica, Surinam, Guyana, and other bauxite-producing countries have met to discuss pricing and other actions. The purpose of these discussions has been to increase revenues from bauxite extraction and sale. Some officials have taken unilateral action to increase the effective price of bauxite being shipped from their countries. Others are pressuring the multi-national aluminum companies to build new alumina and aluminum facilities within their borders to increase the "value added" by manufacture.

All of these actions point to less control by the United States over future supplies and prices of bauxite and other materials produced from it. A need to assess the possibility of substitutes for bauxite is recognized,

(2) The first step following the recognition is to identify all of the end uses of bauxite and develop historical data and projections on the amounts of bauxite required in each end use, About 90 percent of the bauxite consumed in the United States is converted to alumina and about 10 percent is converted directly into abrasives, aluminum chemicals and refractories, Of the alumina produced, about 94 percent is converted directly to aluminum metal and about 6 percent is used in making high-purity abrasives, aluminum chemicals, and refractories.

The end uses for aluminum metal cover a broad range of consumer and industrial goods—autos and other transportation equipment, electrical equipment, construction—to name just a few,

End-use patterns are the province of market research staffs of companies at every level in the materials systems. Valid data are difficult to obtain. Forecasts vary, End-use patterns shift from year to year, depending upon advantages and disadvantages of alternative materials as perceived by users. It is necessary, therefore, to obtain end-use data on all materials used in competition with aluminum, alumina, abrasives, aluminum chemicals, and refractories.

At the raw material level, there is no material in commercial competition with bauxite. R&D is currently under way on developing processes for recovering alumina from alunite and other high alumina clays, Capital and process-cost estimates for such processes are now unreliable,

