A RATIONALE FOR THE OPTIMISATION BY COMPUTER METHODS OF THE EFFICIENT USE OF METALS AND MATERIALS

THESIS

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by

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SUMMARY

The aim of the research project was to gain a complete and accurate accounting of the needs and deficiencies of materials selection and design data, with particular attention given to the feasibility of a computerised materials selection system that would include application analysis, property data and screening techniques.

The project also investigates and integrates the three major aspects of materials resources, materials selection and materials recycling.

Consideration of the materials resource base suggests that, though our discovery potential has increased, geologic availability is the ultimate determinant and several metals may well become scarce at the same time, thus compounding the problem of substitution.

With around 2- to 20- million units of engineering materials data, the use of a computer is the only logical answer for scientific selection of materials. The system developed at Aston is used for data storage, mathematical computation and output. The system enables programs to be run in batch and interactive (on-line) mode. The program with modification can also handle such variables as quantity of mineral resources, energy cost of materials and depletion and utilisation rates of strategic materials.

The work also carries out an in-depth study of copper recycling in the U.K. and concludes that, somewhere in the

region of 2 million tonnes of copper is missing from the recycling cycle. It also sets out guidelines on product design and conservation policies from the recyclability point of view.

"And the science which knows to what end each thing must be done is the most authoritative of the sciences, and more authoritative than any ancillary science; and this end is the good of that thing, and in general the supreme good in the whole of nature."

ARISTOTLE

(Metaphysics, Book 1)

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CHAPTER 1

THE MATERIALS SYSTEM

1.1 INTRODUCTION

Materials come from the natural environment; primarily the earth's crust. They are processed to be used and discarded by mankind.

Materials systems fall into two broad categories: 1) The Open System, and 11) The Closed System.

An Open System has three stages; supply, use and disposal. Materials move from resources in the ground to the pool of available supply. This supply stage of the system consumes energy to extract materials and process them for use. Main sources of this energy are themselves materials, such fuels as coal, gas and oil. These fuels get consumed in the use stage of the system. Most materials at this point, except energy materials and some others which are dissipated remain in the use stage for varying lengths of time. For example, the average lifetime of a disposable can is a few weeks; most of the materials in an automobile are on the average, retired after ten years. Some materials such as concrete, iron or copper in a building, may remain in use for decades, or even centuries. The last stage is disposal, in which material if not re-used is disposed off in open dumps, landfills or the sea.

In the Closed System, recycling introduces a recovery stage. The recovery stage is a major factor and economies of energy and materials and an enhanced environment, will be the major contributions of this system in today's world. A schematic diagram of the Closed System is shown in Fig. 1.1.

Control of materials flow lies with human institutions: producers, consumers, technology and government. Consumption determines the rate at which materials flow through the system. Industrial output includes material goods and goods that are allocated to services, like, houses, schools, hospitals and banks. Demand for goods and services pulls at one end of the system, activating the producing industries which transform resources into materials and materials into goods and services at the other end. The economy is the clearing house for supply and demand between producers and consumers.

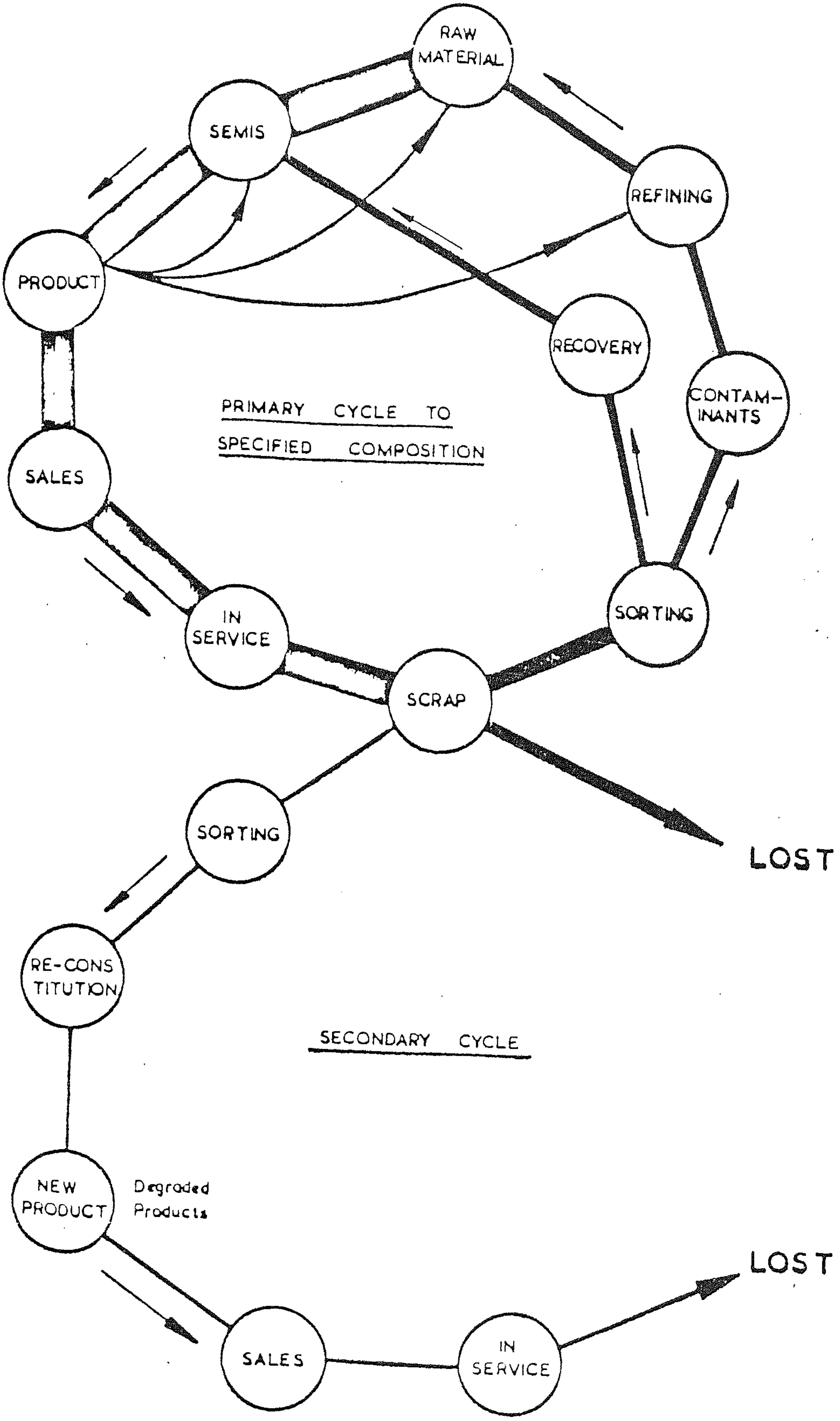
The last two parts of the system, technology and government, directly influence other parts of the system.

Technology consists of the knowledge to turn resources into materials and materials into goods. The development and sustenance of processes, power generation, new materials and new uses for familiar materials.

Through economic and fiscal policy, regulations and research, government affects the nature and the rate of flow

FIG. 1.1

RECYCLING OF METALS OR MATERIALS (SCHEMATIC DIAGRAM)



of materials.

Interaction between these parts compose a materials system; they function like a system and have to be treated by economists, scientists and policy-makers as a system.

1.2 METALS AND MATERIALS

This view of materials for engineering applications looks at metals, plastics, other non-metals, such as concrete and timber and evaluates likely developments from the resources availability and materials competitiveness points of view.

In recent years a slowing down in the rate of growth of steel demand relative to that of the economy in general was observed in a number of countries. Among the causes to which this phenomenon can be ascribed, competition between steel and other materials is mentioned as a factor which may have had an influence on the rate of growth of steel demand. During the last decade the quality of materials competing with steel has improved substantially and their fields of application have widened, in many cases to the detriment of steel.

Copper is another example where a substantial portion of the market has been captured by aluminium.

Among those modern materials which have achieved tonnage significance in the present day world must be included aluminium, magnesium, uranium, zirconium, titanium, nobium and beryllium.

The availability of any material is reflected inversely by its commercial price. The great attraction in the availability of concrete, for example, is that virtually all the materials are readily and commonly available on the surface of the earth. The product is very cheap, has good strength and rigidity and relatively low density.

Although plastics are capable of giving high strength/ weight ratios, they have not found sufficient favour as engineering materials. This is because minimum guaranteed properties for plastics are subject to numerous variables.

Another important aspect is that in many applications one of the requirements relates to the bulk of the material, while a secondary requirement relates to the surface in the particular environment in which it is called upon to work. Bulk is usually required to give strength and stiffness while surface is needed to give form and durability. These two basically separate needs lead one to clad materials or composites.

This avalanche of new materials and new applications makes the old approach of selecting materials from a limited number, based on past experience, outdated, and calls for a more comprehensive and scientific approach.

1.3 SCOPE OF PRESENT STUDY

In the past, the most dominant items in any materials system have been availability and cost. The situation has now changed and factors such as overall resource potential, substitution, energy cost and recyclability will tend to become increasingly important.

This study considers some of these factors and their interaction and brings together hitherto widely-scattered information on the rational use and selection of potentially valuable materials by analysing some of the existing selection systems and introduces two new systems developed at the University of Aston in Birmingham.

One aspect of recycling which has hitherto not been studied is the dissipative losses of metals which have been in service. A quantitative study has therefore been made of copper consumption in the UK over the last fifty years and compared with used scrap which is being recycled.

In conclusion guidelines are set as a basis for a rational materials policy with the emphasis being on 'materials effectiveness'.

CHAPTER 2

THE LIMITS TO GROWTH

2.1 MATERIAL GROWTH

The world's resources are not infinite but until recently there has never been any significant shortage of specific materials except in wartime. It has been pointed out that this situation cannot last forever. For example Brooks' says:[1]

"Many aspects of developed societies are approaching.... saturation, in the sense that things cannot go on growing much longer without reaching some fairly fundamental limits. This does not mean that growth will stop in the next decade, but only that a declining rate of growth is forseeable in the lifetime of many people now alive. In a society now accustomed .... to 300 years of growth, this is something quite new, and it will require considerable adjustment".

The most important limits to growth are those imposed by population, pollution, food production, energy and mineral resources.[2,3,4,5]

Unlike energy, which can be derived almost without limit from the Sun or from nuclear sources, our mineral resources are finite. Once they have been dissipated they cannot be recovered in any economically usable form.

In a modern industrialised system a large number of materials are of crucial importance. Some are so abundant that there need be no cause for long-term concern, e.g. aluminium, calcium, iron, magnesium, oxygen and silicon. But others such as copper, mercury and tin are not.

2.2 ROLE OF MATERIALS IN THE ECONOMY

The advance of our civilisation through its technology and industry is primarily dependent on materials. In recent years this advance has depended mainly upon solving materials problems. This is specially true in electronics, space technology, atomic energy, as well as in the planning, design and manufacture of systems, devices and machinery for transportation, housing and pollution control.

The first major study of a nation's raw materials prospects after World War II was undertaken by the Paley Commission in the United States and submitted as a five-volume study entitled 'Resources For Freedom' in 1952.[6] The Commission's evaluation of the future situation regarding minerals was derived from its forecasts of the probable domestic demand for the major minerals in the 1970s. Several major assumptions were made by the Commission's forecasters. It was assumed in 1950 that the next 20 to 30 years would see no major wars and be a period of sustained economic growth. Another assumption was that the anticipated demand for raw materials must be supplied at no increase in real cost in order to avoid crucial supply problems.

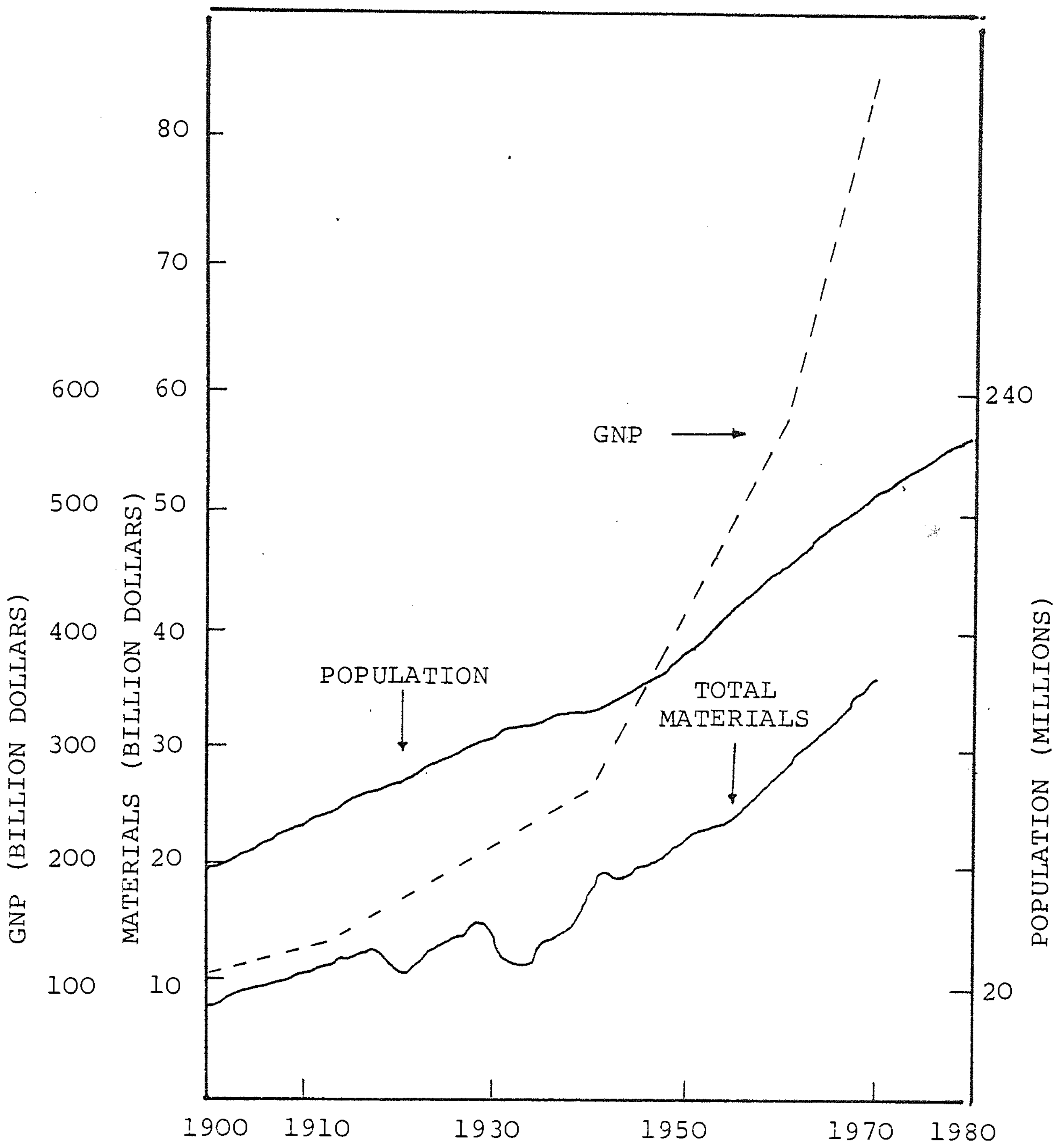
The Paley Commission's most important single recommendation was that there be a continuous attempt to anticipate the future, and adjust policy. Among the important conclusions the Commission presented was that the task of ensuring an adequate and dependable flow of materials at the lowest cost consistent with national security must be sustained cooperatively by Government and private citizens. Emerging situations demand continuous reevaluation. Each generation should reassess its requirements for raw materials and adequacy of the resource base.

The historical role of materials related to population growth and GNP in the United States is shown in Fig. 2.1. The figure shows that services like housing, education, banking etc. are growing at a faster rate than materials in the national economy. As the United States evolved from a basic agricultural and manufacturing economy in the early decades of this century to a more mature service-oriented economy in recent decades, requirements and supplies of materials kept pace with population growth despite wars and trade recessions. The faster rise of the GNP since 1940 reflects the increase in services and the material standards of life in the United States.

FIG. 2.1

RAW MATERIALS IN THE UNITED STATES ECONOMY

(1900 - 1969)



In Table 2.1, the per capita value and weight of raw materials required by the United States during 1972 are shown in juxtaposition because values and quantities of materials cannot be considered independently in planning a materials policy.

TABLE 2.1

WEIGHT		VALUE	
Material	kg	Material	$
SAND and GRAVEL	4000	PETROLEUM	85
STONE	3800	IRON and STEEL	24
PETROLEUM	3700	FOREST PRODUCTS	20
COAL	2000	NATURAL GAS	19
NATURAL GAS	2000	COAL	17
FOREST PRODUCTS	1000	FIBRES and OILS	15
IRON and STEEL	600	ALUMINIUM	12
CEMENT	400	COPPER	8
MISCELLANEOUS	2500	MISCELLANEOUS	40
TOTAL	20000	TOTAL	240

Thus in 1972, the United States required about 4 billion tonnes of new basic mineral and non-food organic materials valued at approximately $50 billion. Non-food organic materials like basic forest products, natural oils and fibres and rubber were included because they are primary in character. Plastics and ceramics were omitted because they are derived from the mineral and fuel segments already included. This total tonnage is equivalent to about 20000 kg per person, or in value terms this is equivalent to about $240 per person. On a weight basis it will be noted that non-metallic materials and mineral fuels predominate. When requirements are considered on a value basis, note how important the mineral fuels become, also that although the weight of metals required is relatively small, the per capita value is nearly one-quarter of the total value of all materials required.

2.3 THE MATERIALS USE STAGE

2.3.1 GROWTH STAGE

The economy is measured conventionally by the Gross National Product (GNP), an overall indicator that combines all the fiscal value factors that enter into trade. Goods and services are interacting components of growth.

It is anticipated that growth will continue with the current tendency toward an increase in the proportion of services over goods maintained. As working hours per week diminish, more time and money will be spent on recreation , communication and the pursuit of knowledge. The trend toward devoting more time to delivery and execution of services and relatively less to the production of goods will persist. What is uncertain is how long this trend toward an increasing service economy will be sustained. Since the turn of the century, the world economy expanded at more than double the rate of the use of materials, and the current trend should be to use less and less materials per unit of GNP. This has and will be the case for the United States and other advanced Western economies; but for some of the emergent developing countries like Brazil, China, the Middle Eastern and African countries, the exact opposite will hold. In the next 25 years, there will be a tendency toward the use of more materials per unit GNP and the production of goods will take priority over the execution of services.

2.3.2 USE STAGE

Consideration of the ultimate uses of materials is essential to the formulation of an integrated materials selection system and the implementation of a national materials policy.

Patterns of materials use are subject to continuous changes, depending on supply, demand, technology, price and fashion.

The forces that shaped the consumption pattern, outlined in Table 2.2, were rooted in the demands for materials resulting from engineering requirements and the needs of the market, arbitrated by price. These factors exclusively have governed materials selection in the past. In the future, materials usuage will be subject to the same forces, modified by concern about the environment, by the growing interest in recycling, by energy audits and by national policies concerning imports, exports and their strategic global implications.

In the last 25 years, prices of metals, building

TABLE 2.2

Production and growth of selected materials in the United States based on 5-year averages for 1948-52 and 1966-70

	Millions of short tons		GROWTH FACTOR
	1950	1970	
Steel	71.0	100.0	1.4
Aluminium, primary and secondary	1.3	4.2	3.2
Copper, secondary	1.39	2.04	1.5
Lead	1.17	1.33	1.1
Zinc	0.89	1.3	1.5
Cement	45.5	76.5	1.7
Rubber	1.36	2.67	2.0
Plastics	1.12	8.16	7.3
Paper and Board	29.0	55.5	1.9
Lumber	38.2	40.3	1.1
Coal	478.0	569.0	1.2
Crude Oil	365.0	598.0	1.6
Natural Gas, billion MCF	7.3	19.5	2.7
Population, million	150.0	200.0	1.3

materials and wood products have been remarkably stable. The prices of crude fuels have been variable, within the period 1950-70. Coal has declined 28% and oil 14% but natural gas has risen 64%.