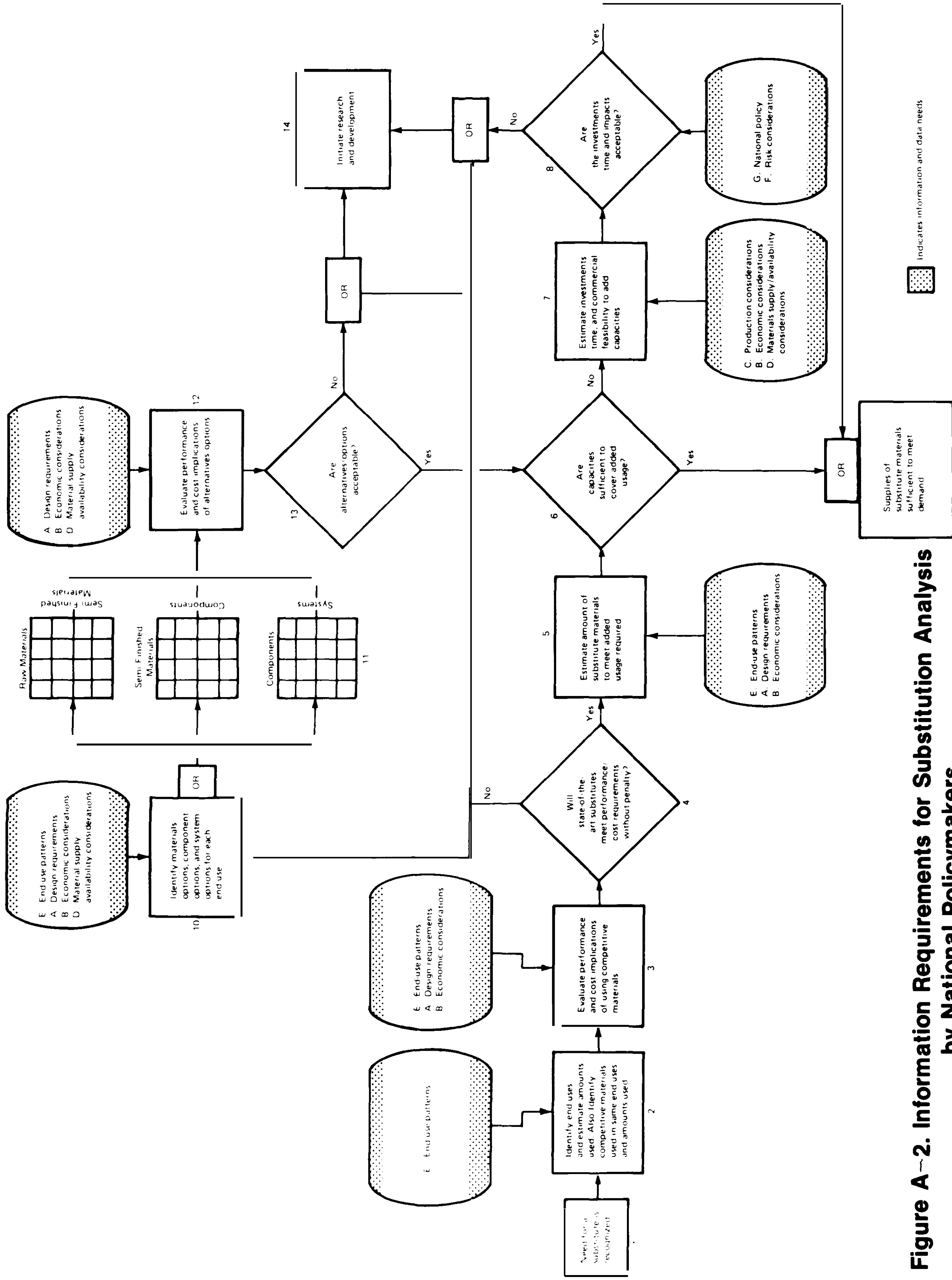


Figure A–2. Information Requirements for Substitution Analysis by National Policymakers

There are, however, a host of materials currently used in competition with materials produced from bauxite—aluminum metal, aluminum chemicals, abrasives, and refractories. For example, aluminum metal, in most end uses, is in direct competition with one or more of the following-copper, steel, stainless steel, tin plate, magnesium, lead, wood, plastics, rock wool, and fiberglass. The investigator needs to estimate the amounts of competitive materials currently consumed in each use. Little, if any, information and data are available to make such estimates directly. Some information and data are available—but scattered in the minds and files of thousands of people producing and using materials. Furthermore, even if historical data at this level were readily available, the changing technology and changing economics render routine forecasts of future end-use patterns to be of little or no value. This is not to say that useful estimates cannot be made.

(3) In order to estimate the additional amounts of competitive materials that might be used without performance or cost penalties, it is necessary not only to know the amounts now used, but also to have information and data on the design requirements for each use, the properties of competitive materials that might satisfy these design requirements, and the economic considerations that will help shape design. This—in essence—requires knowledge of the design choices made by each of the designers in each of the end uses, where competitive materials were used instead of aluminum and where aluminum was used. Again this information is scattered in the minds and files of designers. Much of the information on design criteria and reasons for choice are considered to be proprietary.

Knowledgeable people in a host of industries can make reasonable estimates of specific conditions of competition between aluminum and competitive materials in specific applications—for example, for storm windows, lawn furniture, automobile engine blocks, automobile body components, etc.

(4) The investigator next asks the question, will state-of-the-art substitutes meet performance and cost requirements without penalty? If the answer is “no”, other options must be sought. This raises a key issue in national policy determination. If substitution is viewed in a simplistic way—one material for another—there is no present commercial substitute for bauxite. If a national emergency were to occur, literally thousands of steps would be taken to find substitutes for aluminum metal, aluminum chemicals, bauxite in abrasives and bauxite in refractories, The logic path following a “no” answer will be discussed later.

(5) If the answer is “yes”, the investigator will then estimate the amount of materials that might be used which are already in competition with bauxite and materials produced from bauxite. In the case of substitutes for aluminum, the estimates will include additional quantities for copper, steel, stainless steel, tin plate, magnesium, lead, wood, plastics, rock wool, fiberglass, abrasives and refractories, Information needed in order to make these estimates includes:

(a) The design requirements for all products made from bauxite and its derivatives, end-use patterns of bauxite and all competitive materials; and

(b) The economic considerations surrounding all of these.

This kind of information is not available in intimate detail; only broad estimates of the amounts of substitute materials can be made. Furthermore, there are competitive pressures among companies which limit data availability. No one company or industry has a significant fraction of the data that would be needed by an analyst not familiar with the technology and the wide spectrum of industries involved. Even if valid historical data were available, forecasts of future usage depend in part upon the acceptance of the substitutes by industrial and home consumers.

(6) If additional quantities of state-of-the-art substitutes can be used, the question must be asked: are capacities sufficient to cover the added usage? if the answer is "yes", the substitution analysis is complete and Box 9 indicates that supplies of substitute materials are sufficient to meet the demand. If the answer is ''no', an additional investigation is needed,

(7) If capacities are not sufficient, it is possible to make additional investments in facilities for producing the substitute materials, This step involves detailed estimates of the investments required, the time needed and the commercial feasibility y of adding capacities of all of the various state-of-the-art materials for which there is insufficient capacity, This kind of information is not readily available. Estimates, however, can be made, depending on the likely location, availability and costs of raw materials, transportation charges for raw materials, availability and costs of energy, etc.

(8) The investigator then asks the question: are the potential investments in dollars and time acceptable, and are the various impacts also acceptable for adding capacities of these state-of-the-art materials? If the answer is ''no' new options must be sought and that will be discussed in the next paragraph. If the answer is "yes", the supplies of substitute materials can be made available within an acceptable time to meet the demand. The policy analysis would be completed.

(10) If state-of-the-art substitutes are not available, the impacts of building new capacity are unacceptable and it is necessary to identify other substitution possibilities, This requires searching for materials options, components options, and systems options for each end use, Here again, information is needed on end-use patterns, design requirements, economic considerations regarding each of the end uses, and materials supply and availability. At the raw material level, there is no state-of-the-art substitute for bauxite, At the component level, there are a wide variety of substitute materials that approach the performance and cost requirements of the various end uses, but with varying degrees of penalty.

(11) The detailed information on materials options, component options, and systems options for each end use is made explicit in any array so that the relationships among all alternatives/options can be assessed.

(12) It is necessary for the investigator now to evaluate the performance and cost implications of all of the alternatives/options. Although figure A-2 indicates that design requirements, economic considerations and materials supply/availability considerations are taken into account, it is exceedingly difficult to get data at a sufficiently disaggregate level to make estimates of all of the options. Useful estimates however can be made.

(13) After the information has been assembled and evaluated, the question must be asked: are the available alternatives/options acceptable? —if the answer is "no", the investigator must return to Box 10 to identify additional materials options, component options, systems options, or he must go on to Box 14, initiate research and development. If, on the other hand, the answer is "yes", the investigator asks the question: are the capacities of the substitute materials sufficient to cover the added usage?—and the remainder of the analysis proceeds as indicated before.

b. Coal for Petroleum Products

(1) The unilateral action by OPEC members has increased the United States negative balance of payments in energy by over **$20** billion per year. A need for a substitute for foreign petroleum has been recognized.

(2) The first step undertaken by the investigator is to identify end uses of petroleum products and to estimate the amounts used in each of the end uses. It is also necessary to identify the competitive materials that are used in the same end uses and the various amounts used. The primary material used in competition with foreign petroleum is domestic petroleum. Further, petroleum from all sources supplies virtually all of the energy

required for automotive and other transportation devices In other uses, such as space heating, process steam and central power station production of electric power, petroleum products are in competition with coal, natural gas, and uranium. Petroleum and natural gas provide feedstock for making plastics and synthetic fibers.

(3) Based on the end-use patterns and the design requirements for energy in each of the end uses, and the economic considerations, it is necessary to evaluate the performance and cost implications of using domestic coal, uranium, and natural gas. It is here that the current policy considerations of energy bog down. There is no agreement on the performance and cost implications of using alternative energy systems for the next 20 to 30 years. Businessmen, however, investing stockholders' money must make decisions today that will be considered prudent throughout the lifetime of the investment.