Only in some instances do these price trends appear related to the growth of the market. As plastics rose by 730% the price fell to 45%. Against substantially stable prices, aluminium consumption grew by 320%. The use of natural gas almost tripled while the price more than doubled in dollars.

As noted elsewhere, the ability of modern technology to substitute one material for another softens the hardships of temporary or even permanent deficiencies in individual items. Such deficits can also be reduced by recycling and the rational and efficient use of the available supply.

2.4 TRENDS AND PROJECTIONS

Detailed studies of projected material usage have been made in the United States; the first such study since the Paley Commission report, was made in the early sixties by a group called Resources For the Future (RFF).[7] This study assumed that future development would follow the patterns and trends currently visible, including price structures. The second study was an Interim Report by the National Commission on Materials Policies (NCMP).[8] This report used materials projections to the year 2000 as furnished by the Departments of Interior, Commerce, Agriculture and the Atomic Energy Commission. The NCMP also sponsored a study by Professor W. Malenbaum on key materials for world and United States usage.[9] Another very exhaustive report is the United States Bureau of Mines publication entitled 'Mineral Facts and Problems'.[10]

The use or demand levels projected to the year 2000 in these studies are close to the medium-level projections of the RFF report for materials considered in common use.

The fact that there is a broad agreement among the projections lends credence to the judgments. As these projections are based on the assumption that present materials policies and trends will continue over the long term, they form a reasonable baseline for consideration of new policy.

Essential to such projections is the historical record of the production, consumption and inventory of a commodity with implicit population and economic growth factors.

These recent studies [10,11] suggest that certain key metals will become scarce before the year 2000, among them copper, lead, mercury, silver, tin and zinc. However these findings may be misleading for the reasons outlined in the following sections.

2.4.1 UNCERTAINTY OF RESERVE PROJECTION

Projections such as those mentioned above always ignore certain very important factors which are beyond projection. For example:

1. No allowance is made for new discoveries, e.g. new deposits, new techniques that make low grade ore economic, or improvements in transportation that make remote deposits accessible.

2. General mineral consumption throughout the world is doubling every 15-25 years.[12] Although the search for new deposits goes on, they are becoming increasingly leaner, less accessible and mineralogically more complex. Large tracts of land are theoretically sterilised, because they are closed to exploration, or any mineral-related activites. It is thought that approximately 70% of the United States is closed to exploration activity. Hence although some metals may become physically scarce only after 50-100 years,

the scarcity of cheap metals has already begun.

3. The occurrence of many key metals appears to be highly localised. Long before deposits are physically exhausted they may become politically inaccessible except on terms dictated by the producing country. Such geopolitical effects have been adequately discussed elsewhere[13,14,15]. and are not covered here.

As a result the many predictions of resource crises which have been based upon such projections have always been wrong as shown in Table 2.3.[6,16,17]

TABLE 2.3

	World Reserves (10^6 tonnes)			
	Cu	Pb	Sn	Zn
1950 estimate	181	36	5.1	45
Amount left by 1964	130	4	2.5	1
New 1964 estimate	140	29	5.1	64
Amount left by 1974	78	-3	2.9	13
New 1974 estimate	298	108	3.6	101

In other words, adequacy of supply in the past has depended not so much on existing reserves as on the discovery of new ones and on improvements in technology.

2.4.2 UNCERTAINTY OF DEMAND PROJECTION

Even the best projections of demand can be wrong. For example, in 1952, the Paley Commission[6] forecasted the demand for a number of key metals in the year 1975. Most of their forecasts for the rest of the world were low by a factor of two or more due largely to the unforseen growth in Western Europe and Japan:

TABLE 2.4

		$\frac{\text{Consumption in 1975}}{\text{Consumption in 1950}}$				
		Cu	Pb	Sn	Zn	Mean
USA	Forecast	1.5	1.6	1.2	1.4	1.4
	Actual	1.5	1.1	0.8	1.3	1.2
Rest of World	Forecast	1.5	1.8	1.5	1.6	1.6
	Actual	4.0	2.9	2.0	3.6	3.1
World	Forecast	1.5	1.7	1.3	1.5	1.5
	Actual	2.7	1.8	1.4	2.4	2.1

In any projection made today there is always the chance that similar misjudgments may occur again. Nevertheless two major factors seem to be beyond dispute:

1. The growth in population alone would cause demand for metals to increase at the same rate (about 2%-3%p.a.)... at least until the population stabilises, (which according to some authorities it might be some 50-100 years hence).

2. Aspirations for a higher standard of living are pushing consumption rates even higher. Standards are climbing rapidly in many developing countries, e.g. Brazil, China and the OPEC and CIPEC blocks.

Apart from the fact that exponential growth rates are not a reality (and this has been proved by the copper consumption in the U.K. remaining relatively constant for the past 10-13 years), it seems inevitable that on a world basis the rate of metal consumption will continue to rise over the next 25 years much as it has done over the last.

Evans[18] reports that metal-producing capacity would have to be expanded to meet the 1999 requirements by:

75% for tungsten
88% for iron and steel
100% for copper, tine and lead
150% for nickel and zinc
175% for magnesium
200% for aluminium
3000% for uranium

2.5 CONTINGENCY FORECASTING

The forecasting method used for predicting future mineral resource supply-demand relationships in each of the above studies is called contingency or technological forecasting. This technological label is the one most frequently applied to the method and indicates that much of the work is concerned with technological contingencies. However, in view of the method's potential for taking other influential variables or contingencies besides technology into consideration, the term technological can be misleading.

In brief, contingency forecasting consists of predicting and simulating alternate futures based on contingencies for technological, social, economic, environmental and other relevant influences. The contingencies and the assumptions for these are identified, quantified and analysed through "scenarios". The techniques used for the preparation of the scenarios may be described as eclectic or opportunistic since there is considerable flexibility for the use of judgment, experience and intuition in the forecasting procedure. The method may avoid many of the rigidities of projection by trend extrapolation, such as mechanical curve fitting, or the uncertainties of trend correlation or econometric procedures where influential variables cannot be precisely identified, quantified and forecast within a mathematical framework. Conversely, any or all of these techniques may be applied as a part of technological forecasting procedure. Hence, the use of the term eclectic for describing the method.

In an article on the troubles with forecasting, H. D. Doan,[19] former president of Dow Chemical, has established a philosophy which seems perfectly suited to forecasting in the metals and materials industry. This philosophy is summarised as follows:

"to distrust predictions based on established trends and to work hard identifying incipient trends that are only dimly perceived".

It is also important to feed in accurate anticipatory data early, so as to give longer time to plan and to react.

To arrive at realistic forecasts of production and growth, the following factors, sorted in accordance with Doan's philosophy, have to be taken into account.

Firstly, established trends:

1. Production of all metals has been growing faster than world population.
2. Where there was a change in the rate of growth, it was always to a higher level.
3. Where it was possible to establish relationships, they were invariably straight-line.
4. Toward a constantly increasing participation by governments in the ownership and affairs of metal resource industries.
5. An increasingly competitive situation with regard to the availability of professional employees as well as a continuing shortage of labour, leading to more automation.
6. An inevitable increase in taxes - at all government levels.

Secondly, incipient trends:

1. Towards an increasing recycle of used scrap.
2. In the possible re-treatment of certain flotation and gravity concentration tailings dumps, of metal-carrying slag dumps and of leach residue stockpiles.
3. Towards more efficient mining methods, improved recoveries

using new and improved processes.

4. The emergence of producer blocks, such as OPEC and CIPEC, with the aim of controlling prices by control of supply.

5. Public pressure to conserve resources primarily for national use.

6. An increasing substitution by lower-priced metals or materials. The duel between copper and aluminium - particularly for cables and conductors - has been studied for years.

A technique developed by Reisman et al[20] increases the sensitivity of the forecasting system, so that it may respond to sudden changes in the economy. Reisman's method combines forward looking objective forecasts obtained using regression analysis with backward looking objective forecasts obtained using adaptive smoothing to give a set of algorithms which when continuously combined with updated management information gives an accurate final forecast.

2.6 RESOURCE ECONOMICS

2.6.1 RESOURCES

Resources comprise:

1. Current reserves

2. All deposits that might become available given adequate prospecting and which, by various extrapolation techniques,

can be estimated.

3. Known and unknown deposits that cannot be mined profitably now but which - due to higher prices, better technology or improved transportation - may become available in the future.

Resources are thus the only realistic measure of the total available supply base.

2.6.2 RESERVES

As material supply systems are based on resources which can meet current needs, it is necessary to distinguish between resources that are potential and those that are economically usable. In the mineral industries, usable resources are referred to as reserves. Reserves are defined as "those resources whose extent is measured or estimated and which are currently extractable at a profit at current prices and existing technology".

To convert a resource into a reserve, the resource first must be located, identified, measured, or estimated as to extent; it then may or may not be judged to be economically extractable with current technology.

Minerals on the ocean floor illustrate the difference between resources and reserves. These minerals are resources which, through investment, technological development, political action and the price mechanism, may well become rich resources of metals that may be falling into short supply.

Potential reserves may be found in garbage dumps, incinerator ash, sewage sludge, industrial wastes or farm refuse. In a closed materials system, these reserves are potentially reusable.

2.6.3 RESERVES VS RESOURCES

Natural resources have traditionally formed the foundation for the economic development and growth of virtually all industrialised countries.

Malthusian and Ricardian logic are built on the foundation of the inevitable depletion of natural resources either due to an absolute limit to resource availability or to the non-homogeneity of the quality of the resources.

Conventional economics in a laissez-faire system reflect relative scarcity by the inevitable increases in the prices of resources due to increases in long-term costs of exploration and development. If one, therefore, accepted the above logic of inevitable resource depletion, one would expect an inexorably rapid increase in the prices of those resources which are threatened with eventual depletion. The anticipated price increases due to concerns of future scarcity have generally not materialised, but rather in minerals they are decreasing, perhaps reflecting diminishing scarcity.

It would seem that Malthusian and Ricardian style of resource scarcity fails to explain observed phenomena and one is therefore left to ponder why such originally plausible theories of "resource fixity" and "ultimate depletion" are not validated by the market mechanism.

The relationship of resources to reserves is illustrated schematically by a McKelvey[21] diagram shown in Fig. 2.2. It has axes showing the degree of certainty with which the ore is known to exist, and the ease and cost with which it can be mined and the metal extracted from it. Although these elements are quantified, it is evident that the quantities represent a judgment rather than an actual measurement.

An important factor in the analysis of the McKelvey diagram is the so-called fourth dimension. As shown, the scheme implies only one point in time. As time passes, mineral deposits move from the reader's right to left until they vanish along the left side of the reserves block. Through recycling and discovery other reserves may appear at right.

The flow of resources to reserves indicates the prospective near-term supply, but is not a reliable index of the rate of depletion or of the long-range supply.

Economists seek data on the effects of cost-price changes that affect the economic value of a deposit, associated with the vertical axis of Fig. 2.3. They are interested less in the techniques of discovery than in the costs of exploration because ultimately these costs determine whether the resources will flow into reserves. On the other hand, geologists and mining engineers are concerned with the feasibility of economic recovery and the degree of certainty of discovery. Fig. 2.3 shows the areas of concern for both these professions.

FIG. 2.2
McKELVEY DIAGRAM

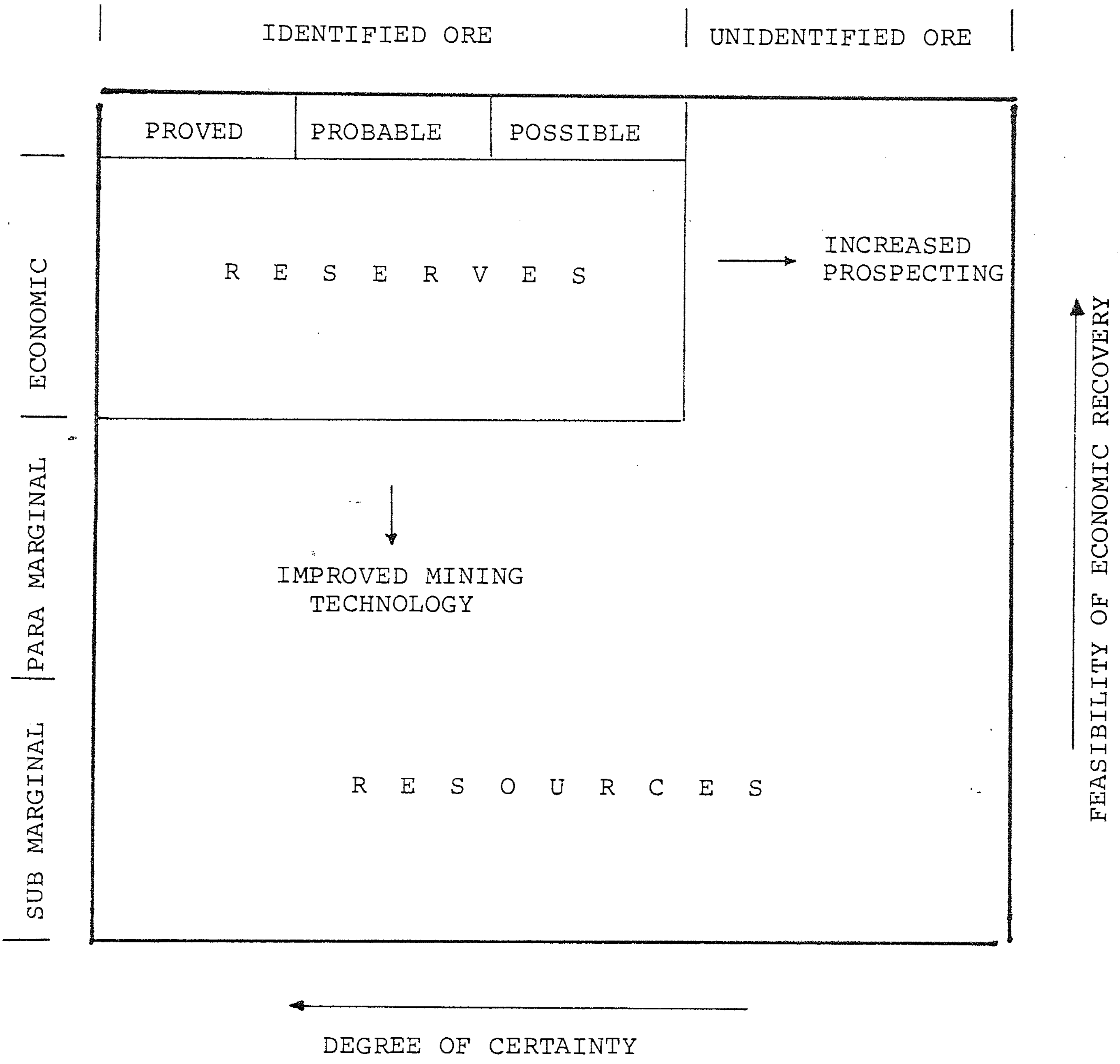
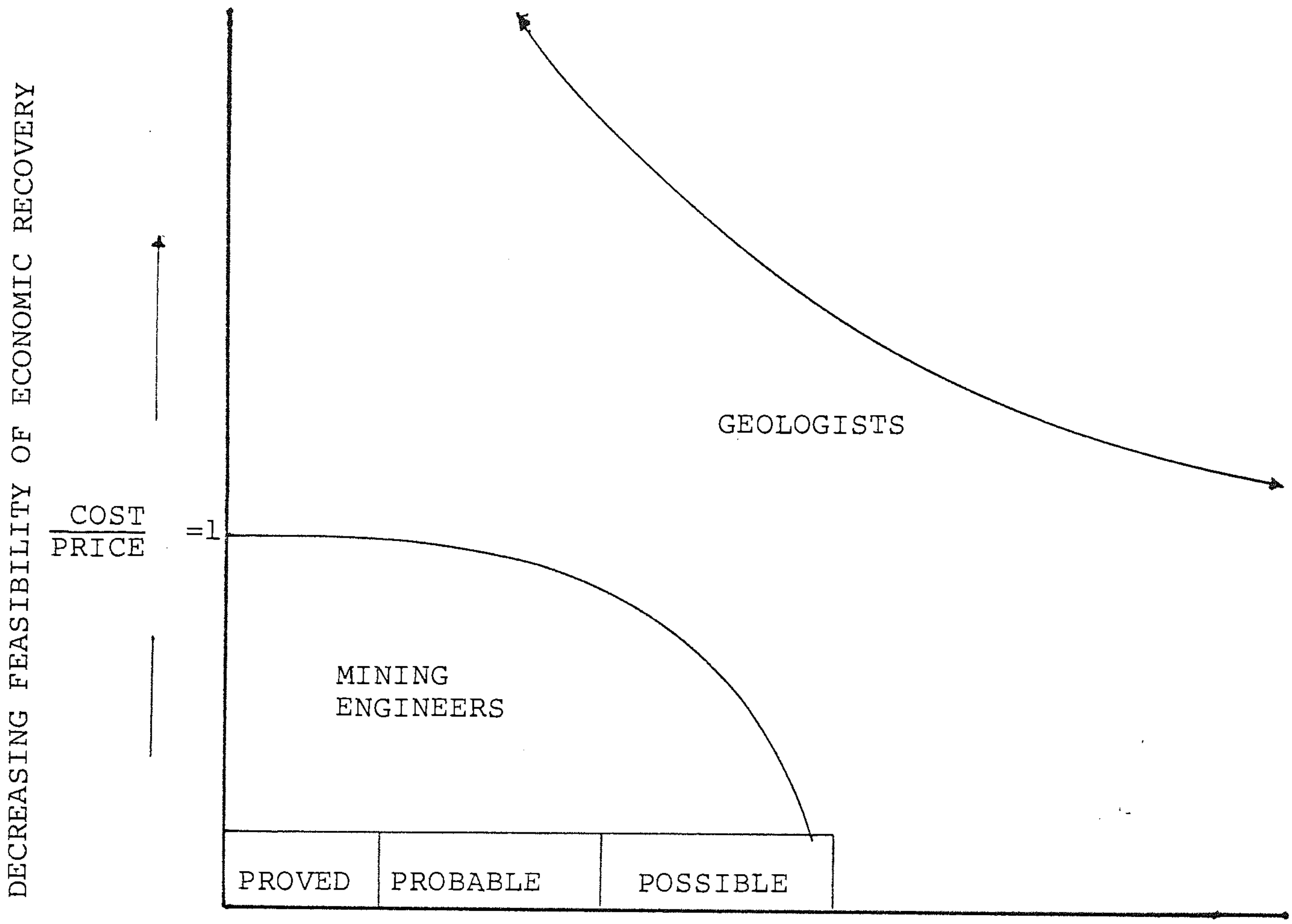


FIG. 2.3
MAJOR SPHERES OF CONCERN OF MINING
ENGINEERS AND GEOLOGISTS



DECREASING DEGREE OF CERTAINTY

2.6.4 A CRISIS IN RESOURCES?

There have been many predictions of resource crises in the past. The prediction that United States oil reserves would not last more than 15 years has prevailed for over 50 years.[22] The Paley Commission[6], reporting in 1950, foresaw exhaustion of the world's lead and zinc reserves by 1970, yet in that year reserves stood higher than ever before. At least two recent publications[10,11] quote data showing that reserves of many metals are inadequate to last until the end of the century. In general, as much metal will be required in the next 25 years as has been mined in the entire history of mankind; and that current reserves are inadequate to meet this demand for nearly all the metals except antimony, cobalt and platinum.