The options for substituting coal or other materials for feedstocks must be considered in R&D.

(4) At this point, the investigator needs to ask the question: will the state-of-the-art substitute coal meet the performance and cost requirements without penalty? Depending upon the projection of cost and performance, the answer is "yes", there is plenty of coal and the performance and cost requirements involve inconsequential penalties, Or the answer is "no", and we must rely on solar and other forms of energy.

(5) If the answer is "yes", it is necessary to estimate the amount of substitute materials that will meet the added usage requirements. The capacity in the United States for mining coal is limited. The amount of coal being mined now is not much more than was mined 20 years ago. The reserves of uranium are limited.

(6) The investigator must then ask the question: are capacities sufficent to cover the added usage?—and the answer is obviously "no."

(7) The investigator needs then to estimate the investments in time and commercial feasibility of adding coal and uranium mining capacity sufficient to meet energy demands. These investments include not only design and development of mines, but also design and construction of facilities to burn coal and handle it in an environmentally acceptable way. They also of course include design and development of nuclear facilities that are environmentally acceptable.

(8) The investigator now asks the question: are the investments of time and impacts acceptable? Most would agree that coal and uranium cannot, in the near term, replace all of the energy needs now satisfied by imported oil.

(10) The next step is to identify materials options and other systems options for each of the end uses of petroleum. This involves options relative to increasing the supplies of natural gas from domestic sources. It includes solar, geothermal, breeder and fusion energy, Some of these options can be installed today at a rather substantial penalty. All options, however, have to be evaluated in light of their effectiveness, cost, and penalties over a **20-** or 25-year period.

(11) The relationships among all of the options from raw materials through alternative systems are made explicit.

(12) The investigator next evaluates the performance and cost implications of all of the alternatives/options.

(13) Based on the above evaluation, the investigator asks the question: are any of the alternatives/options acceptable ?—if the answer is "no", there is the need for research and development. And, if the answer is "yes", the next step is to examine the question: are capacities of those substitute materials sufficient to cover the added usage ?—and the analysis goes on,

D. INFORMATION REQUIREMENTS FOR SUBSTITUTION ANALYSIS

The type, amount, and specificity of information required by the two identified potential user groups—the Materials Users and the National Policy makers—for making substitution analyses varies over a wide range.

Complexity of the substitution selection process occurs at all levels. For example, a designer seeking a substitute material may consciously recognize that only one or two factors are important in his selection process. In choosing a substitute for stainless steel tubing in a chemical processing plant, he may consider only high-temperature corrosion as being the important requirement for the material. But, obviously, he must also take into account such other requirements as the cost of the material, its availability, whether it can be welded, and so on. Although many of these requirements appear to be quite obvious, they would require precise definition for any information system to assist the designer in his selection. Likewise, a National Policy maker must consider a multitude of technical, economic and political factors in making decisions involving materials substitution, Some of these also might be obvious, such as assurance that an unexpected war would not be initiated because of a substitution decision (it has been suggested that the lack of substitutes for chromium may have played a key role in causing Germany to enter WW 11), However, other factors such as the extent of disruption to the economy or to a particular class of workers that might occur by employing the substitute are perhaps more difficult to ascertain. Table A–5 offers a listing of information/data identified in this study as required by the two user groups in making substitution decisions. These have been categorized into seven broad classes, coinciding with those shown in figures A-1 and A-2.

It is possible to compare both user groups with their particular information needs, and to consider whether such categories of information (and data) can appropriately be included in responsive materials information systems. In many instances, it is recognized that such information must come from outside the "system", that is, be provided as "a priori" to an inquiry to the "system". In table A-5, the notation "I" has been used for information items required, and possible to be included in the system; "O" indicates those items essential to decisions, but probably obtained from outside sources; and "N" designates those items generally not required by the particular user group.

Some of the information items in table A-5 are self-explanatory; however, a few comments are in order to explain some that aren't quite so obvious.

Under the category "Design Requirements", the first listed item—"Customer Acceptance"—is identified as the starting consideration by Materials Users in essentially all substitution analyses. If a judgment is made that the market is not likely to accept the substitute, all further consideration generally is terminated. Although this item is of high importance for the Materials-User group, such information either is so specific to the individual substitution or is so judgmental. the information most likely would not be found within the formalized information system. And as a result it would have to be obtained

[4] As used here data are specific facts, usually numerical, quantitative, measurable. Examples are the properties of materials, the populations of cities, the dimensions of land masses. Being primarily numerical, data are fairly readily stored and manipulated in automated systems, Information is the broader class of knowledge. encompassing judgments, experience, art. behavioral (considerations, etc. Examples include directions on how to do something, expressions of policy. social considerations, esthetics, alternatives. Because it is expressed in words, the broader aspects of ' in format ion' are more difficult to mechanize. Data are a category of information. These cons iderat ions are significant when one contemplates the implementation of an automated information system,

Table A-5.—Information Requirements for Substitution Analysis

	Materials Users	National Policy-makers
A. DESIGN REQUIREMENTS		
Customer Acceptance		
Esthetics	0	N
Personal Bias	0	N
Market Acceptability	0	N
Performance Criteria	0	0
Materials Performance		
Mechanical Properties	I	N
Chemical Properties	I	N
Physical Properties	I	N
Fabricability	I	N
Machinability	I	N
Toxicity	I	N
Ease of Joining	I	N
Corrosion, Oxidation, and Fire Resistance	I	N
Compliance with Specifications and Codes		N
Protection Against Misuse	0	N
Vandalism Protection	0	N
Reuse/Recyclability /Disposal	I - o	I-o
Compliance with Specifications and Codes	I-O	I-O
Reliability and Maintainability	I - o	I-O
B. ECONOMIC CONSIDERATIONS		
Material Cost	I	I
Cost/Price Stability	I	I
Transportation Coats	1--0	10
Marketing Costs (to use substitute)	0	N
Production Costs	0	I-o
Investment Required to Incorporate		I-o
Life-Cycle Costs	0	0
Tariffs and Taxes	I-O	I
C. PRODUCTION CONSIDERATIONS		
Availability of Fabrication Facilities	I-o	I
Availability of Labor (specific skills)	I-o	I
Production Rates Achievable	0	I
Time Required to Incorporate Substitute	0	I - o
Use of Existing Facilities and Labor	I	I - o
Energy Requirements	I-o	I
Inspectability	0	N
D. MATERIALS SUPPLY/AVAILABILITY CONSIDERATIONS		
Supply - Present and Future, Current and Potential		
Resources/Reserves	I-O	I
Stockpile Level	t-o	I
Imports/Exports	I-o	I
Defense Allocation	I-o	I
Inventories	I-o	I
Supply Assurance (including trade agreement)	0	I - o
Identity and Location of Supplies	I	I
Forms of Materials Available	I	I
Delivery Time (Lead Time)	I-o	I
E. END-USE PATTERNS - Historical and Projected	I-o	I
F. RISK CONSIDERATIONS		
Legal Liability	0	N
Technical/Professional	0	N
Business		
Political	0	0
G. NATIONAL POLICY CONSIDERATIONS		
Regulatory Agency Compliance (Federal, State, local)		
Environmental	I-o	I
Health/Safety	I-o	
Energy	I-o	;
Economic Impacts of Using Substitutes	I-- O-N	I
Political Impacts of Using Substitutes	O-N	o

I = required and possible in system (hard data, either technical or economic).

O = required but obtained outside system

N = generally not required by user group.

from outside the system. Further, it is interesting to note that, although this item is important to Materials User decisions, it is considered to be of little significance in substitution decisions made by National Policy makers. It should be noted that many differences, such as those mentioned above were found in the information required for the two user groups.