Nevertheless there is little doubt that, like the projections of the Paley Commission, these recent projections are unduly pessimistic. This is because they are calculated not from the resources of each metal but from the reserves, i.e. from known ore deposits which can be mined profitably at current prices using current technology. Unfortunately reserves bear little relationship to the true magnitude of the resource base; in fact the two are not even proportional.

A technique developed by Ashby[23] in which the quantity of metal available is plotted as a function of the minimum economically-minable grade and correlating this data with the energy cost of the metal, has shown that some estimates of the reserve life are much longer than other widely-quoted figures. Some examples, based on conservative extrapolation methods, are shown in Table 2.5.

TABLE 2.5

Metal	Conservative estimate of time required to consume half the resource base. Years.
Copper	>150
Lead	40 - 70
Mercury	50 - 80
Silver	40 - 80
Tin	50 - 120
Tungsten	50 - 80
Zinc	35 - 70

In general the resource base appears to be adequate to cover world demand up to 2000 AD and well beyond, even allowing for exponential growth. But around 2030 AD scarcities due to resource depletion may begin to appear.

Hence, there is a clear case for studying:

1. How nations should adjust to an era in which the supply of mineral resources may be dictated largely by the nations which possess them.

2. How materials might best be conserved, reducing the drain on the resource base, and helping to maintain supply and avoid extreme increases in price.

2.6.5 RENEWABLE RESOURCES

The renewable materials, timber and cellulose fibres, do not fit in with the model used to distinguish between resources, reserves and supply of minerals. They grow on land, are visible and need not be discovered. Reserves grow as photosynthesis combines the energy of the sun with carbon dioxide in the atmosphere to produce vegetative materials. With good management, this supply can be perpetuated indefinitely and even, with improved technology, dramatically increased.

In 1963, the United Nations Food and Agriculture Organisation (FAO) assessed the world forest area at 33% of the world's land area; about one-third of this was classified as being "in-use", i.e. exploited for the production of timber and other forest products[24].

United States requirements of basic forestry products are projected to increase from 0.33 billion cu.m. in 1970 to approximately double this figure by the year 2000 AD. At the same time, fibrous material consumed in the manufacture of paper and board, including wood pulp, wastepaper and other materials, is projected to increase from around 50 million tonnes in 1970 to more than 150 million tonnes annually by the year 2000.[25]

To attempt an analogy between minerals and timber, the resource would be the land capable of growing timber; reserves would be the inventory of timber on land available for commercial production; and supply would be the timber crop that can be economically harvested from the land each year.

Like other natural resources, timber resources experience a difference between economic and physical supplies in response to changing prices. A price increase expands the economic supply by raising previously submarginal inventories into a supermarginal class.

A major difference between mineral and timber resources is in the renewability of timber and the influence of expected prices upon future supplies. Higher prices economically justify the intense forest management which produces more and higher quality timber for future markets and encourages developing timber of increased growth rates.

Intensified forest management offers a major potential for increasing timber supplies in the future and for maintaining an acceptable forest environment.

2.7 ALTERNATIVE RESOURCES

The increasing price of petroleum and natural gas and the growing concern over their continued availability, have stimulated much interest in alternative feedstock materials for plastics.

Not all plastics now in use are based on petroleum or natural gas feedstock. In the United States, the most notable exceptions are nylon 11 and the vulcanised-fibre materials.

Nylon 11 is made from castor oil - a totally renewable source, while vulcanised fibre is an all-cellulose polymer made from wood pulp.

2.7.1 ALTERNATIVE FEEDSTOCKS

Plastics can be derived from coal; indeed, many were first developed from coal as a feedstock material. It would be possible to revert to this feedstock source relatively easily because the conversion processes are already known.

More important, while the supply of coal may be adequate for quite some time, coal is not a renewable source and would, some day, be in short supply and more costly. Also to be taken into account would be the increasing costs involved in restoring ecological damage resulting from mining operations.

Feedstocks other than petroleum - particularly those that are renewable - are receiving considerable research attention. Most work involves wood and agricultural oils.

Deriving chemicals from wood by methods such as pyrolysis and distillation is based on old technology. These methods were used widely until the more convenient fossil materials - coal, oil and natural gas - became abundantly available.

Current economics still favour petroleum and natural gas by a large margin, but since these are finite resources, wood or some other renewable material may eventually be our principal source of carbon for organic materials. Besides being the most abundant renewable source, wood also offers an advantage over annual vegetation crops in that it is "stored" in the tree for many years until it is needed.

Also trees have a high solar radiation capturing efficiency. A tiny 0.006% of the flux of inbound solar energy is captured on the earth. Trees are a significant factor in capturing that amount for powering the natural cycle. An intensively managed forest may easily produce 3 to 4 tonnes of wood per acre per year.

About 92% of the polymers produced in the United States are conceptually derivable from wood, according to Dr. I. Goldstein of the School of Forest Resources, N. Carolina State University.[26] In terms of total requirements, this would amount to about 60 million tonnes of lignocellulose per year. Ethylene, butadiene and phenol are the base chemicals for 92% of the polymers produced in the United States. These building blocks are all obtainable from cellulose and lignin. Table 2.6 shows estimated quantities required, based on 1974 production of plastics, fibres and rubber.

Most observers, including Goldstein, feel that wood-based chemicals for production plastics are of the order of decades away.

Another potential source for plastic feedstock materials being examined by scientists is that of agricultural oils, or "agoils". Some source crops such as castor beans and soybeans are already well known. Other agricultural plants being investigated for sources of commercially useful oils

TABLE 2.6

MATERIAL	1974 POLYMER PRODUCTION 10^3 tons	LIGNOCELLULOSE REQUIRED 10^3 tons
PLASTICS		
Polyester	455	1220
Phenolic	670	1915
Nylon	100	285
LD Polythene	2985	11940
HD Polythene	1420	5680
Polypropylene	1125	4500
Styrene	2505	7445
PVC	2425	4255
Others	800	
SYNTHETIC FIBRES		
Nylon	1065	3045
Polyester	1500	4020
Olefin	230	920
Others	920	
SYNTHETIC RUBBER		
Styrene butadiene	1615	5700
Others	1155	
TOTAL	18970	
Obtainable from Lignocellulose	17490 (92%)	58445

and acids include glyceride oil, epoxyolein acid, long-chain fatty acids and epoxy acid. Of these, glyceride oil or crambe, appears to be the most likely candidate for commercialisation for the manufacture of polymers.

Certainly, industry will rely heavily on petroleum and natural gas as long as current technology and economics hold, but continued near-total dependence on finite mineral resources seems unwise.

CHAPTER 3

ECONOMICS OF ENGINEERING MATERIALS

A number of interacting factors have to be considered when choosing a material for the production of a given component. One of the most important of these factors is, of course, the cost of the material. However, this is not always the only factor which decides the overall cost of the component. The engineering properties of the material, for fabrication and finishing costs and the useful life of the material, all play a very important part. In many cases it is false economy to use the cheapest material that will be functionally satisfactory because excessive fabrication and finishing costs may be involved. The total number of components required and, consequently, the method of production may also influence which material is selected. There are numerous books and articles available on engineering materials and manufacturing methods, but very few analyse in detail the cost data and the consequent interplay of materials costs and processing costs.[27-33]

3.1 MATERIALS IN DESIGN

The prime function of the design will usually determine the properties of the majority of the materials used in the design. Care in the selection of these materials to ensure that, although adequate, they are the cheapest and easiest to fabricate, will result in the most economic design. Portable appliances, for example, will tend to be based on the low-density materials such as plastics, and magnesium and aluminium alloys, rather than steel - or copper - base alloys, but there are exceptions like pressed steel-sheet used for light components. Because of the greater flexibility of such low-density materials it is necessary to design in the component as much inherent rigidity as possible by utilising efficient ribbing and three-dimensional forming. Mechanical designs will require the selection of materials to give the necessary tensile strength and fatigue resistance at the minimum cost. A systematic approach to the design function can be found in many excellent books, but again the cost component is not considered.[34,35,36]

3.2 MATERIALS IN COMPETITION

The main property and economic factors which determine the usage of the vast bulk of materials today may be listed as 1) cost in the job; 2) strength; 3) space filling; 4) surface behaviour and durability in service.

The last requirement is frequently met by a wide range of materials so it is not usually in critical consideration.

The space filling factor can, in many cases, be met as a cost criterion by making hollow shapes and so this may not be critical unless great rigidity is required. This leaves strength and cost in the job as the ultimate factors.[37]

There are, of course, applications where high electrical conductance, or high strength/weight ratio, or possibly good corrosion resistance are of primary economic significance, but such dominant property requirements are only of minor importance for the majority of materials or a minor cost item; the greatest exception being copper.

3.3 TRENDS CAUSING MATERIALS COMPETITION

At the present time the main cause of competition, particularly between the various metals and plastics, is that in the more advanced countries there is an excess of production capacity over demand in steel, aluminium, copper, zinc and certain forms of plastics. In many cases this excess of production capability applies both to the raw metal and to its subsequent shaping for finished use, either by casting or mechanical working.

A second effect is created by technological advances of an engineering nature, resulting in a lower usage rate. For example, with the generation of electric power, which was growing at the rate of 8 to 10 per cent per annum, the need for copper for the generators was at the rate of 0.028 tons/MVA compared with 0.100 tons/MVA 10 years ago; i.e. reduced to 28%,for transformers the corresponding values are 0.086 tons/MVA as compared with 0.125 tons/MVA, i.e. down to 68%. Similarly the use of cupro-nickels and copper base alloys in tube form for heat exchangers in the same industry is now only 0.55 tons/MW-hr of installed capacity as compared with 0.9 tons/MW-hr of installed capacity in 1950. Similarly tube plates have decreased from 0.27 to 0.09 tons/MW.[38,39]

Very great advances have been made in the commercial aircraft industry as a result of which, only one-tenth the weight of metal will be needed per unit passenger kilometer in 1970 as compared with 1940. The same increasing trend in the efficient usage of metal is continually occurring in the automobile and construction industries.

3.4 EXAMPLES OF MATERIALS IN COMPETITION

Simple bar charts showing metals and materials selling prices are shown in Figs. 3.1 and 3.2. The general observations show that whereas most metal prices have continued to rise, although zinc and aluminium have to some extent levelled off, the price of plastics since the war has shown a marked decrease particularly in the tonnage plastics, PVC and polythene. The decrease in price has reached its lowest point and is now rising. Another interesting aspect is that the price of cement, having stayed constant for the past 20 years, is now rising also. The price of timber has been increasing since 1970. Despite these trends in metal prices, if one discounts the decreasing value of sterling then, since the year 1900, most

FIG. 3.1

PRICE PER TONNE OF VARIOUS METALS

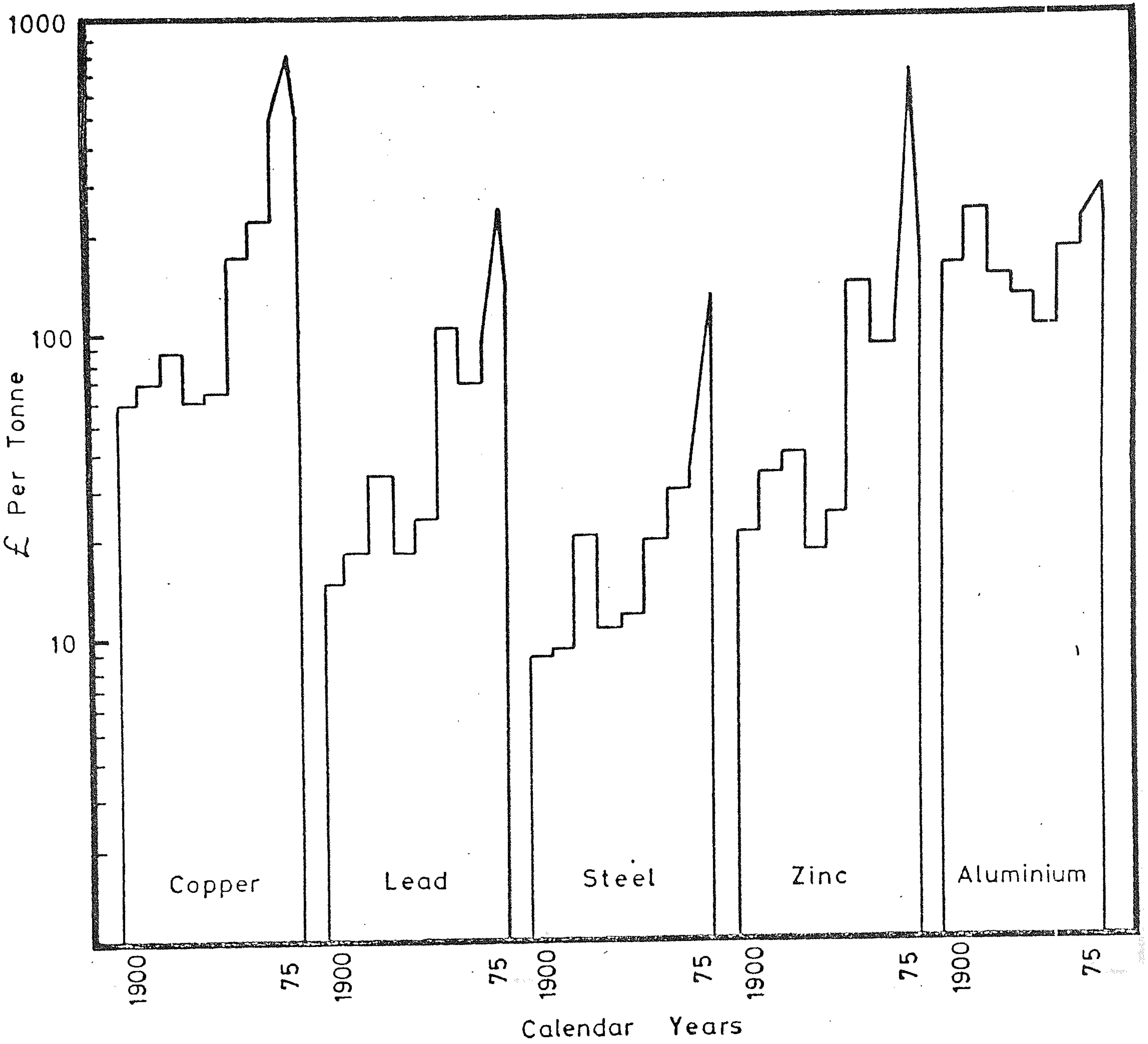
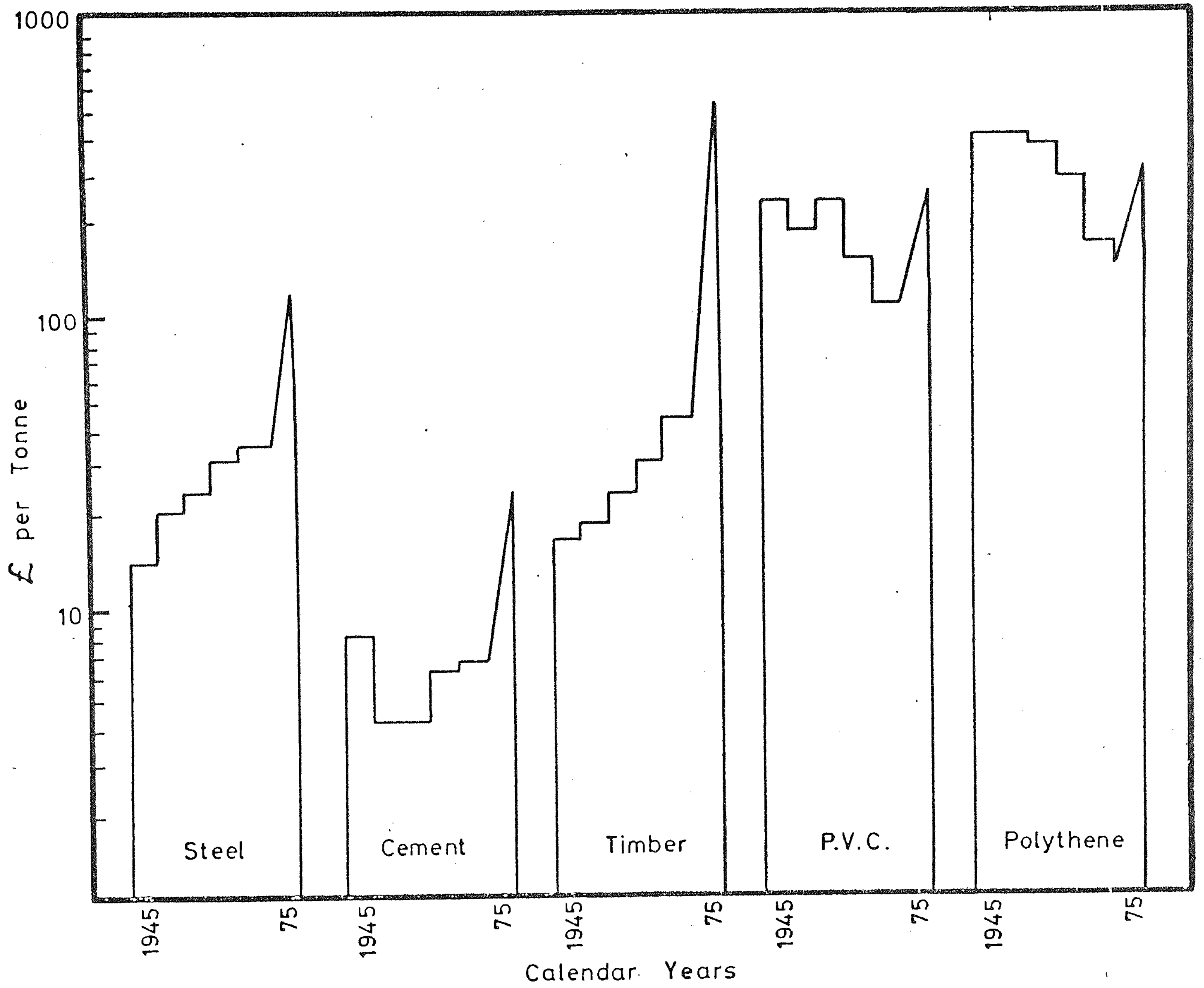


FIG. 3.2

PRICE PER TONNE OF NON METALLIC MATERIALS



metals have stayed remarkably constant in price.[40]

3.4.1 STEEL VS TITANIUM

Titanium made a dramatic entry on the metal world when it was first introduced around 1953. Later it was found to be lacking in creep properties at moderately elevated temperatures, and thus, it designed itself out, as a significant structural component of aircraft. The United States Government spent over 3 billion dollars upto 1958 to encourage special alloy steel firms to produce titanium alloy sheet and rod. The result was that the advent of titanium caused a flurry of intensive research on a whole range of highly alloyed steels, both compositionally, in heat treatment and in methods of fabrication. Thus have emerged a new range of steels in sheet and strip form such as PH4 stainless steel with tensile strengths of up to 2000 MN/m^2 (150 $tons/in^2$).

This aspect of history is an interesting example of the advent of a new set of engineering design objectives creating a demand for a new metal which demands were, in fact, more than met by some existing steels which had not been previously fully exploited.

Since then, the main applications now for titanium seem to be in missiles, in the corrosion field, and also condenser and heat-exchanger tubing for desalination.

3.4.2 STEEL VS ALUMINIUM

Although the total tonnage of aluminium produced in the world in 1973 was 12.7 million tonnes as compared to the 695 million tonnes of steel production, 50% of the aluminium output went into markets competitive with steel. Economic design considerations, such as a high strength/weight ratio, rigidity, stiffness, good impact resistance and corrosion resistance explain the overall application advances which aluminium has made at the expense of steel.