The listed items regarding "Materials Performance" obviously are required by the Materials Users, but evidence indicates they are not required by the National Policy makers. And, although these items are required by the Materials Users, the degree of specificity of each item that is required will vary significantly from one substitution analysis to another. Also, in some analyses the requirements are easily stated (including the range over which the performance can vary and still maintain acceptability). whereas in others the requirements may not even be known with sufficient specificity to allow the substitution decisionmaker to ask the information system the necessary questions. As an example, a recent study involved the assessment of plutonium as a power source for an implantable heart pacemaker, the motivation being significantly increased life and reliability. In addition to consideration of some of the performance requirements listed, it became apparent in the assessment that the plutonium source required unique packaging that included its being fire resistant and bullet proof. Although these were criteria which were not considered in the original analysis, they became of critical importance when the consequences of the plutonium source being in a fire (during cremation, if not removed first) or accidentally or intentionally being struck by a bullet, were recognized.

The item of "Compliance with Specifications and Codes" in the listing under "Materials Performance" refers to compliance of the material (e.g., ASTM specifications)—these same words are listed later under "Design Requirements" where they refer to compliance of the system which is made from the materials, Although this information is considered required by the Materials User, it has been judged as not being required by the National Policy makers. It is believed that specifications and codes would not be deterrents to policy decisions, for, if they were, the Policy maker would simply see that the specifications and codes were changed.

The item "Protection Against Misuse" is best explained by example. Polyethylene bags proved to be a highly successful substitute for paper ones (e.g., for dry cleaning); however, when they began being used in baby beds and several deaths from suffocation resulted, a large campaign was conducted to educate consumers not to misuse the product.

"Economic Considerations" are, of course, required by both user groups, but again. the level of detail required would vary for the two groups and for each analysis. The item of "Marketing Costs" refers to the cost of convincing consumers the substitute will satisfy their needs. Consider, for example, the difficulty the automobile manufacturers have had in convincing the public that fiberglass automobiles are as safe as metal ones. National Policy makers most likely would not be concerned with market factors of this type.

The item identified as "Investment Required to Incorporate" relates to how much capital would be required to develop the needed technology for the substitute and then to incorporate it into the economy. An example is the previously mentioned proposed substitution of alunite for bauxite as an ore for aluminum, Although the essential technology exists for this substitution, large investments would be required to make it a reality and knowledge of the magnitude of these commitments would be required by the various decisionmakers in their assessment of whether or not to proceed with this substitution.

Certain items relating to "Production Considerations" are required by both user groups. If the facilities required by the substitute are not available within a producing facility, the substitution may not be acceptable to the individual company, On the national policy level, the availability of facilities within the country may determine the acceptability y of the substitute. The same considerations also apply to the availability of labor with specific skills, For example, widespread substitution of coal by gas and oil during the recent past may not have occurred if the magnitude of the plight of the coal miners could have been predicted. On a Materials-User level, it is unlikely that a company would change from producing a cast part to using a welded one, if they already had the skilled labor for making castings and could foresee a problem in acquiring the needed welders.

Recent difficulties in obtaining energy have vividly pointed out the necessity of including this factor in any substitute selection process. This not only relates to the amount of energy required but also to the type. The gas shortages in various parts of the country have caused changes to other forms of energy, and this in turn has caused numerous substitutions to be made in products or processes.

A recent experience can be used as an example of the necessity for "Inspectability". A change in material, coupled with a change in heat treatment, was recently recommended for use in a high-volume automotive part. The part, because of its function, required rather complete inspection for internal defects-which could only be accomplished reliably by ultrasonic techniques. Although the recommended substitution met essentially all other requirements, because of its structure, ultrasonic waves would not pass through it. Therefore, the substitute was judged unacceptable.

Regarding "Materials Supply/Availability", most of the information identified as being required for substitution analyses would most likely be included in a national materials system. An exception might be "Supply Assurance", particularly at the Materials User level, This is because many of the factors which influence the assurance of supplies are interpersonal relationships that might exist between the supplier and the consumer which, although very significant, certainly could not be included in a new integrated materials information system.