Some years ago aluminium alloys were considered for bridge building in the United States. However, this proved uneconomic and steel and reinforced concrete still retain that section of the market.

Another field is that of shipping, where in all new liners and a majority of cargo carriers, the top weight is significantly reduced by the use of aluminium-magnesium alloy plates. This is another trend which is in the direction mentioned earlier of more efficient engineering resulting in less weight of structural material per tonne-km of cargo moved. This basically is why, even though aluminium-magnesium alloy plate is much more expensive on a strength for strength basis than steel plate, its use is completely justified on overall economic ship strengths and stability considerations.

3.4.3 ALUMINIUM VS COPPER

As the "incomparable metal", copper's participation in all its traditional uses is limited, theoretically, only by its availability. Furthermore, its attractions are greatest in precisely those areas of modern technology where growth has been most rapid: in electricity generation and distribution, transportation, plumbing, heating, refrigeration, air-conditioning and general engineering.

Uncertainty about supply, whether on account of strikes, transport problems, political troubles or other causes, has been a factor which has been working increasingly against the use of copper in the past few decades.

By far the most important of the competing materials which began to make their presence felt in the fifties was, and still is, aluminium.

Aluminium, as the more recent metal, has for a considerable number of years been competing in certain spheres of application with copper. The one which is very well known is that of the electrical industry, where, particularly since some basic redesign of electrical cabling for aluminium has resulted in much greater efficiency on a weight per kVA basis, the chances of copper staging any significant recovery seem to be remote. It appears that aluminium is now considerably cheaper for distributing electricity in cables down to 11 kVA and even lower, thus leaving copper to be used mainly for generators and motors, because of its higher conductivity per unit cross-section and, therefore, greater compactness in design and also because of its higher mechanical properties at operating temperature.

Indication of trends can be deduced from figures produced by the United States Bureau of Business Administration concerning the 7-year period 1947-54 when the copper usage in some 25 groups of industries consuming 70-80 per cent of wrought copper alloys was compared with the growth in the use of aluminium by those same industries. The overall findings were that, whereas increase in copper was only about 1.6% over the entire period, increase in the use of aluminium was about 66%. This is a very good example of a newer material apparently cashing in on all the new applications and new designs in industries where an older metal might reasonably have been expected to go on expanding in its usage.

Aluminium being the most serious competitor to copper, the price relationship between the two metals warrants a somewhat more detailed discussion.

The copper/aluminium price ratio during the past 75 years is shown in Fig. 3.3. It is interesting to note that this ratio has changed tenfold over the period covered, from 0.2 to about 2.0, but that this change came about in two large strides, one between 1895-1900, the other during the 1940's. In between these periods of change, and from about 1955 onwards, the price relationship between the two metals has remained fairly stable. Most important, over the last ten years, no trend in the price ratios can be detected. This finding is at considerable variance with experience of earlier periods.

Over the past 100 years, aluminium has gradually become

FIG. 3.3

HISTORICAL COPPER/ALUMINIUM PRICE RATIO
(USA 1975)

cheaper in relation to copper. This long-term change in the metals price ratio goes a long way towards explaining the substitution in many markets of aluminium for copper. If, however, the more recent stability in the price ratio continues into future years, one may expect that the most profitable opportunities for substitution will soon be exhausted. Such a development would obviously decrease the price elasticity of demand for copper. The relative price information contained in the graph should be useful in studies of long-term substitution between the two metals.

3.4.4 METALS VS PLASTICS

Engineering applications probably account for as much as a quarter of the current annual production of thermoplastics in the United Kingdom.

Long runs of pipework are extruded from PVC and from polyethylene and polypropylene; the largest high-density polyethylene pipes are 1.5m diameter and 50 mm walls. Liquid storage tanks are being manufactured from acrylic, PVC and polyolefin sheet, holds 45 m^3 and weighs about 2 tonnes empty. Gears range in size from the minute injection-moulded precision components to the huge 4.25 m diameter, monomer cast in nylon.

Load-bearing applications include bottle crates, mechanical-handling pallets and chairs made from PVC, polystyrene, polyethylene and polypropylene.

The use of low-density polyethylene as a dielectric for transatlantic telecommunications cables and of slot liners used to provide electrical insulation in the stators of electric motors, are but two examples taken from electrical engineering.

Thus, surveying the present-day wide application of the range of plastics, it is difficult to find any one metal which is particularly subjected to attack by the plastics industry.

The greatest attractions of plastics are their low density, continued fall in price, the facility with which they can be made into intricate finished shapes and the attractive colour ranges and aesthetic appeal. The areas in which different types of plastics have made inroads and are likely to continue are as follows:

1. Polythene and PVC used instead of copper, lead and cast iron tubes for water conduits.
2. Polythene used instead of galvanised iron for downspouts, window frames, building applications, buckets and other containers.
3. PVC used instead of cast iron for water pipes, etc.
4. Glass-filled nylon may be used instead of zinc, magnesium or aluminium base diecastings.
5. Glass fibre mats and epoxy resin laminates used instead of sheet steel and sheet aluminium magnesium pressings.

In the overall plastics field there is over-capacity and intensive research work is continuing to develop plastics which are (a) able to withstand higher temperatures for prolonged periods without loss in mechanical properties, and (b) made from cheaper and more abundant raw materials. There is always a chance that a plastic with radically new properties will be developed overnight which could completely alter the conflict for applications. Nevertheless, when one remembers that over 30,000 polymers have now been explored, the chances of finding a new cheap plastic seem increasingly remote.

3.4.5 COMPOSITES

Under this general heading, probably the first metallic combinations were the bi-metals.

More recent developments include PVC-coated steel for the automobile industry, laminates for various types and combinations of glass fibre with plastics showing extremely high strength/weight ratios. Glass Reinforced Plastic (GRP) and Carbon Fibre Reinforced Plastic (CFRP) deserve special mention.

Carbon fibre itself is of little use; only when it is incorporated into a matrix of glass or metal, which acts as a means of load transfer and enables the fibres to act collectively, do we obtain useful engineering material.

Yet another development is oxide or refractory powder dispersed in metals of the "sintered aluminium, (SAP)" type.

Another example of composites is the elaboration of reinforced concrete into prestressed concrete which results in considerable economies in steel and concrete.

3.4.6 INORGANIC RESIN COMPOSITES

A departure from petroleum-based materials is represented by a new and exciting family of low-cost, high-solids, cement compositions that can be used in the same way as thermosetting organic resins to produce glass-fibre-reinforced parts. The inorganic-resin-system (IRS) is based on magnesium oxychloride cement containing 10 to 15% water. The water combines with the cement during the cure cycle, so there is no moisture to remove.

IRS can be formulated with various reinforcements, additives and fillers, as is commonly done with polyesters and epoxies. The composite material can be processed on conventional equipment used for FRP parts. Fabrication costs are expected to be about the same as for comparable reinforced plastics.

While the IRS composites generally have lower flexural and tensile strength than thermosetting resin systems, they are stiffer, noncombustible and much cheaper - about 10¢/lb (20 ¢/kg), for the matrix cement raw material. The composites can also be foamed to densities as low as 20 lb/cu.ft. (320 kg/m^3).

Applications envisioned for IRS materials by their developer, the A.D. Little Corp., USA, include mass-transportation seating, interior truck panels, and housings for office machinery and house appliances.

3.5 TECHNO-ECONOMIC FACTORS OF COMPETITION BETWEEN STEEL AND OTHER MATERIALS

The principal sectors in which the impact of competing materials on iron and steel use is already felt, are the following:

1. Construction industry
2. Packaging and containers
3. Automobile industry
4. Shipbuilding
5. Railway rolling stock
6. Pipes and tubes
7. Machinery manufacture

In Table 3.1 a comparison is made of the main properties of competing materials with those of widely used commercial grades of steel (for equal dimensions).

Numerous attempts have been made in recent years by national and international institutions to quantify the degree of competition between steel and other materials. It is evident that information of this type is useful for the production and planning of the iron and steel industry, as well as for decisions on investment and on technical research. Very few of these studies are, however, published; one of the reasons being that data is very scanty.

A general survey is given in Table 3.2 of the different

TABLE 3.1

COMPARISON OF THE MAIN PROPERTIES OF STEEL SUBSTITUTES WITH THOSE OF WIDELY USED COMMERICAL GRADES OF STEEL (For equal dimensions)

PROPERTY	PLASTICS	ALUMINIUM	GLASS STANDARD	CONCRETE (not reinforced)	TIMBER
Tensile strength	Usually lower; but with reinforcement may be the same or two to three times higher.	$\frac{1}{2}$ to $\frac{2}{3}$	$\frac{1}{15}$ to $\frac{1}{10}$	$\frac{1}{100}$ to $\frac{1}{20}$	$\frac{1}{20}$ to $\frac{1}{10}$
Plasticity under tension.	Higher or lower	The same, or slightly higher	None	None	None
Compressive strength	$\frac{1}{10}$ to $\frac{1}{5}$	$\frac{1}{4}$ to $\frac{2}{5}$	$\frac{1}{100}$ to $\frac{1}{20}$	$\frac{1}{15}$ to $\frac{1}{5}$	$\frac{1}{20}$ to $\frac{1}{10}$
Modulus of elasticity (Young's modulus)	$\frac{1}{4000}$ to $\frac{1}{120}$ but with reinforcement $\frac{1}{20}$ to $\frac{1}{2}$	$\frac{1}{3}$	$\frac{2}{5}$	$\frac{1}{18}$ to $\frac{1}{6}$	Lower
Density	$\frac{1}{8}$ to $\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{3}$ to $\frac{1}{2}$	$\frac{2}{7}$ to $\frac{1}{3}$	$\frac{1}{16}$ to $\frac{1}{10}$
Resistance to corrosion (atmospheric)	Higher	Higher	Much higher	Higher	Lower
Resistance to heat	Much lower	Lower	Lower	Lower, but in special cases may be equal or higher	Much lower
Insulating capacity - heat - electricity	 Higher Higher	 Lower	 Higher Higher	 Higher Higher	 Higher Higher

TABLE 3.1 CONTINUED

PROPERTY	PLASTICS	ALUMINIUM	GLASS STANDARD	CONCRETE (not reinforced)	TIMBER
Conductivity					
- heat	Lower	Higher	Lower	Lower	Lower
- electricity	Lower	Higher	Lower	Lower	Lower
Workability	Much better	Better	Worse	Worse	Much better

TABLE 3.2

SURVEY OF COMPETITION ARISING FOR DIFFERENT IRON AND STEEL PRODUCTS FROM VARIOUS MATERIALS IN INDIVIDUAL SECTORS OF THE ECONOMY

Product / Consumer group	Railway-track material	Heavy sections	Light sections	Wire Rods	Plates	Sheets	Strip	Tinplate	Steel tubes and fittings	Cast iron pipes	Castings and forgings
Mining, crude oil and natural gas	CO;TI	TI;CO	TI;CO; AL		AL;CO	AL;PL; AB	AL;PL		PL;AL; CO;AB	PL;CO AB	
Electricity supply, gas-works, water supply	CO;TI	CO;TI	AL;CO; TI		AL;CO	AL;PL; AB	AL;PL		PL;AL; CO;AB	CO;PL; AB	
Railways (building and permanent track)	CO;TI	CO;TI	AL;CO TI		AL;CO	AL;PL; GL;AB	AL;PL		PL;AL; CO;AB	PL;AL; CO;AB	CO
Construction		CO;TI	AL;CO TI		CO;PL AL	CO;AB; AL;PL; TL;GL	CO;AL; PL		PL;AL; CO;AB	PL;AL; CO;AB	AL;CO
Hollow-ware and containers			AL;TI		AL;PL	AL;PL; CB;FB; GL;TI	AL;PL; CB	AL;PL; GL;CB; FB;TI	AL;PL		
Wire, wire products, fastenings, etc.			AL;PL	AL;PL							
Household equipment, non-electrical			AL	AL	AL;PL; TI	AL;PL; TI;FB	AL;PL; TI	AL;PL; GL			AL
Machinery, other than electrical		CO	AL	AL	AL;PL	AL;PL	AL;PL	AL;PL	AL;PL		CO;AL
Electrical machinery (incl.appliances)			AL	AL	AL;PL	AL;PL	AL;PL	AL;PL	AL;PL		AL

TABLE 3.2 continued

Product / Consumer group	Railway-track material	Heavy sections	Light sections	Wire Rods	Plates	Sheets	Strip	Tinplate	Steel tubes and fittings	Cast iron pipes	Castings and forgings
Shipbuilding		TI	AL;TI		AL;PL	AL;TI; PL			AL;PL		AL
Railway and tramway rolling stock			AL;TI		AL;PL; TI;GL	AL;PL; TI;GL; FB	AL;PL; TI		AL;PL		
Motor vehicles, cycles and aircraft			AL		AL;PL; GL;TI	AL;PL; TI;GL	AL;PL	AL;PL	AL;PL		AL
Other metal-manufacturing			AL;PL; TI		AL;PL; GL	AL;PL; GL	AL;PL; GL	AL;PL; GL	AL;PL		
Other consumers		TI	AL;TI		AL;PL	AL;PL	AL;PL	AL;PL	AL;PL	AL;PL	

AB - Asbestos Cement
AL - Aluminium
CB - Paper and Paperboard
CO - Concrete

FB - Particle Board
GL - Glass
PL - Plastics
TI - Timber

materials which are competing with iron and steel products in the different sectors of the economy.[41] The concentration of symbols in the table indicates to some extent those products and those consuming groups which are exposed to particularly fierce competition from other materials: the use of sheets and steel tubes in construction, of sheets and tin-plate in the manufacture of containers and the use of plates and sheets for railway rolling stock. Steel tubes and fittings, and also cast-iron pipes, are mainly exposed to competition in the sub-groups of "Mining, railways and construction", i.e. in uses where their function is for carrying liquids and gases rather than a structural one.

A characteristic trend is that steel is no longer a material which 'sells itself', as competition with other materials becomes more and more severe. The producer is no longer the only one who deisgns the steel and puts it on the market. It is the consumer who wants to have more and more say about the material he intends to use for different applications; his knowledge potential has increased sharply. The emphasis will not only be on commercial agreements but also on research, and in the future it will often be the consumer who formulates the goals for steel production. The petrochemical, fertiliser, food and inorganic chemical industries will all need a gradual improvement in the corrosion resistance of steels at increasingly high temperatures. The development of steels with smaller additions of certain rare and expensive alloying elements will be necessary. The ferritic ELI steels with low carbon and nitrogen contents offer interesting possibilities, but much development is still needed regarding their durability, weldability and price. The growing scarcity of certain alloying elements will gradually influence future steels. Iron itself is abundant, but Mo, W, Cr, Ni etc. are limited and will probably be used on a much more selective basis.

Steel processing, including optimsation of heat treatment and surface treatments, will be regarded as an integral part of the materials system.[42] In the science of metals, developments will occur in powder metallurgy, hot gas pressure bonding, fluid-fluid extrusion, superplasticity and high strength steels[43] and improvements will be primarily in increased reliability, uniformity and toughness rather than in strength.[44]

Although the overall degree of present replacement appears to be moderate, analysis has confirmed that in some sectors of the economy, particularly in packaging and tubes, competition is already much stronger and the degree of replacement considerably higher. It is estimated that the total gross replacement of iron and steel could rise from around 5% to perhaps 10%.

The examples given in this chapter appear to indicate that major tonnage replacements occur mainly in the iron and steel sector. Iron and steel products are mainly replaced by competing materials in areas like packaging, in the production of certain types of tubes and pipes, casings for light machinery, appliances and small components for automobiles and rolling stock. The actual replacement will, however, only occur when the price of a competing material (of equal or superior properties) is lower, or if lower costs connected with the use of a particular material (e.g. of installation, of manufacture or further processing, or maintenance) justify a higher initial expense.

In view of the competitive situation, the iron and steel industry has every incentive to continue to watch very closely the changes occurring in this field and to take appropriate measures for improving the competitiveness of its products.

CHAPTER 4

A SYSTEMS APPROACH TO MATERIALS SELECTION

4.1 INTRODUCTION

One of the most important requisites to the development and manufacture of satisfactory products at minimum cost is making a sound, economic choice of engineering materials.

Good design, good material, treatment, assembly and inspection are the keys to satisfaction in production and service. If the design is poor, then the best of material or treatment will not give a satisfactory product. The results obtained with an average design, however, can be improved by the use of good material and its subsequent treatment and assembly. The importance of good design cannot be overemphasised. Present day competition demands the requird strength and performance at minimum cost. Materials have always been the limiting factor in engineering design.

Effective materials selection and utilisation is one of the most important control centres and characteristics of a profitable manufacturing process. A satisfactory service application occurs as a result of complex interactions of various properties. Thus selecting a material for a definite purpose requires a critical comparison of its relevant properties with those of various other materials. So, finding the optimum materials for an application requires a rigorous engineering and systems approach. It is only in the past couple of decades that materials selection procedures have been formulated and integrated into the methodology of engineering development and manufacturing. Prior to this, the general procedure was to rely almost entirely on past experience and fit the design of a product to the properties of the few materials with which the engineers and suppliers were familiar. Indeed, the product development program was often completed before any thought was given to materials. Under such circumstances, materials changes took place gradually and each change usually provided only small improvements. In recent years, growth and development in the fields of nuclear power, aerospace, electronics and other applications have demanded severe service requirements from materials. Also the emergence of new materials to meet these requirements have given a new impetus to the philosophy of materials selection.

Today, materials selection is a complex process that operates throughout the entire span of a product's evolution, and usually involves a number of different technical departments. Procedures have been developed to analyse complex interaction of requirements and performance properties. Materials engineering departments are now a common adjunct to engineering or manufacturing departments.

It is therefore the purpose of this chapter to survey the entire materials selection process. The first section describes in brief, how materials selection fits into the overall engineering and manufacturing framework. The second section covers the operating principles of the materials selection process. And finally, the third section describes some of the analytical and systematic methods for evaluating and selecting possible candidate materials.

4.2 THE MATERIALS SELECTION PROCESS

Materials selection is not a simple function that is performed at a certain time and place in the history of a product.

The materials selection process operates in two distinctly different areas of the engineering and manufacturing complexes. First, it is an indispensable part of new product development projects. Second, it has an important role in the review and reevaluation of existing products and their performance with regards to cost and reliability.

4.2.1 NEW PRODUCT EVALUATION

In integrated and efficient engineering organisations, each development project goes through a series of major stages that begin with concepts and culminate in a finished product or system.

The four broad stages of a new product's history are: 1) concept formulation and sales potential; 2) engineering development; 3) production design; and 4) manufacturing. The materials selection process can operate in any or all four stages.

CONCEPT FORMULATION AND SALES POTENTIAL - In the first stage an overall concept, which will be the guide for the final detailed design, is developed. The concept starts as a broad system image that represents the general functioning of the product to meet a given set of requirements and market.

In this initial stage, the materials requirements are broadly outlined, chiefly to determine whether the concept is seriously limited by materials or processes and whether a market does exist for the product.

ENGINEERING DEVELOPMENT - In this stage a practical and workable design is developed. A major share of the materials evaluation work is often performed at this time, and cost and reliability factors are considered along with manufacturing capabilities and tooling cost.

PRODUCTION DESIGN - The outcome of the development stage may be the final production drawings. Design modifications are now made to achieve production economies or to fit existing facilities and equipment. Frequently, these modifications required significant changes in materials.

Or the design may be refined to the exact properties of the selected materials.

MANUFACTURING - When the product is finally in production, the materials selection function may still continue. Materials problems may arise during the pilot run (or later) causing replacement or requiring some redesign in assembly or inspection and testing.

4.2.2 EXISTING PRODUCT EVALUATION

Although the materials selection process is most often thought of in terms of new product development, studies have shown that materials selection is just as often involved in changes to existing products.

Some of the major reasons for making materials changes in existing products are:

1. To solve materials processing problems arising in production
2. To reduce production costs.
3. To reduce basic materials costs.
4. To improve service performance.
5. To take advantage of a new material or processing development.
6. To develop substitutes in times of national emergencies.

Whatever the reason for initiating a material change, it generally determines the selection procedure. When the materials selection process operates in existing product applications it is not as neatly structured as in new product development. Usually it is not tied to a specific product, but involves the generation of materials knowledge that can be used in a number of different ways.

Finally, information and data is generated and stored for use in the development of materials and processes specifications and approved vendor lists that become a materials selection tool for the entire engineering organisation.

4.3 THE PRINCIPLES OF MATERIALS SELECTION

Like most engineering efforts, materials selection is a problem-solving process. Much has been written on problem-solving and very little on materials selection. The few studies [46-52] that have been made deal mainly with characterisation and evaluation rather than selection of materials.

The major steps in any materials selection procedure are:

1. Analysis of the materials requirements.

2. Selection of candidate materials.

3. Evaluation of candidate materials.

4. Selection of the most "effective" material.

4.3.1 MATERIALS REQUIREMENTS

The materials requirements are derived from a study of the desired attributes, functions and performance of the product or system being developed as well as the environment in which it will operate. But in order to be useful the materials requirements, in turn, must be translated into materials property data.

The materials requirements of any product or system can be divided into five categories:

FUNCTIONAL - Because the successful functioning of a product is heavily dependent upon the materials, the functional properties are usually one of the principal criteria of selection. These requirements are directly dependent upon the functions the product is being designed to perform. It is not always possible to assign quantitative values to these product functions and characteristics. Nevertheless, in one way or another, they must be related as precisely as possible to the most closely applicable properties.

PRODUCIBILITY - This is characterised in several different ways. One way is in terms of the various processing methods - that is, the ease with which a material can be cast or machined or welded.

Another way is in terms of the mill shapes and semi-finished forms in which the materials under consideration are available.

Processing operations will almost always have some effect on a material's performance properties. This effect may either improve or reduce performance; therefore, producibility considerations are closely inter-related with functional end-service performance factors.

COST - Perhaps cost, more often than any other requirement, is the controlling factor in evaluating and selecting materials. In every application there is a cost beyond which one cannot go and which therefore prescribes the limit that can be paid for a material to meet the application requirements.

Two important considerations affect materials cost. One is that although materials are usually priced in terms of cost per unit weight, comparisons on this basis are not strictly valid. A fairer comparison is often by cost per unit requirement (CUR) as described later.

The other cost consideration is producibility, that is, the cost of processing and fabricating materials into the finished forms. This cost will often exceed the cost of the material itself.

RELIABILITY - Simply stated, reliability is the degree of probability that a material will function in the intended service for the intended life of the product without failure. With the increased demand for failure-proof hardware in the space and electronic fields, reliability has become an increasingly important materials selection criterion. Despite the difficulties of evaluating reliability, systematic techniques for the measurement and control of reliability have been developed.[53,54]

ENVIRONMENT - This aspect cannot be overlooked, for its influence on service performance can be critical in different ways. Environments, such as humidity, chemicals, extreme temperatures and stress fluctuations alter adversely the service performance of most materials. On the other hand, environments are sometimes beneficial to the service performance of materials. For example, oxide formation on aluminium improves its corrosion resistance.

4.3.2 SELECTION OF CANDIDATE MATERIALS

Once the requirements are clearly specified, the rest of the selection process involves a search for the materials that best meet those requirements. Materials that satisfy the minimum requirements are termed candidate materials.

The principal objectives, then, are to narrow the selection of candidate materials down to a managable number for subsequent detailed evaluation and, at the same time, to make certain that no important possible solution is omitted.

It is in this phase of the selection process that different approaches to the solution of the materials problem, as distinct from simply choosing candidate materials for evaluation, should be considered. Because of the need for innovation and inventiveness to devise different approaches to the solution of materials problems, creativity is essential in this step. This is the stage when value analysis, computer techniques and other new approaches should be and are often applied.

4.3.3 EVALUATION OF CANDIDATE MATERIALS

The objective of the evaluation step is to weigh the candidate materials against the specified requirements for the purpose of finding the best material. In principle, this step is a continuation of the previous one, in that it is eventually a screening process.

The screening process may begin with the most critical property and then proceed to those of lesser importance. Or, where most of the requirements are of equal importance, the candidates may be compared on the basis of all the pertinent properties. In other applications, rating systems or analytical techniques, such as failure analysis, can be used to advantage.

Whatever the approach, an essential part of it is to obtain the data and factual information needed to evaluate accurately and compare the candidate materials. The sources of such data are numerous.[55] Often published data (internal or external), specifications, or previously generated test data, are adequate for at least the preliminary screening. However, when the field is narrowed down to the final few, these is no substitue for a carefully structured testing program.

4.3.4 SELECTING FOR MATERIAL EFFECTIVENESS

In the most general sense, selection for effectiveness in a given application means that, 1) use the materials that most efficiently meet the functional requirements; 2) apply and process the selected materials in the most efficient manner in order to consume the least quantity; and 3) select and apply materials for maximum durability, life cycle and recyclability.

The significance of these materials effectiveness principles are easily demonstrated. For example, an unwise materials selection leading to the failure of one part of a system causes the premature scrapping and waste of all the other materials making up the system.

In many cases the evaluation and screening operations described above automatically point to the best material to use. Sometimes, even when quantitative and formal evaluation procedures are used the results may not be unequivocal. Trade-offs and modifications in the deisgn or in the materials requirements may be required before a final decision can be made.

Hence, the materials selection procedure may not always proceed step-by-step along the problem-solving path. The process often operates in an iterative manner. That is, in collecting, analysing and evaluating information in any given stage, new insights may be gained that require a repetition of earlier steps.

When all the factors are evaluated and taken into consideration, one has what is called a systems approach to materials selection and the choice will be the most effective material.

4.4 THE METHODS OF MATERIALS SELECTION

The materials selection stage can be considered as a screening process. And, considering the importance of materials selection, it is surprising that until recently most methods of materials selection fell into the general category of "successive approximation" methods.

Lately, however, there has been a trend toward organised methods that will quickly screen materials to meet the given requirements. Consequently, in the past few years there has been the development of such systematic methods of materials selection as value engineering, failure analysis, weighted property factors and computer evaluation.

Following is a brief analysis of the important methods that are now available and their limitations.

4.4.1 VALUE ENGINEERING

Value engineering or value analysis is an organised method of finding the least expensive way to make a product perform a function without compromising quality or reliability. It is a systematic step-by-step method designed to eliminate haphazard cost reduction approaches, and to allow no cost reduction alternative to escape examination. The whole product development philosophy is oriented around the cost of the product, including product function, materials and process cost.

Value engineering depends on the programmed application of proven techniques. These techniques were developed largely by Miles[56] of the General Electric Co., and are now widely used by G.E. and other companies. One of these techniques is to avoid general critisms in the early stages of product analysis because they may stop progress and cause quick dismissal of an idea of proposition which, on closer analysis, may turn out to be good.

Another key technique is the so-called "blast, create and refine" technique. This technique is designed to free the cost analyst from thinking in conventional ways. The main intent of this type of thinking is to create and not let traditional or judicial thinking interfere with the exploration of ideas.

Although value analysis has been used in industries on a noticable scale in the last few decades and has been responsible for saving large sums of money, it does not incorporate a regular, systematic approach to materials selection. A decision-making process is involved to determine the necessary functions of the product or system, rather subjectively and this could lead to serious errors in judgements or interpretations when selecting materials. The engineering concepts prevail over the materials aspects, and the latter is not given adequate examination or consideration.

If a critical and scientific method of materials selection could be integrated into value analysis, then the latter would assume added importance.

4.4.2 FAILURE ANALYSIS

Failure analysis is a method of materials selection based on predicting and anticipating all of the ways that a system can fail and then selecting materials so that failure does not occur.[57] It bears some similarity to value analysis in that it is a goal-oriented method. In value analysis the primary goal is minimum cost; whereas in failure analysis the goal is reliability and therefore not relevant to short-life and non-critical components.

Failure analysis is a systematic approach to the measurement, control and improvement of reliability.

The theory of failure analysis is based on the fact that in the majority of cases it is weakness in materials which ultimately cause failure in the system. Thus, all failure theory and generalisations are drawn almost exclusively at the materials level.

Failure analysis can be used in either new product development, or in the review and reevaluation of existing products.

Once the failure mechanisms are analysed, controls are then established on the materials in the form of suitable procurement documents, vendor specifications, materials and processes specifications, control or assembly techniques and inspection procedures.

4.4.3 COST VS PERFORMANCE INDICES

Cost is one of the most important, if not the most important, factor in selecting materials.

But the traditional technique of selecting materials on the basis of cost per unit weight has little engineering significance especially for the tonnage materials.

Taking a given property requirement, it is sometimes possible to find out how much various materials will cost to provide the requirement.

Table 4.1 illustrates the technique for a given requirement of yield strength.

The cost per tonne of hot finished carbon steel bars remain fairly constant over wide ranges of chemical composition. Therefore, the cost per unit strength of the high carbon grades is lower than for the low carbon grades. The reduced sections allowable with higher strength grades can provide considerable saving in fabrication and dead weight in addition to the reduced material costs.

Eight common carbon and carbon manganese steels, cold drawn from the hot rolled condition are listed in Table 4.1. It can be seen that the steel highest in strength is the most economical on cost per unit yeild strength basis. It is worthwhile to note that comparison of 070M20 and 120M19

TABLE 4.1

STEEL NO	ESTIMATED YIELD STRENGTH AT LIMITING RULING SECTION OF 13MM N/mm^2	BASIC PRICE £/TONNE	COST PER 100 N/mm^2 OF YIELD STRENGTH £
070M20	385	136.60	35.48
080M30	450	138.30	30.73
080M46	555	141.60	25.51
070M55	620	141.00	22.51
120M19	450	139.40	30.97
120M36	555	139.90	25.20
216M28	430	142.80	33.20
212M36	480	142.80	29.75

steels shows a distinct advantage for the use of 120M19 on this basis. Comparison of 080M30 and 080M46 steels shows the same is true for steels with the same manganese contents but different carbon contents.

If the ultimate tensile strength according to specifications of a range of metals and materials is considered, the cost per unit of tensile strength can be evaluated, by calculating the cost per unit of volume and then deriving the cost per newton of strength. This is shown in Table 4.2. This data when compared with the tonnage of the material used reveals a broad techno-economic relationship:

"the cheaper it is to 'buy' tensile strength, the greater is the tonnage of the material used".

This is shown graphically in Fig. 4.1. Thus, the demand for a material varies inversely with the cost/strength ratio, particularly in the structural field. No precise mathematical relationship between the two is possible due to interactions of various factors and the difficulty in predicting and measuring them.

4.4.4 WEIGHTED PROPERTY FACTORS

One of the most useful methods of evaluating a complex interaction of requirements is the weighted property factor (WPF) technique. Briefly, it is a technique of evaluating materials in which each parameter is assigned a certain weighting, depending on its importance to the system.

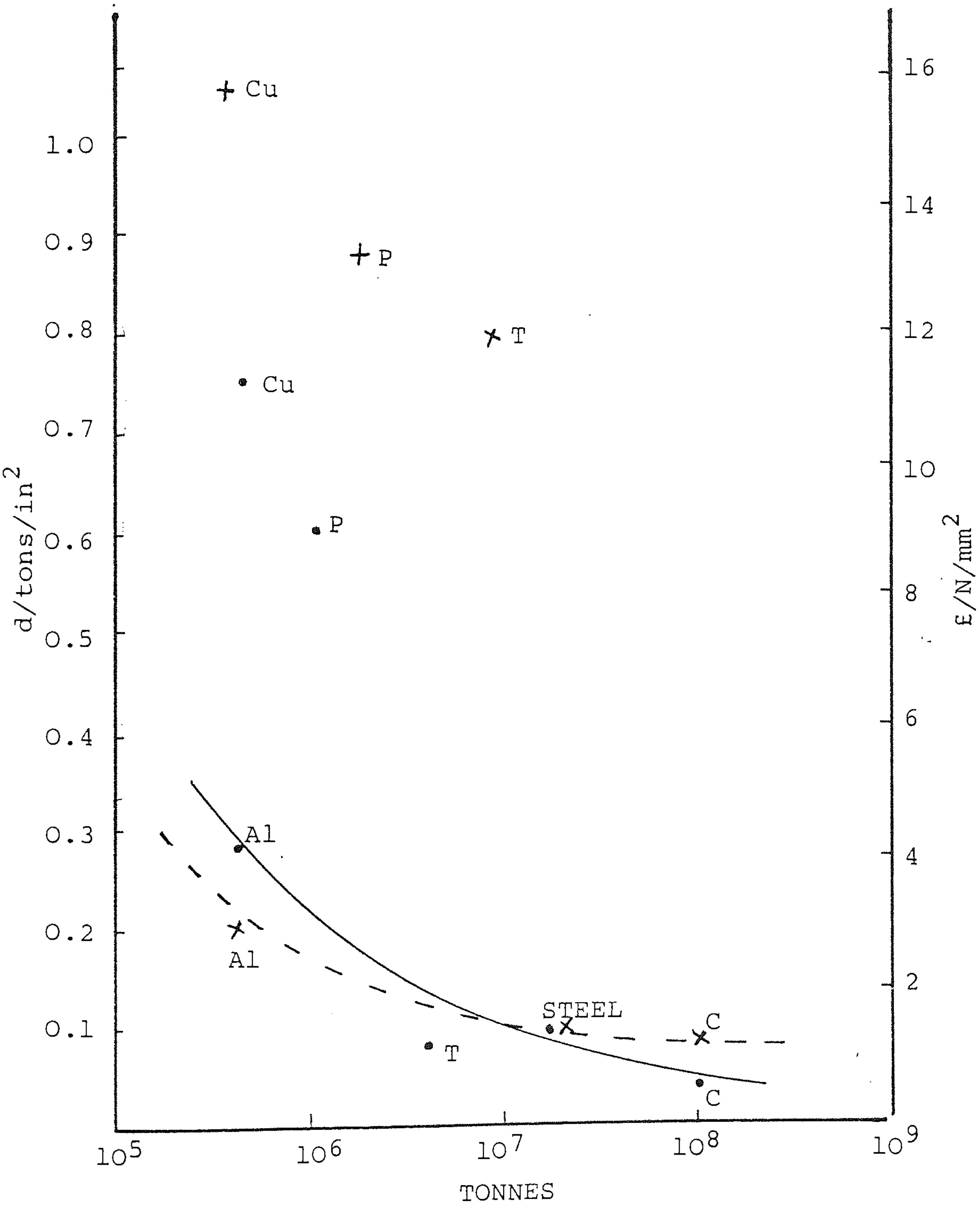
TABLE 4.2
COST RELATED TO MATERIAL PROPERTIES

Material	Tensile Strength	Modulus of Rigidity	Fatigue Strength	Density	Cost	Cost (£) per unit of		
	MN/m^2	MN/m^2	MN/m^2	kg/m^3	£/tonne	Tensile Strength	Modulus of Rigidity	Fatigue Strength
Cast Iron	400	35000	105	7300	135	2.46	0.03	9.40
STEELS								
EN-1	250	77000	193	7850	140	4.40	0.01	5.70
EN-8M	600	77000	300	7830	109	1.42	0.01	2.84
EN-24	800	77000	495	7830	212	2.10	0.02	3.40
EN-56	1000	77000	280	7730	285	2.20	0.03	7.87
EN-58	700	77000	350	7900	635	7.17	0.07	14.33
AISI-309	600	86000	360	7900	1128	15.00	0.10	24.75-
AISI-420	600	86000	680	7900	483	6.40	0.04	5.60
Copper-Zinc Alloys	400	37300	140	8360	515	10.75	0.12	30.75-
Aluminium Alloys	300	26000	90	2700	800	7.20	0.08	24.00
Magnesium Alloys	190	17500	95	1700	2500	22.00	0.24	44.75-
Titanium Alloys	960	45000	310	4510	6500	30.50-	0.65-	94.50-
Polypropylene	30	-	7.5	900	325-	9.75	-	39.00
Propathene	35	-	7.5	900	240	6.20	-	29.00
Polythene L.D.	13	-	3.25	920	315	22.00	-	89.00
Rigidex 2000	30	-	4.00	950	210	6.60	-	50.00
Nylon 66	80	-	20.0	1360	925	15.70	-	63.00
PVC (R)	50	-	12.5	1400	240	6.70	-	27.00
R. Concrete	38	10000	23.0	2400	23	1.45	0.01	2.40
Softwood	5	2000	3.0	500	175	17.5	0.044	29.00

FIG. 4.1

THE TECHNO-ECONOMIC LAW

. 1967 x 1973



The WPF method of materials selection is not entirely new. For years, engineers and designers have mentally assigned a relative scale of importance to various performance requirements or simply weighted some requirements more importantly than others. With experience, this is done almost unconciously. For example, if yield strength is more important than toughness in a product, the two requirements are not treated as co-equals in evaluating materials for that product.

At present, the biggest problem with the above approach is that it is largely intuitive. And when several properties must be considered it is obvious that materials selection becomes quite complex. However, with careful planning, a weighted property factors method can be employed that is considerably more systematic and that assigns weightings to properties or requirements in order of their importance; so that a true assessment can be made of the total cost to get a combination of properties which is the core of the materials selection problem.

4.5 APPLIED MATERIALS SELECTION SYSTEMS

Many organisations have incorporated some of the methods described in preceeding sections, such as value analysis and failure analysis, in their materials selection programmes. But, rigorous and quantitative methods have been developed recently and the following sections review some of the systems which are in industrial use today.

4.5.1 THE NASA WEIGHTED INDEX SYSTEM

This system is an outstanding example of the weighted factors technique described in the previous chapter. This weighted index system, developed by NASA for the Supersonic Transport (SST), appears to be potentially useful for any product.[58] It is one of the best attempts yet made to organise and rationalise the process of materials selection, which is often intuitive and imprecise.

It is a method of evaluating materials in which each parameter is assigned a certain weight, depending on its importance to the system. In case of the SST, for example, parameters such as strength, stiffness, toughness, corrosion resistance and cost are defined as being the key materials selection requirements.

The first step separates the requirements into three groups, each of which performs a separate screening function. These groups are 1) go-no-go parameters; 2) non-discriminating parameters; and 3) discriminating parameters.

Go-no-go parameters are those requirements of a material which must meet a certain fixed minium value.

PARAMETERS FOR THE SST

MATERIALS RATING

GO-NO-GO	PARAMETERS
1	Corrosion
2	Weldability

NON-DISCRIMINATING	PARAMETERS
1	Availability
2	Producibility
DISCRIMINATING	**PARAMETERS**
1	Strength
2	Fatigue
3	Stiffness
4	Toughness
5	Stability
6	Cost

As shown in the chart, these include such properties as corrosion resistance and weldability. The reason these are classified as go-no-go parameters is simply that the material is either satisfactory or unsatisfactory. Any merit in excess of a minimum level is of no special advantage, nor would it make up for any lack in another parameter. Thus, the go-no-go requirements do not lend themselves to compromise or relative rating.

Non-discriminating parameters, such as availability and producibility are requirements that must be met if a material is to be considered at all. Like the go-no-go group, they represent parameters that do not allow comparison or quantitative discrimination. Thus, if a material is not readily available or cannot be formed in the shape desired, then it should not be considered in the first place.