It has been judged that a system must include “Identification and Location of Supplies”. This suggests an index of all materials producers and supplies. Also included should be their supply and production capacities. The “Forms of Materials Available” should, ideally, be keyed to the supplier in the system. “Delivery Time” data presently is tabulated by various groups within industry (e.g., Aerospace Industries Association) and Government (NAVSEA) and would constitute a key factor in the decisionmaking process regarding substitute selection.

As indicated in the DELTA charts, the starting point for considering substitution by national policy makers would be a determination of “End-Use Patterns”, current, historical, and future. Ideally, this would require information on all the products that are made from each material and the amounts of the materials consumed by each use. Such information often is proprietary and of limited availability.

Substitution decisionmaking is affected strongly by the amount of “Risk” that the various decision makers involved in the selection process are willing, or are forced, to accept. Essentially all substitution decisions have some degree of risk associated with them, but the intensity of the risk and the factors causing the risk vary significantly. Risk can be tied to the “Legal Liability” that is associated with the end use of the item, i.e., the consequences that can arise from failure, use or misuse of the item, For example, selection of a material for a critical airplane component would have high risk, whereas the choice of a paint for an office desk would have low risk.

Risk also may be described as being “Technical or Professional”, i.e, how the quality of the substitution selection decision reflects on the decisionmaker’s technical and/or professional reputation. If loss of one’s job is the “reward” for a wrong decision, that risk is high! And, this might occur to both the person selecting the desk paint and the one selecting the material for the critical aircraft part. Further classifications of risk are “Business” risk, which is associated with the effect of the substitution decision on profitability (e.g., the amount of money affected by how the substitution decision turns out) and “Political” risk, which is associated with the potential political ramifications of the decisions (e.g., how seriously will a substitution decision affect our relationship with another country—will it lead to war?).

Considerations of “National Policy”, such as compliance of the substitute with regulatory agencies’ policies, have become increasingly more important in recent times; and these agencies exist on all levels—Federal, State and local. For example, a technically acceptable substitute for mica for certain high-temperature insulating applications might be asbestos, but the environmental problems associated with the use of asbestos probably would cause it to be ruled out as a possible substitute material.

Although the National Policy maker will be concerned with the effects of the substitution on the economy, a Materials User’s attention to the effect on the national economy perhaps will vary from a similar concern to essentially none at all, depending on the size of his company, the amount of material involved in the substitution, and on his national responsibility. This also holds true for considerations of the “Political Impacts” of the substitution. Although this aspect might be of little concern to the Materials User, the specific choice of a substitute material could have a severe political impact. Consider, for example, the decision to find substitutes for Middle-East oil-e. g., the development of self-sufficiency and the encouragement to reduce consumption (a defined form of substitution) and the effect such a decision would have on OPEC countries.

Tables A-6 and A–7 restructure the listing of information requirements from table A–5, identifying separately the information needs of the two user groups; these are categories of information/data that can be included in an improved materials information system. These listings are not intended to be exhaustive and certain individual items could be disputed. However, the primary intent of the list is to provide an identification of the significant items required by materials users.

Table A-6.—Information Requirements for Substitution Analysis: Those Specifically Required by Materials Users are Underlined

A. DESIGN REQUIREMENTS

- Customer Acceptance
  - Esthetics
  - Personal Bias
  - Market Acceptability
- Performance Criteria
- Materials Performance
  - Mechanical Properties
  - Chemical Properties
  - Physical Properties
  - Fabricability
  - Machineability
  - Toxicity
  - Ease of Joining
  - Corrosion, Oxidation and Fire Resistance
  - Compliance with Specifications and Codes
- Protection Against Misuse
- Vandalism Protection
- Reuse/Recyclability/Disposal
- Compliance with Specifications and Codes
- Reliance and Maintainability

B. ECONOMIC CONSIDERATIONS

- Material Cost
- Cost/Price Stability
- Transportation Cost
- Marketing Costs (to use substitute)
- Production Costs"
- Investment Required to Incorporate
- Life-Cycle Costs
- Tariffs and Taxes

C. PRODUCTION CONSIDERATIONS

- Availability of Fabrication Facilities
- Availability of Labor (specific skills)
- Production Rates Achievable
- Time Required to Incorporate Substitute
- Use of Existing Facilities and Labor
- Energy Requirements
- Inspectability

D. MATERIALS SUPPLY/AVAILABILITY CONSIDERATIONS

- Supply—Present and Future, Current and Potential
  - Resources/Reserves
  - Stockpile Level
  - Imports/Exports
  - Defense Allocations
  - Inventories
- Supply Assurance (Including trade agreements)
- Identify and Location of Supplies
- Forms of Materials Available
- Delivery Time (Lead Time)

E. END-USE PATTERN-Historical and Projected

F. RISK CONSIDERATIONS

- Legal Liability
- Technical/Professional
- Business
- Political

G. NATIONAL POLICY CONSIDERATIONS

- Regulatory Agency Compliance (Federal, State, local)
- Environmental
- Health/Safety
- Energy
- Economic Impacts of Using Substitutes
- Political Impact of Using Substitutes

Table A–7.—Information Requirements for Substitution Analysis: Those Specifically Required by National Policymakers are Underlined

A. DESIGN REQUIREMENTS

- Customer Acceptance
  - Esthetics
  - Personal Bias
  - Market Acceptability
- Performance Criteria
- Materials Performance
  - Mechanical Properties
  - Chemical Properties
  - Physical Properties
  - Fabricability
  - Machinability
  - Toxicity
  - Ease of Joining
  - Corrosion, Oxidation, and Fire Resistance
  - Compliance with Specifications and Code
- Protection Against Misuse
- Vandalism Protection
- Reuse/Recyclability/Disposal
- Compliance with Specifications and Codes
- Reliability and Maintainability

B. ECONOMIC CONSIDERATIONS

- Material Cost
- Cost/Price Stability
- Transportation Cost
- Marketing Costs (to use substitute)
- Product ion Costs
- Investment Required to Incorporate
- Life-Cycle Costs
- Tariffs and Taxes

C. PRODUCTION CONSIDERATIONS

- Availability of Fabrication Facilities
- Availability of Labor (specific skills)
- Production Rates Achievable
- Time Required to Incorporate Substitute
- Use of Existing Facilities and Labor
- Energy Requirements

D. MATERIALS SUPPLY/AVAILABILITY CONSIDERATIONS

- Supply—Present and Future, Current and Potential
  - Resources/Reserves
  - Stockpile Level
  - Imports/Exports
  - Defense Allocation
  - Inventories
- Supply Assurance (Including Trade Agreement)
  - Identify and Location of Supplies
  - Forms of Materials Available
  - Delivery Time (Lead Time)

E. END-USE PATTERN&Historical and Projected

- Supply-Present and Future, Current and Potential
  - Resources/Reserves
  - Stockpile Level
  - Imports/Exports
  - Defense Allocation
  - Inventories
- Supply Assurance (Including Trade Agreement)
  - Identity and Location of Supplies
  - Forms of Materials Available
  - Delivery Time (Lead Time)

F. RISK CONSIDERATIONS

- Regulatory Agency Compliance (Federal, State, Local)
  - Environmental
  - Health/Safety
  - Energy
- Economic Impacts of Using Substitutes

Close examination of these tables establishes the most significant findings of this study, namely that the scope of substitution analysis is so broad that it calls on information covering virtually every aspect of the materials cycle. In effect, the information requirements for substitution studies are no different than they are for materials selection or, more generally, for overall materials policy analysis.

The implications of this are several. First, substitution analysis is hindered by the same deficiencies in the existing materials information system that impede policy analysis. The deficiencies with respect to policy makers' requirements (as developed above) appear to be worse than for materials users, but both are severe. Second, modifications to the existing system that are designed to improve its support for policy analysis will also make it more capable for substitution studies. In so far as this brief study can evaluate the additional costs and time needed to include the capability for substitution analysis in a generalized new integrated materials information system would be negligible.