Discriminating parameters are those characteristics of a material to which quantitative values can be assigned. It is on the basis of these parameters that "trade-offs" can be made in terms of the relative importance of parameters. As shown in the table, typical discriminating parameters are: strength, toughness and cost.

Each of the parameters is assigned a weighting factor, depending on its importance. For example, in the case of the SST, strength has a weighting factor of 5, indicating the strength is a factor of great importance. On the other hand, cost is relatively unimportant and is given a weighting factor of 1.

Each of the pertinent properties of the candidate materials is then assigned a rating depending on how closely it meets the requirements. These rating factors in turn are multiplied by the weighting factor for each parameter. The final material rating number for each candidate is obtained by taking the sum of the relative rating numbers and dividing by the sum of the weighting factors used. If the rating process is right in concept and execution, then the material with the highest rating number is the optimum material.

Some of the shortcomings of the NASA method are
1) a very narrow range for all the weighting factors;
2) combination of unlike properties without proper adjustment of the units. Also the assignment of weighting factors and rating factors is a critical step in the method. Since it is the one step which involves subjective judgment it can be controversial. However, in any materials screening

method some subjective judgments have to be made and this method eliminates a lot of guesswork and intuition.

4.5.2 THE HANLEY-HOBSON ALGEBRAIC METHOD

The Hanley-Hobson[59] method employs a very direct approach to choosing materials from a data bank by minimising the sum of the per unit deviations of the properties of candidate materials from the specified properties.

If the specified properties are designated y_i and the properties of candidate materials are x_i, then the criterion is expressed algebraically as follows:

$$\text{Min } Z = \sum_{i=1}^{n} \left| \frac{x_i}{y_i} - 1 \right|$$

With the incorporation of subjective weighting coefficients α_i between zero and unity, the process assumes the form:

$$\text{Min } Z = \sum_{i=1}^{n} \alpha_i \left| \frac{x_i}{y_i} - 1 \right|$$

The algebraic approach to the problem of materials selection is based on the above simple algorithm.

For any data bank it is necessary to limit the number of candidate materials presented for consideration. In the example given by Hanley and Hobson, the selection process ignores materials if any property goes outside limits by a weighted value of 0.4 or if the sum of all weighted deviations exceeds 2.0. Hence, materials are listed if and only if:

i) $\alpha_i \left| \frac{x_i}{y_i} - 1 \right| < 0.4$

ii) $Z < 2.0$

Using a conversational language such as BASIC permits this to be programmed and run on a small computer. Used in an interactive mode the approach also assists evaluation of trade-offs. The method has general applicability for many classes of materials.

There is one major drawback in this method. Both positive and negative deviations from the specified target properties are penalised.

In the example shown, two candidate materials A and B are under consideration for a certain requirement.

	PROPERTY 1	PROPERTY 2
TARGET	200	100
A	400	100
B	250	150
Weighting	5	1

Now,

$$Z = \alpha_1 \left| \frac{x_1}{y_1} - 1 \right| + \alpha_2 \left| \frac{x_2}{y_2} - 1 \right|$$

Hence,

$$Z_A = 5\left|\frac{400}{200} - 1\right| + 1\left|\frac{100}{100} - 1\right| = 5$$

$$Z_B = 5\left|\frac{250}{200} - 1\right| + 1\left|\frac{150}{100} - 1\right| = 1.75$$

And according to theory material B would be selected. Assuming costs to be the same, it seems the method is not very sensitive to the weightings and gives a very controversial decision.

4.5.3 THE CARPENTER SELECTALOY SYSTEM

The Carpenter Technology Co. of Reading, Pa., USA, developed this system for the selection of stainless steels.

Since stainless steels vary in their chromium composition from as little as 12% to as high as 27%, there have arisen a wide variety of compositions each one designed for a particular task. The problem is to choose the right steel for the right application.

Selection is based upon five criteria:

1. Corrosion resistance
2. Mechanical properties
3. Fabrication operations
4. Total cost
5. Product availability.

The search begins with type 304, the familiar 18-8 alloys. If the steel required is subjected to more severe or less severe environments the choice then goes to other alloys of the type.

Once the level of corrosion resistance is established, the requirements for mechanical properties have to be ascertained. And as the five criteria are considered in turn, the field narrows down to a few steels which satisfy these criteria. The system suffers, however, from the a priori assumption of the material type, and a major part of the system is not automatic - the engineer has to consult a large number of data tables and charts to aid him in his analysis.

4.5.4 THE WHITTAKER CORPORATION SYSTEM

This is a more generalised system constructed by Duke and Kobrin of the Whittaker Corporation in Los Angeles, USA.[60]

Of primary consideration in this system is the definition of a material in terms of well-understood precise terms, i.e., the material must be well characterised. The Materials Advisory Board in the United States has defined 'characterisation' as describing those features of composition and structure of a material that are significant for a particular preparation, study of properties, or use, and suffice for reproduction of the material. Character is thus considered to consist of a precise description of the chemical composition, the factors associated with grain structure and other engineering properties.[52]

Once the characteristics are defined, tables are constructed where one column is a material, and the other columns show what parameters of the character can be controlled. Thus there is formed a relationship between material and character.

In another table, an attempt is made to determine what effect a particular manufacturing process has on the character.

Character affects properties, but from the above analysis it is now known what parameters of character should or could be controlled to change the properties; and what processes affect character and in turn how these processes change properties.

The main advantages of this type of character analysis is to suggest where research and development can make significant contributions. Character analysis will offer new insights into the capability of materials with the added advantage of'tailor-making' materials.

The major part of this system is primarily qualitative and will require a large amount of data compilation and evaluation. It also suffers from the fact that it does not weigh the properties but treats all properties as equally important.

4.5.5 THE FULMER MATERIALS OPTIMISER

The Fulmer Materials Optimiser is a new materials information system for the selection and specification of engineering materials.[61]

The system consists of four volumes of readily assimilated information on the performance and current costs of commercially available metals, plastics, ceramics and related component manufacturing processes, plus an unbiased method of selecting the optimum material for a given application.

There are two main reasons for the setting up of this information system.

1. To select and specify the materials and manufacturing route for a new product.
2. To evaluate alternative materials or manufacturing routes for an existing product.

The method of using the Optimiser for each of these purposes is as follows:

a. Selection and Specification of Materials and Manufacturing Routes for a New Product.

   1. Define the function of the product and translate into materials requirements of strength, stiffness, corrosion resistance, etc..
   2. Define the production requirements in terms of number required, tolerances, surface finish, etc.
   3. Search for possible combinations of materials and production routes and compile short list according to performance/cost relationship.
   4. Investigate candidate materials in more detail.

5. Specify optimum materials and processing routes.

b. Evaluation of Alternative Materials and Manufacturing Routes for an Existing Product.

1. Characterise currently used material in terms of performance, manufacturing requirements and costs (from internal data).
2. Evaluate which characteristics are necessary for product function.
3. Search for alternative materials and if permissible alternative manufacturing routes.
4. Compile short list of materials and manufacturing routes and estimate costs.
5. Compare existing materials and production routes with the alternatives.

The quantitative basis for optimising in this system is the well-known weighted properties factor. For each material, materials characteristics M_i are determined along with the relevant weighting factors W_i and the manufacturing cost C. The number of the characteristic considered is i and this value can range from 1 to n, where n is the total number of characteristics considered.

Thus compute,

$$\sum_{i=1}^{i=n} \frac{M_i W_i}{C}$$

for each material, and specify material/manufacturing route with maximum value of the summation.

The optimiser has been used to identify alternative materials for clients faced with supply problems or threatened with unprofitable production due to increased costs. Another application of the optimiser is the identification of the competition for a materials supplier's products and the opportunities for new markets.

4.5.6 INTERNATIONAL HARVESTER CHAT SYSTEM

This is a systems approach incorporating the use of a digital computer. Within International Harvester, it is called the CHAT system, an acronym standing for Computer Harmonised-Application Tailored.[62,63]

Application Tailoring, AT, is the quantitative determination of hardenability requirements, in terms of D_I, for a given application. D_I, is known as the "ideal diameter". The larger the D_I value, the greater the hardenability. The calculation of D_I relies on a series of hardenability factors for each alloying element in the composition: multiplied together, they give a D_I value.

AT involves a formalised process in which cooling rates are used to define the hardenability required to meet engineering design criteria such as hardness and microstructure.

A key factor in AT is the determination of the equivalent Jominy equivalent cooling R(Jec) Rate for a specific part given a production heating and quenching cycle. The Jec Rate at a given location in the material of a part is the cooling rate, expressed as J distance, or a Jominy bar of the same material that produces the same hardening response.

Computer Harmonised (CH) steels are designed with one of three objectives. These are 1) to provide a special steel that meets a component's AT requirements; 2) to aid in the selection of the most economical standard steel that meets a component's AT requirements; or 3) to develop replacement steels.

The distinction between using Computer Harmonising for the first or second objective lies in whether or not the tonnage requirements of the component justify a special steel. Using Computer Harmonising for the third objective provides a systematic method for devising chemical compositions for replacement steels, which are steels which match the base and case hardenability and other characteristics of the original steel.

In each instance, the resulting CH steel has a chemical composition that is optimised with respect to the cost of alloying elements.

The need for using a computer approach to develop a least-cost steel becomes apparent when the various aspects of the problem are considered. A least-cost steel which only needs to meet a specified base hardenability, D_{Ib}, value could be designed fairly easily by a manual method with tables or nomographs containing alloy costs and hardenability multiplying factors. When a carburising grade is designed, however, at least one additional restriction, a minimum case hardenability D_{Ic} value, is added to the problem. If further restrictions, such as the martensite start temperature (M_s) of the case and base analyses are added, it becomes impossible to find, manually, the least-cost combination of alloying elements that satisfies the multiple requirements.

The concept of cost minimisation while simultaneously satisfying a number of other requirements is a familiar one that has been dealt with through the use of linear programming.

Two restrictions must be placed on a set of equations for them to be solved by this method. First, an objective, such as cost, must exist to be optimised, and it must be expressable as a linear function. Second, there must be restrictions on the attainment of the objective, and these restrictions must be expressed as a system of linear inequalities.

The CHAT system is designed to optimise one property while simultaneously satisfying multiple restrictions. In the work described, the CH system determines the least costly alloy combination which will satisfy specified values for D_{Ib}, D_{Ic} and M_s. Other properties can be optimised and other restrictions added, provided all features can be expressed as quantitative functions of the chemical elements.

CHAPTER 5

COMPUTERISED MATERIALS SELECTION

Engineers in the past have been considering all the parameters as best they could but there has been no scientific approach in their method. To overcome this, the weighted property factors method was suggested. This method is the building block on which, the materials selection system described in the following sections is based.[64,65]

5.1 THEORY

The most important aspects in the selection of any material are the properties which will be required to withstand the service conditions. But since most service requirements dictate a combination of properties there should exist some system which will grade these properties according to their importance. For example, taking the case of overhead electrical conductors, electrical conductance is the most important parameter followed by the design strength particularly at the temperature encountered in service.

A little digression is necessary here to bring in the concept of design strength. The majority of engineering components fall into the category of 'unstressed' components, largely because the prime requirement is rigidity. In the case of 'stressed' components, however, the prime property required in the majority of cases is an adequate yield-point i.e. the component must not permanently change its dimensions when subjected to its maximum service stress. It is most unfortunate, therefore, that the general practice is still to discuss engineering materials largely on the basis of ultimate tensile strength.

For the purpose of the present work, yield strength has been used as the criterion for calculating design strength for all ductile materials. For brittle materials, a factor of safety of 2 has been incorporated in the data, and therefore, design strength is half the ultimate tensile strength.

Returning back to the overhead electrical conductor, electrical conductance can be given a weighting of 10 and design strength a weighting of 5. This indicates approximately that conductance is considered to be twice as important as strength for this particular application. Thus a material which has the higher weighted average would be selected - not considering the cost aspect for the time being. The weighted average in this case would be -

$$\text{weighted average} = \frac{(10 * \text{Conductance}) + (5 * \text{Strength})}{10 + 5}$$

To a conventional designer, this approach would seem dubious and he may not accept it at first. But designers have been using this very method by mentally assigning a relative scale of importance to various performance requirements.

Consider the following example -

An overhead electrical conductor is to be designed and its service parameters are known. Only two properties are thought to be of importance, Design Strength and Electrical Conductance and the latter, is the more important criterion.

Material	Design Strength (N/mm^2)	Conductance (IACS)
A	500	50
B	1000	10
Weighting	5	10

The weighted averages or the Weighted Property Factors (WPF) of A and B are next calculated, and the material with the higher WPF is the one which should be selected.

$$WPF_A = \frac{(500 * 5) + (50 * 10)}{5 + 10} = 200$$

$$WPF_B = \frac{(1000 * 5) + (10 * 10)}{5 + 10} = 340$$

Hence even though conductance was considered to be the dominant property, in accordance with the calculations, material B (with lower conductance) should be selected.

Two difficulties are immediately apparent:

1. The design strength is in N/mm^2 and the conductance is in International Annealed Copper Standard (IACS). Can unlike units be combined as above and would that have any rational meaning? The NASA Weighted Index System and the Fulmer Materials Optimiser suffer from this problem.

2. The deisgn strength has a much higher absolute value than conductance, hence the sheer order of values will wipe out any influence of conductance and a material with higher design strength will nearly always have a higher WPF irrespective of electrical conductance.

Therefore to overcome these shortcomings the following modification is suggested. Each property is scaled to range from 0 to 100, such that the highest recorded properties value is given a rating of 100 and the rest are scaled accordingly. Hence all materials will have all their properties ranging from 0 to 100. Factors which accomplish this conversion are called Scaling Factors (SF). The calculations now use Scaled Property values instead of Actual Property values.

SF = 100/(Maximum value in list)

Scaled Property = Actual Property * SF

By doing this, i) each property is given equal importance and will affect the WPF according to its weighting only, and ii) the units are dropped and the properties can be added and multipled when necessary. They become dimensionless and so does the WPF.

Continuing with the same overhead electrical conductor but with scaling factors incorporated in the analysis an entirely different picture appears. In the given list of two materials, the maximum value of design strength is 1000 N/mm^2 and Conductance 50 IACS.

Material	DS	MAX	SF	COND	MAX	SF
A	500	1000	$\frac{100}{1000}=0.1$	50	50	$\frac{100}{50}=2$
B	1000	1000	$\frac{100}{1000}=0.1$	10	50	$\frac{100}{50}=2$
Weighting	5			10		

Using scaled properties,

$$WPF_A = \frac{(500 * 5 * 0.1) + (50 * 10 * 2)}{5 + 10} = 83$$

$$WPF_B = \frac{(1000 * 5 * 0.1) + (10 * 10 * 2)}{5 + 10} = 47$$

Hence the calculations now favour the material with the higher conductance in accordance with the weighting and requirements.

Generalising the above theory, if

P_{ji} = property j of material i

W_j = weighting factor for property j

SF_j = scaling factor for property j

NC = number of material characteristics considered

and WPF_i = weighted property factor for material i, then

$$WPF_i = \frac{\sum_{j=1}^{NC} (P_{ji} * W_j * SF_j)}{\sum_{j=1}^{NC} (W_j)} \qquad \ldots\ldots\ldots\ldots \qquad 1$$

Since materials selection is also a comparison exercise between materials, a Basis Material BM, is assumed, against which we compare the other materials. All parameters relating to the Basis Material will be denoted by the subscript 1, whilst all parameters for the other materials will be denoted by the subscript i, ranging from 1 to N, where N is the total number of materials in the selection system.

Once the Weighted Property Factors have been calculated, the next step is to calculate the Relative Weighted Property Factor (RWPF), which is effectively comparing the WPF of material i with that of the Basis Material.

$$RWPF_i = \frac{WPF_i}{WPF_1} \qquad \ldots\ldots\ldots\ldots \qquad 2$$

The higher the value of $RWPF_i$ the better it is for material i as it has more to give in terms of properties for that particular service. The RWPF is a kind of overall property of a material, with the property weightings incorporated depending on the service requirements. The RWPF is thus a comparison between the overall combined properties of two materials.

The Relative Cost (RC), between material i and the Basis Material is next calculated. From elementary analysis (see Appendix 1) it is known that:

$$RC_i = \frac{P_{j1}}{P_{ji}} * \frac{S_i}{S_1} * \frac{K_i}{K_1} \qquad \text{............} \quad 3$$

where,

P_{j1} = Property j of Basis Material 1
P_{ji} = Property j of material i
S_1 = Density of BM 1
S_i = Density of material i
K_1 = Cost per tonne of BM 1
K_i = Cost per tonne of material i

Then, Cost per Unit Requirement (CUR), is calculated as:

$$CUR_i = \frac{RC_i}{RWPF_i} \qquad \text{...........} \quad 4$$

If $CUR_i<1$ material i is cheaper than BM 1
If $CUR_i=1$ material i is equal in cost to BM 1
If $CUR_i>1$ material i is dearer than BM 1

Thus, lesser the CUR, the better it is and a material with least CUR would be the cheapest for a chosen service requirement.

Again returning to our overhead electrical conductor, cost and density were neglected from the analysis. Assuming that materials A and B belong to a large family of alloys, and that material B is the basis material, established on the market, while A is a new alloy challenging B for market dominance.

Density of A = 7850 kg/m^3 cost of A = £500/tonne
Density of B = 7850 kg/m^3 cost of B = £400/tonne

then,

$$RWPF_A = \frac{WPF_A}{WPF_B} = \frac{83}{47} = 1.77$$

and

$$RC_A = \frac{P_B}{P_A} * \frac{S_A}{S_B} * \frac{K_A}{K_B}$$

$$= \frac{10}{50} * \frac{7850}{7850} * \frac{500}{400} = 0.25$$

The dominant or cost-determining property is incorporated into this formula. Since in the above case electrical conductance is the primary property, it was used.

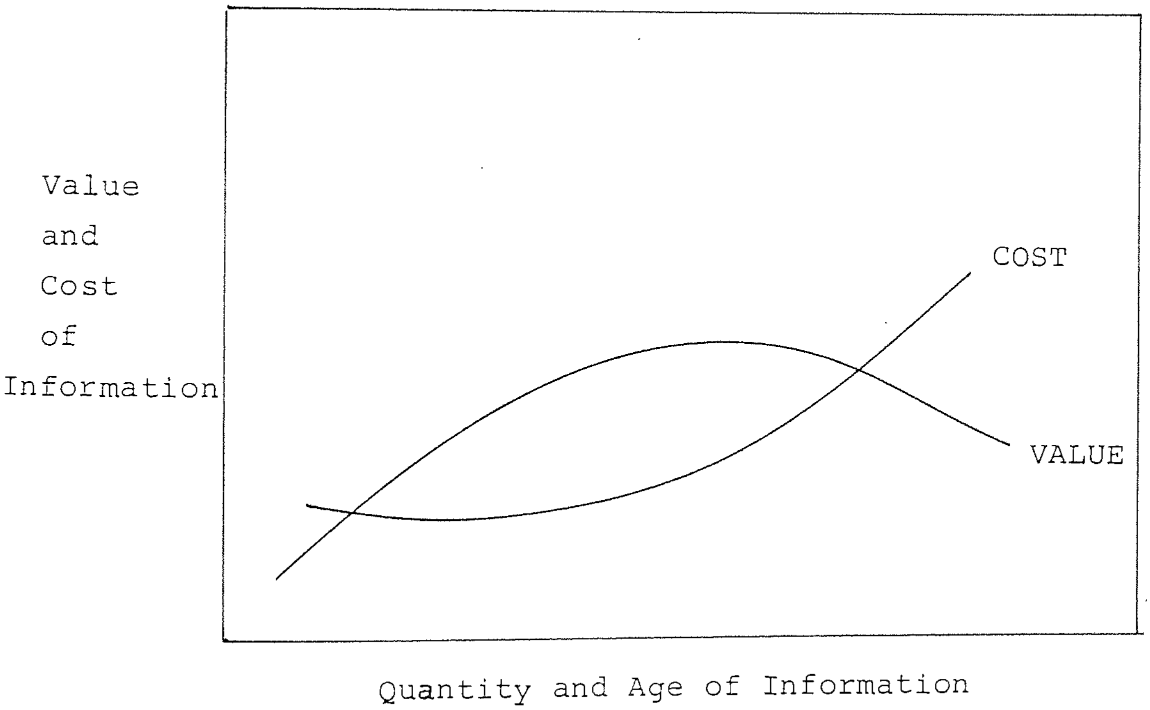
$$CUR_A = \frac{RC_A}{RWPF_A} = \frac{0.25}{1.77} = 0.14$$

Therefore alloy A is cheaper than basis material B.

5.2 INFORMATION AND KNOWLEDGE

In a society such as ours, one that benefits greatly from the use of mass communications and computer facilities, information is a valuable commodity. In fact, people concerned with the social aspects of computing emphasise that "information is power", and that it can be used as a control mechanism to influence the behaviour of individuals and organisations. However, major problems arise in information-based societies when information is not up-to-date. As depicted in Fig. 5.1 the value of information changes with age.

FIG. 5.1



Two major components of the value of information are "quantity" and "quality". The quantity of information is measured in terms of volume, completeness and accessability. The volume of information refers to the capacity of the system and the amount of information that is available for use by a user of the information system. There is a natural limit to the volume of information that a system can store and a user can reference. As shown in Fig. 5.1, this limit is reached when the cost of storing and maintaining the information exceeds its value. Most information systems utilise a storage hierarchy concept, wherein infrequently used information can be stored on a relatively inexpensive storage facility.

The capacity of an information system is also related to the efficiency of the system or the accessibility of information, since there exists a relationship between the volume of a storage medium and the speed of access. Completeness refers to the degree to which an information system satisfies the information needs of a user. Completeness can also be transformed into an economic variable since complete information is obviously of greater value than incomplete information but is more costly to maintain. The last attribute of the quantity of information is accessibility, which denotes the response time of the system and the facilities available for using it. To sum up, the quantity of information is not an absolute measure, but rather, is a "trade-off" between the value and cost of information.

The quality of information implicitly relates to how information can be used and the degree of confidence that can be placed on it. The attributes of quality are timliness, relevance, accuracy, reliability and flexibility. Timeliness, refers to the process of collecting, storing and processing of data and the time factors involved. The relevance of information is the measure of how well the information system meets the needs of the user. Accuracy refers to errors in the collecting, storing and processing of data, and may refer to explicit inaccuracies caused by faulty data or implicit inaccuracies caused by information that is out-of-date. Reliability is an operational characteristic that measures the degree of confidence that the user can place on the information system and the information it contains. Flexibility is the last attribute of information and of an information system and indicates the diversity of applications for which a given information set can be used.

The world is filled with information. It is inherent in the design of builidngs and automobiles, the structure of organisations and the operations of groups and teams. Yet to a computer or information scientist, it becomes data only when it is recorded on a storage medium of some kind. Informally, information may be regarded as raw or processed data used for making decisions. Knowledge implies organisation and is defined as the systematic organisation of information and concepts, and can also be further defined as the assignment of meaning to information.

Information is a prerequisite for growth.[66] To paraphrase Boulding[67]: only information and knowledge escape from the iron laws of conservation and decay. This is to assert that information is the fundamental source of all productivity and growth.

5.3 MATERIALS SELECTION AND INFORMATION SYSTEMS

One of the biggest stumbling blocks in conducting a large scale evaluation of materials and processes is the sheer amount of data that has to be processed to insure that nothing is missed out, it is frequently necessary to evaluate a considerable number of materials and, quite often, a wide range of engineering properties and designs. These data have to be assembled, analysed and classified into a useful form. Confronted with these problems, the use of a computer seems the only logical answer.

A computer can only effectively select materials if it is given complete and up-to-date data in the whole spectrum of engineering materials. However, it appears that in the future it will be possible to plug data on a large number of materials into a computer so that, if a given property or combination of properties is required, the entire range of materials that meet the requirements could be read out. A pioneering work in the field of computerised materials selection has been carried out at the University of Aston in Birmingham.[64,65,68]

This work described later approaches the kind of system mentioned above.

Eventually it should be possible to create a computerised materials information centre where for a fee, a company could obtain a complete screening and selection of materials to meet the requirements of a product.

Big engineering organisations are accumulating information about materials and processes for a computerised materials data file,[69] and in the future computerised information, where all the parameters can be taken into consideration, will be used to an increasing extent.

The process of filing, storage, search and retrieval, though difficult, are manageable by computer technology. The acquisition and classification of reliable and comprehensive data is the heart of the system. Acquisition of data, however, is largely a human and social operation, and classification and analysis are intellectual tasks. To be useful, data must be accurate, timely and complete before processing. The basic task is to establish standard terms and parameters, so that programs for processing or analysing may be founded on reality.

As Milek[70] points out, we are in the midst of an information explosion and to meet this explosion numerous Information Analysis Centres have arisen especially in the United States. Milek lists some of their characteristics:

1. Provides technical information service to industrial, university and governmental organisations.

2. Possesses a genuine interest in the fields of information retrieval and materials engineering.

3. Is service oriented, to be of assistance to engineers, designers, management etc..

4. Possesses a staff of broad interdisciplinary technical background and education.

5. Possesses a knowledge of and capabilities for data

processing.

6. Generate new data and information by assembling and evaluating the best data and information from a wide range of sources.

A lot of work has been done on developing data centres for mineral resources. In 1965, the Canadian National Advisory Committee on Research in the Geological Sciences began development of a national system for geological data storage and retrieval.[71] The analysis of Canadian Northwest data contributed to the decision to create a transportation corridor through the Canadian Northwest.

Advanced data systems in France and the U.S.S.R. cover both domestic and international mineral resources.

Three systems functioning in the United States are the CRIB (Computerised Resources Information Bank) system of the United States Geological Survey which has 13000 domestic entries and 1000 entries of international data,[72] the MERIT (Mines, Energy, Resources, Information and Transportation) system of the Bureau of Mines, and the MAS (Minerals Availability System) system of the Bureau of Mines.[73]

5.4 COMPUTER TECHNOLOGY AND SYSTEMS

Results achieved from the implementation of computer systems always depend on a compromise between requirements and technology.

Changes in computation speed and density of stored information characterise the rapid development of computer technology since 1945. At the beginning of the 1970's, the major swing to monolithic memories greatly improved the economics of computer systems,[74] as shown in Fig. 5.2.

Between 1955 and 1975, speed increased from $9*10^3$ to $2*10^6$ instruction/sec. In the same period the cost of storing information decreased from 12.0 to 0.5 cents/character. This indicates a tremendous improvement in the so-called price/performance factor, which is one way of stating the amount of work a computer system can perform per unit cost. Instant access at a reasonable cost to billions of characters of information, stored in complex data banks, is not unusual anymore.

Four categories of data processing involved in an integrated data processing system as shown in Table 5.1. The required system response time, which is the time elapsing between a request for action and system response, as well as the complexity of the necessary data storage, illustrates the difference between particular categories. Computerised materials selection involves the first two categories both of which have been successfully implemented at the University of Aston in Birmingham.

The first two categories, batch and on-line processing are ideal for minicomputers. A minicomputer costs around $50,000, and it can do a good deal of work of computers

FIG. 5.2
DEVELOPMENT OF DATA PROCESSING SYSTEMS

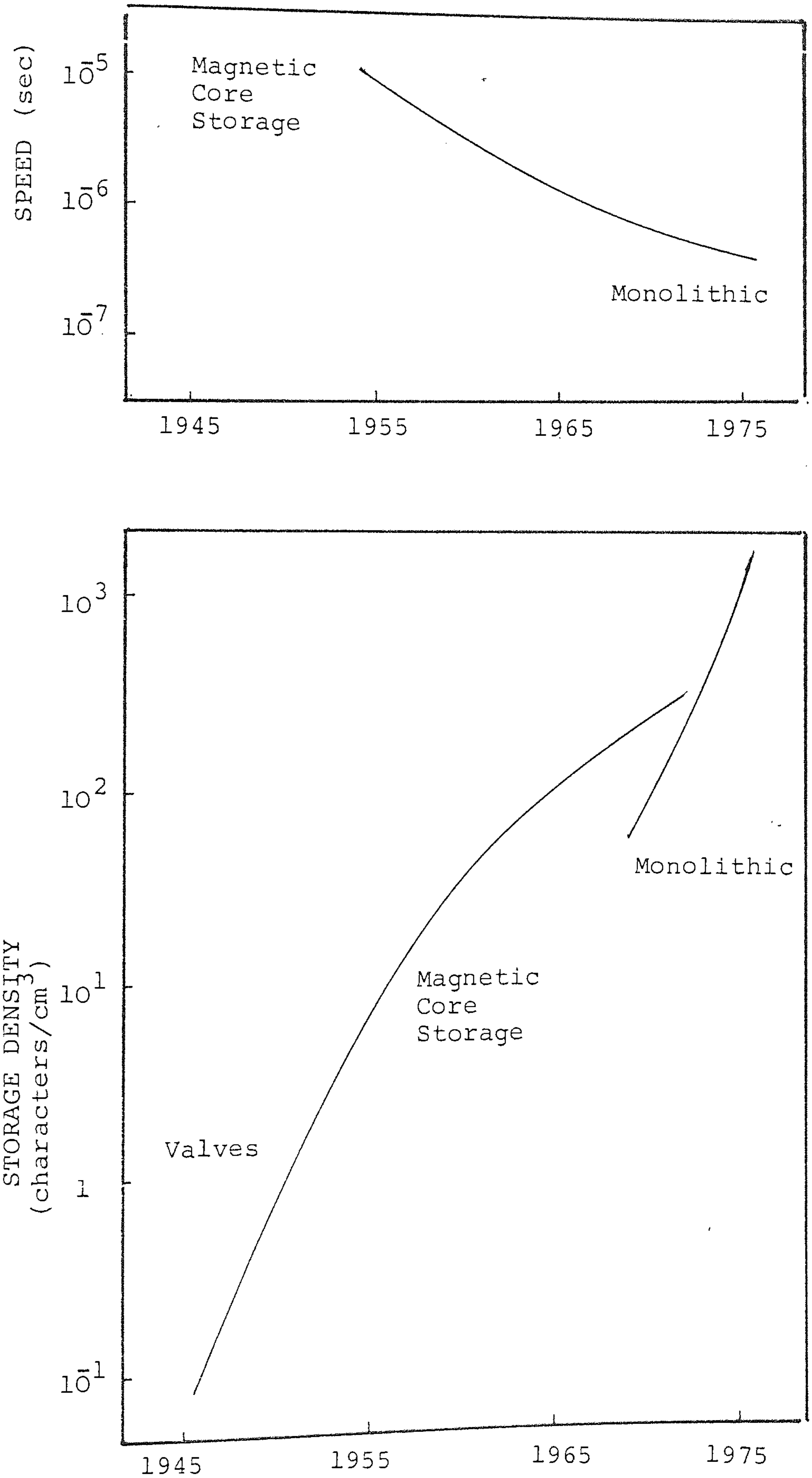


TABLE 5.1

DATA PROCESSING CATEGORIES AND APPLICATIONS

CATEGORY	SYSTEM RESPONSE TIME	DATA STORAGE COMPLEXITY	APPLICATIONS
BATCH	Processing once in 8 hours, or on user's request	Very complex	Payroll, budget, costs invoicing, material balances, etc.
ON-LINE	>5 sec	Complex	Order entry, production planning and scheduling, simulation, etc.
REAL-TIME INTERACTIVE	≤5 sec	Relatively simple	Production control, process control, stores control, etc.
EVENT-DRIVEN AUTOMATIC PROCESSING	<1 sec	Simple	Process control, supervisory control, data acquisition, etc.

costing around $2,000,000. Stated another way, minis cost approximately one fortieth of large computers, but they can do a great deal more than one fortieth of the work.

In table 5.2 the key design characteristics of large, medium and small computers have been outlined. Large computers are represented by the IBM 370/168, medium computers are represented by the IBM 370/135 and minicomputers by the DEC PDP 11/45. Other comparable large computers include the Burroughs B 6700, the Univac 1110, the CDC Cyber 175 series and the ICL 2980. Other comparable medium computers include the Burroughs 3700, the Honeywell 2050 and the ICL 1904S. Finally, other comparable minicomputers include the Data General Nova 840 and the Varian V73.[75,76]

Two general observations can be drawn from this table. First, though the minicomputer is not as "powerful" as the large or medium computer, it is surprisingly close, considering the substantial price differentials. One reason for this closeness is that is has been possible to utilise new hardware technology earlier in minis than in large machines because, there is a smaller investment in hardware and software design for a mini. Consequently, a vendor can produce and integrate a new mini into his line much more rapidly than a large computer.

Since an important characteristic of new technology in the computer field has been rapidly decreasing cost, the price for a given amount of power in minis has been lowered consistently and quite rapidly. For example, in

TABLE 5.2
TECHNICAL COMPARISON OF COMPUTERS (LARGE, MEDIUM, MINI)

Key computer architectural characteristics	Large computer IBM 370/168	Medium computer IBM 370/135	Minicomputer Digital Equipment PDP 11/45	Effect Minicomputer vs. medium and large computers	Signficance Minicomputers vs. medium and large computers
HARDWARE					
Word length	32 bits (a bit is equivalent to a binary digit)	32 bits	16 bits	Size of readily addressable program or data areas is restricted instruction repertoire is smaller	Efficiently implemented higher level languages are hard to provide thus only a few exist. Large applications execute less efficiently and are harder harder to program.
Maximum memory size	8,400,000 bytes (a byte consists of 8 bits which provides enough binary digits to to represent one numeric or alphabetic character)	524,000 bytes	262,000 bytes	Multiprogramming (the ability to execute programs simultaneously) is restricted. Substantial manipulation of large arrays of data is restricted.	The multiprogramming limitation is not significant, since minis are relatively inexpensive and can thus be dedicated to one or a few applications.
Data capacity: Memory path (width of the link between the main memory and central processor)	64 bits	16 bits	16 bits	Execution is less efficient	The data capacity architecture of the large computer makes it more effective for large data processing demands in a multiprogramming environment.
Number of channels (channels operate the 1/O devices)	Many	A few	One	Configuration and overlap of activity of 1/O devices are restricted	
1/O channel data rate (the rate that data can be transferred over all channels to main memory)	16,000,000 bytes/second	2,400,000 bytes/second	2,360,000 bytes/second	Simultaneous transfer of data from multiple 1/O devices is restricted (compared with the large computer)	

ey computer rchitectural haracteristics	Large computer IBM 370/168	Medium computer IBM 370/135	Minicomputer Digital Equipment PDP 11/45	Effect Minicomputer vs. medium and large computers	Significance Minicomputers vs. medium and large computers.
rocessor architecture: entral processor unit ycle time (how fast nstructions can be arried out)	80 nanoseconds (1 nanosecond= 1 billionth of a second)	275 nanoseconds	300 nanoseconds	Instruction execution is slower compared with large computer	The mini is restricted to applications requiring substantial processing activity; such activity is not typical of business applications
emory cycle (how ast instructions or lata can be retrieved rom main memory;it should be considered together with the width of the memory path)	480 nanoseconds	800 nanoseconds	850 nanoseconds	Instruction and data transfer to memory is somewhat slower (compared with large computer).	
Number of basic instructions	Approximately 150	Approximately 140	Approximately 80	Execution is less efficient.	
SOFTWARE					
Operating systems: Batch (application programs are submitted to computer in self-contained units with no strict timing requirements)	Multi-programming (Batch applications are run simultaneously)	Multi-programming	Multi-programming (2 programs only)	Computer system resources can be sufficiently utilised in each case.	Systems software for the large and medium computer is complex and designed for multiple tasks in order to share expensive resources; this is not necessary for the mini, since it is relatively inexpensive.
Real time (application programs are called into operation in response to requests from I/O devices)	Separate tele-communications system added to other operating system facilities	Same as for large computers	Computer must be dedicated to time sharing	Time sharing on a mini is usually dedicated to one application	

ey computer rchitectural naracteristics	Large computer IBM 370/168	Medium computer IBM 370/135	Minicomputer Digital Equipment PDP 11/45	Effect Minicomputer vs. medium and large computers	Significance Minicomputers vs. medium and large computers
me sharing	Supported simultaneously with other systems by addition of separate facilities	Same as for large computers	Computer must be dedicated to time sharing	Time sharing on a mini is usually dedicated to support of on-line terminals.	Systems software for the large and medium computer is complex and designed for multiple tasks in order to share expensive resources; this is not necessary for the mini,since it is relatively relatively inexpensive
rogramming anguages	All 8 major languages	All 8 major languages	Four major languages	COBOL is only gradually becoming available for some minis, which is significant limitation for companies using COBOL as a standard language	Language for some applications may not be perfectly appropriate, but this distinction is not critical since there are enough languages available for minis
Program development Aids (e.g. debugging aids, checkout compilers)	Many	Many	Limited	Programming efficiency is inhibited	More highly skilled applications programmers are required
Application packages (e.g. payroll, bill of materials, models)	Thousands	Thousands	Hundreds	Users must program more applications in-house	More cost is involved in programming, if packages available for large or medium machines
Additional Considerations					
Reliability	High	High	Very high; time to fix is brief because of relative simplicity	The mini is likely to be more reliable, but the distinction is unlikely to be important for most applications	Reliability and vendor support must be considered together

ey computer rchitectural haracteristics	Large computer IBM 370/168	Medium computer IBM 370/135	Minicomputer Digital Equipment PDP 11/45	Effect Minicomputer vs. medium and large computers	Significance Minicomputers vs. medium and large computers
rchase cost	Millions of dollars	Hundreds of thousands of dollars	Tens of thousands of dollars	Minis are substantially cheaper	Purchase and operational cost are the most significant advantages minis have over large and medium computers.
erating equirements	Considerable amount of specially prepared space and air conditioning; operators and well-trained systems programmers required	Same as for large computers	One operator per shift, no special site preparation, good systems programmers requried	Operational costs are much lower	

1965, it cost $25,000 to purchase a machine with 4096 16-bit words and a 2 microsecond cycle time. Because of advances made in microtechnology, by 1974 it cost $2,000 to purchase a machine with similar capabilities.

The second general observation concerns software. Large machine software is more advanced, and thus applications with complex programming require a large or medium machine. However, minicomputer manufacturers have recognised that one of their next big markets is the end-user business application, and so over the past two years they have begun to make substantial investments in software development. As a result, it is now possible to use minicomputers as easily as large machines for many business and technical applications.

Having discussed materials selection, information bases and computer technology, the rest of this chapter is devoted to explaining the concepts, the software and the system developed at the University of Aston in Birmingham by the author.

5.5 THE ASTON COMPUTER SYSTEM

In common with all other UK universities, Aston operates a central computing service. At the present time, this service is based on equipment provided and substantially supported by the Computer Board for Universities and Research Councils. The provision of this service, together with the normal departmental teaching and research function, is the responsibility of the Computer Centre.

5.5.1 ASTON HARDWARE

An ICL 1904S replaced an ICL 1905E in July, 1975 and was operated on a 3-shift basis, i.e. 24 hours/day for 5 days a week.

1904S Central Processing Unit with hardware floating point, 192K words of 500 nanosecond store (K = 1024, 1 word = 24 bits).

Input:

2101 card reader, 2000 cards/minute,

1916 paper tape recorder, 1000 characters/second.

Output:
1933 line printer, 1350 lines/minute, 120 characters/line

1925 paper tape punch, 110 characters/line

1934 graph plotter.

Magnetic Tapes:

4 Magnetic tape decks using 0.5" magnetic tapes. Information is stored across 7 tracks at a density of 556 characters/inch. The maximum transfer rate is 20,800 characters/second.

4 magnetic tape decks using 0.5" magnetic tapes. Information is stored across 9 tracks at a density of 1600 characters/inch. The maximum transfer rate is 160,000 characters/second.

Magnetic Discs:

4 exchangeable disc drives, each drive holding 8,192,000 characters stored on 203 tracks.

The transfer rate is 208,000 characters/second.
4 exchangeable disc drives, each drive holding 60,000,000 characters stored on 203 tracks.
The transfer rate is 416,000 characters/second.

Magnetic Drums:
1 1964 Slow speed drum with storage capacity of 512 K words. The maximum transfer rate is 100 K characters/second.
1 2851 High speed drum with storage capacity of 512 K words. The maximum transfer rate is 1300 K characters/second.

A Digico Micro 16V acts as a front end processor to the 1904S mainframe.

5.5.2 OPERATING SYSTEM CONCEPTS

An operating system is an organised collection of programs and data that are specifically designed to manage the resources of a computer system and to facilitate the creation of computer programs and control their execution in that system. The operating system performs the following main functions: 1) it reads control cards; 2) it allocates input/output devices and storage space to the job; 3) it loads processing programs into storage and initiates their execution in the processing unit; 4) it terminates job processing.

Modern operating systems utilise an operational technique known as multiprogramming that allows several jobs to share the resources of the computer system. Each job is given control of the processing unit according to a scheduling algorithm and executes in the processing unit until one of two events occurs:

1. The program comes to a natural wait condition, such as for an input operation.

2. The program has exceeded the time allocated to it. Control of the processing unit is then given to another job and the process continues.

The ICL 1904S computer at the University of Aston in Birmingham is controlled by the GEORGE 3 operating system (an acronym for GEneral ORGanisation Environment), a permanently active program which controls: running of jobs, scheduling of jobs, manipulation and security of files, multiaccess from terminals and remote job entry.

The term "job" will occur frequently throughout this work. A job is the execution of a series of related processing programs that comprise a total processing application. It is a unit of work for the computer. It refers to the running of a program or programs on the computer, with input, processing and output. A job can occupy the machine for seconds or hours and may be completely self-contained or may use library or systems programs.

Information held in the computer storage system (whether text, data, libraries,etc.) is organised into "files". A file is a set of related records. The structural characteristics of a file govern how the storage elements in the file are organised and how they can be assessed. The content of a file is determined by its user; although records can have different formats, the data records stored within a file are usually stored for a common purpose.

Files are device independent and the GEORGE operating system controls the physical arrangement of all files in the system, known collectively as the filestore.

5.5.3 MOP

The programs designed for materials selection in a dynamic environment must be interactive. Computing activities are described as interactive if the user is able to monitor and control a program while it is actually running. There can be no substitute for a genuinely interactive system in application where it is essential to maintain large quantities of fully up-to-date information available for reference at any time. Such a program requires the use of a multi-access system in programming.[77] A multi-access system is one in which a large number of users can "converse" with the same computer via terminals linked directly to it. The Multi-access system is known as MOP, which is an acronym for Multiple On-line Programming. The terminals used with the 1904S are of two types; these being teletypes and video display units (VDU). The teletypes consist of a typewriter-like keyboard with additional keys used for control purposes. The user types messages on the keyboard, and the computer responds by printing on the telewriter log. The video display units are very similar to the teletypes, but instead of a typewriter log they have a television screen on which the input and output messages are displayed. Thus no hard copy i.e. a permanent paper record is produced by this type of terminal, but it can be requested and collected later.

The main advantages of using MOP are:

1. While a user is in direct communication with the computer, he is said to be "on-line" and the MOP system will keep him informed of the state of his job. For example, if his program goes illegal, a message will be printed out, saying that this has happened and why.

2. The user can communicate with the computer; for example, he can ask the computer to load a program in the core store of the computer.

3. Program editing is possible. When using a MOP terminal, a user can communicate not only with the system but with any program that he is running from the terminal by using his teletype to type in data or receive output from it. Program compiling and testing is much quicker and easier since the user can see how the program handles the data. The MOP use can alter the contents of the files held in the filestore by using editing facilities.

4. Jobs can be run completely interactively. This is perhaps the most important advantage as far as materials selection

is concerned. By using MOP, information can be read into the program in two ways. Information already stored in file can be linked up and made available to the program and information can be fed in directly via the terminals at some intermediate stage and the computer, after acceptance of this information, will proceed to carry out its next operation. Thus information fed in at the intermediate stage will decide the path the program will take and leads to the building of a "decision tree" type of program. The user is always able to monitor and control the program while it is running.

5. Apart from the major time savings by cutting out the "middleman" of conventional data preparation, another advantage is the complete avoidance of unnecessary paper documentation, since the terminals can always be located at the point where the transaction is generated.

5.6 THE MATSEL PROGRAM

This is a general purpose MATerial SELector (MATSEL) program developed primarily for the selection of steels according to BS 970 specifications.[78]

British Standards specifications serve to identify steels with respect to their chemical composition, mechanical properties and hardenability. The treatments given to steels not only affect the mechanical properties but also dictate their prices. The maximum ruling sections that can be attained

```
DOCUMENT     MATSELD

 0      1/6
 1 20 C STEEL      CODR 070M20  136.60  525  385  12        13   16
 2 20 C STEEL      CODR 070M20  136.60  495  370  12        17   40
 3 20 C STEEL      CODR 070M20  136.60  465  355  13        41   63
 4 20 C STEEL      CODR 070M20  136.60  430  340  14        64   76
 5 20 C STEEL      NORM 070M20  151.60  430  215  21            150 126 179
 6 20 C STEEL      NORM 070M20  151.60  400  200  21            250
 7 20 C STEEL      HATE 070M20  165.60  625  355  20  30         19 152 207
 8 30 C STEEL      CODR 080M30  138.30  600  450  10        13   16
 9 30 C STEEL      CODR 080M30  138.30  570  430  11        17   40
10 30 C STEEL      CODR 080M30  138.30  560  420  12        41   63
11 30 C STEEL      CODR 080M30  138.30  530  390  12        64   76
12 30 C STEEL      NORM 080M30  153.30  490  245  20            150 143 192
13 30 C STEEL      NORM 080M30  153.30  430  230  19            250
14 30 C STEEL      HATE 080M30  167.30  620  355  18  25         63 152 207
15 30 C STEEL      HATE 080M30  167.30  690  415  16  25         19 179 229
16 46 C STEEL      CODR 080M46  141.60  690  555   7        13   16
17 46 C STEEL      CODR 080M46  141.60  660  525   8        17   40
18 46 C STEEL      CODR 080M46  141.60  620  480   9        64   76
19 46 C STEEL      NORM 080M46  156.60  620  310  14             63 179 229
20 46 C STEEL      NORM 080M46  156.60  540  280  15            250
21 46 C STEEL      CODR 080M46  141.60  650  510   9        41   63
22 46 C STEEL      HATE 080M46  170.60  690  370  16            100 179 229
23 46 C STEEL      HATE 080M46  170.60  770  450  16             29 201 255
24 46 C STEEL      HATE 080M46  170.60  850  525  14             13 223 277
25 55 C STEEL      CODR 070M55  141.00  790  620   7        13   16
26 55 C STEEL      CODR 070M55  141.00  760  600   7        17   40
27 55 C STEEL      CODR 070M55  141.00  740  585   8        41   63
28 55 C STEEL      CODR 070M55  141.00  710  570   9        64   76
29 55 C STEEL      NORM 070M55  156.00  690  355  12             63 201 255
30 55 C STEEL      NORM 070M55  156.00  600  310  13            250
```

```
31 55 C STEEL     HATE 070M55  170.00  770  415  14            100 201 255
32 55 C STEEL     HATE 070M55  170.00  850  480  14             63 223 277
33 55 C STEEL     HATE 070M55  170.00  930  570  12             19 248 302
34 19 C,MN STEEL  CODR 120M19  139.40  600  450  11       13    16
35 19 C,MN STEEL  CODR 120M19  139.40  570  430  11       17    40
36 19 C,MN STEEL  CODR 120M19  139.40  555  415  12       41    63
37 19 C,MN STEEL  CODR 120M19  139.40  525  385  12       64    76
38 19 C,MN STEEL  NORM 120M19  154.40  490  295  20   25       100 143 192
39 19 C,MN STEEL  NORM 120M19  154.40  460  265  19            250
40 19 C,MN STEEL  HATE 120M19  168.40  620  355  18   35       100 152 207
41 19 C,MN STEEL  HATE 120M19  168.40  690  450  16   35        29 179 229
42 19 C,MN STEEL  HATE 120M19  168.40  770  510  16   25        19 201 255
43 36 C,MN STEEL  CODR 120M36  139.90  690  555   7       13    16
44 36 C,MN STEEL  CODR 120M36  139.90  660  525   8       17    40
45 36 C,MN STEEL  CODR 120M36  139.90  650  510   9       41    63
46 36 C,MN STEEL  CODR 120M36  139.90  620  480   9       64    76
47 36 C,MN STEEL  NORM 120M36  154.90  590  355  15            150 174 223
48 36 C,MN STEEL  NORM 120M36  154.90  570  340  16            250
49 36 C,MN STEEL  HATE 120M36  168.90  690  415  18   30       100 179 229
50 36 C,MN STEEL  HATE 120M36  168.90  770  510  16   25        29 201 255
51 36 C,MN STEEL  HATE 120M36  168.90  850  570  14   25        19 223 277
52 [ 28 CARBON    CODR 216M28  142.80  570  430  10       13    16
53  FREE CUTTING  CODR 216M28  142.80  540  400  10       17    40
54   STEEL ]      CODR 216M28  142.80  530  385  11       41    63
55 [ 28 CARBON    CODR 216M28  142.80  490  370  12       64    76
56  FREE CUTTING  HATE 216M28  171.80  620  355  20   25        63 152 207
57   STEEL ]      HATE 216M28  171.80  690  430  18   25        19 179 229
58 [ 36 CARBON    CODR 212M36  142.80  620  480   7       13    16
59  FREE CUTTING  CODR 212M36  142.80  590  450   7       17    40
60   STEEL ]      CODR 212M36  142.80  570  430   8       41    63
```

```
61 [ 36 CARBON    CODR 212M36   142.80   540   400    9          64   76
62  FREE CUTTING  HATE 212M36   171.80   620   340   20    25         100  152  207
63   STEEL ]      HATE 212M36   171.80   690   400   18    25          63  179  229
64                HATE 212M36   171.80   770   495   16    40          13  201  255
65 1% NI STEEL    NORM 503M40   207.20   620   310   15               250  152  207
66 1% NI STEEL    NORM 503M40   207.20   620   325   15    15         150  152  207
67 1% NI STEEL    NORM 503M40   207.20   620   325   15    20         100  152  207
68 1% NI STEEL    HATE 503M40   221.20   690   430   15    20         250  179  229
69 1% NI STEEL    HATE 503M40   221.20   690   465   17    25         150  179  229
70 1% NI STEEL    HATE 503M40   221.20   690   465   17    35         100  179  229
71 1% NI STEEL    HATE 503M40   221.20   770   525   17    35          63  201  255
72 1% NI STEEL    HATE 503M40   221.20   850   585   15    30          22  223  277
73 1% CR STEEL    HATE 530M40   208.20   770   525   17    40         100  201  255
74 1% CR STEEL    HATE 530M40   208.20   850   585   15    40          63  223  277
75 1% CR STEEL    HATE 530M40   208.20   930   680   13    40          29  248  302
76 [ 1.5% MN,MO   HATE 605M30   215.10   770   525   17    40         150  201  255
77                HATE 605M30   215.10   850   585   15    40         100  223  277
78  WATER HARDE- HATE 605M30   215.10   930   680   13    40          63  248  302
79                HATE 605M30   215.10  1000   755   12    35          29  269  331
80  NING STEEL ]  HATE 605M30   215.10  1080   850   12    35          19  293  352
81 [1.5% MN,MO    HATE 606M36   219.00   770   525   15    40         100  201  255
82  FREE CUTTING  HATE 606M36   219.00   850   585   13    35          63  223  277
83   STEEL ]      HATE 606M36   219.00   930   680   11    30          29  248  302
84 [1.5% MN,MO    HATE 608M38   221.40   770   495   15    30         250  201  255
85                HATE 608M38   221.40   770   525   17    40         150  201  255
86  STEEL WITH    HATE 608M38   221.40   850   555   13    25         250  223  277
87                HATE 608M38   221.40   850   585   15    40         150  223  277
88  HIGHER MO ]   HATE 608M38   221.40   930   680   13    40         100  248  302
89                HATE 608M38   221.40  1000   755   12    35          63  269  331
90                HATE 608M38   221.40  1080   850   12    35          29  293  352
```

```
 91 [ 1.25 %          HATE 640M40   233.10  770   525   17   40        150 201 255
 92                   HATE 640M40   233.10  850   585   15   40        100 223 277
 93  NI,CR STEEL]     HATE 640M40   233.10  930   680   13   40         63 248 302
 94                   HATE 640M40   233.10 1000   755   12   35         29 269 331
 95 [ 3 %             HATE 653M31   269.50  850   585   15   40        150 223 277
 96                   HATE 653M31   269.50  930   680   13   40        100 248 302
 97  NI,CR STEEL]     HATE 653M31   269.50 1000   755   12   35         63 269 331
 98 [ 1% CR,          HATE 708M40   213.40  770   525   17   40        150 201 255
 99                   HATE 708M40   213.40  850   585   15   40        100 223 277
100  MO STEEL ]       HATE 708M40   213.40  930   680   13   40         63 248 302
101                   HATE 708M40   213.40 1000   755   12   35         29 269 331
102 [ 1% CR,          HATE 709M40   217.40  770   495   15   25        250 201 255
103                   HATE 709M40   217.40  850   555   13   20        250 223 277
104  MO STEEL         HATE 709M40   217.40  850   585   15   40        150 223 277
105                   HATE 709M40   217.40  930   680   13   40        100 248 302
106 WITH HIGHER       HATE 709M40   217.40 1000   755   12   35         63 269 331
107   MO         ]    HATE 709M40   217.40 1080   850   12   35         29 293 352
108 [ 3 % CR,MO       HATE 722M24   278.20  930   650   13   30        250 248 302
109                   HATE 722M24   278.20  930   680   13   40        150 248 302
110    STEEL     ]    HATE 722M24   278.20 1000   755   12   35        150 269 331
111 [ 1.5 % NI,       HATE 816M40   240.20  850   555   15   25        250 223 277
112                   HATE 816M40   240.20  850   585   15   40        150 223 277
113 [4% NI,CR,        HATE 835M40   323.30 1540  1235    7   15        150 444
114  CR,MO            HATE 816M40   240.20  930   680   13   40        100 248 302
115                   HATE 816M40   240.20 1000   755   12   35         63 269 331
116    STEEL    ]     HATE 816M40   240.20 1080   850   12   35         29 293 352
117 [1.5 % MN,        HATE 785M19   215.90  690   450   16   30        250 179 229
118  NI,MO STEEL]     HATE 785M19   215.90  690   465   18   40        150 179 229
119 [1.5% NI,         HATE 817M40   249.20  930   650   13   30        250 248 302
120                   HATE 817M40   249.20  930   680   13   40        150 248 302
```

```
121   CR,MO          HATE 817M40   249.20 1000   755    12    35       100 269 331
122                  HATE 817M40   249.20 1080   850    12    35        63 293 352
123    STEEL ]       HATE 817M40   249.20 1160   940    11    30        29 311 375
124                  HATE 817M40   249.20 1240  1020    10    25        29 341 401
125                  HATE 817M40   249.20 1540  1235     5     8        29 444
126 [ 2.5% NI,       HATE 826M31   285.40  930   650    13    30       250 248 302
127                  HATE 826M31   285.40  930   680    13    40       150 248 302
128  CR,MO,MEDIUM    HATE 826M31   285.40 1000   740    12    25       250 269 331
129                  HATE 826M31   285.40 1000   755    12    35       150 269 331
130  CARBON STEEL    HATE 826M31   285.40 1080   850    12    35       150 293 352
131                  HATE 826M31   285.40 1160   940    11    30       100 311 375
132   L       ]      HATE 826M31   285.40 1240  1020    10    25        63 341 401
133                  HATE 826M31   285.40 1540  1235     5     8        63 444
134 [ 2.5% NI,       HATE 826M40   285.40 1000   740    12    25       250 269 331
135                  HATE 826M40   285.40 1000   755    12    35       150 269 331
136  CR,MO,HIGH      HATE 826M40   285.40 1080   835    12    25       250 293 352
137                  HATE 826M40   285.40 1080   850    12    35       150 293 352
138  CARBON          HATE 826M40   285.40 1160   925    11    20       250 311 375
139                  HATE 826M40   285.40 1160   940    11    30       150 311 375
140   STEEL     ]    HATE 826M40   285.40 1240  1020    10    25       150 341 401
141                  HATE 826M40   285.40 1310  1095    10    25       150 363 429
142                  HATE 826M40   285.40 1540  1235     7    10       100 444
143  MO STEEL  ]
144 [ 3.25 % CR,     HATE 897M39   324.00 1310  1160    18    15        63 375
145                  HATE 897M39   324.00 1540  1235    17    10        29 444
146  MQ,V STEEL]
147 [1.5% CR,AL,     HATE 905M31   240.10  770   525    17    40       100 201 255
148 MO,NITRIDING     HATE 905M31   240.10  850   585    15    40        63 223 277
149  STEEL       ]
150 [1.5% MN,NI,     HATE 945M38   222.90  770   495    15    25       250 201 255
```

```
151                 HATE 945M38   222.90  770  525   17   40     150 201 255
152  CR,MO          HATE 945M38   222.90  850  585   15   40     100 223 277
153                 HATE 945M38   222.90  930  680   13   40      63 248 302
154  STEEL        ] HATE 945M38   222.90 1000  755   12   35      29 269 331
155                 HATE 945M38   222.90 1080  850   12   35      29 293 352
156 [FERRITIC 17%  SOCO 430S15   483.00  430  280   20            63     170
157  CR STEEL    ]
158 [MARTENSITIC    HATE 410S21   458.00  620  370   20  40      150 152 207
159 13% CR STEEL]
160 [MARTENSITIC    HATE 420S29   444.00  770  525   15           150 201 255
161 13% CR STEEL]  HATE 420S29   444.00  850  585   13  20       29 223 277
162 [MARTENSITIC    HATE 420S37   446.00  770  525   15  25      150 201 255
163 13% CR STEEL]  HATE 420S37   446.00  850  585   13  20      150 201 255
164 [MARTENSITIC    HATE 416S21   494.00  620  370   15   28     150 152 207
165 13% CR STEEL]
166 [MARTENSITIC    HATE 416S37   489.00  770  525   11   20     150 201 255
167 13% CR STEEL   HATE 416S37   489.00  850  585   10   10     150 223 277
168 FREE MACHINING]
169 [MARTENSITIC    HATE 431S29   628.00  930  680   11   25     150 248 302
170 CR,NI STEEL ]
171 [UNSTABILISED SOQE 304S12   781.00  460        40                   183
172 AUSTENITIC     SOQE 302S25   712.00  510        40                   183
173 CR,NI STEELS]
174 [AUSTENITIC     SOQE 315S16   801.00  460        40                   183
175 CR,NI,MO STEEL]
176 [AUSTENITIC     SOQE 317S16 1092.00  460        40                   183
177 CR,NI,MO STEEL]
178 ****
179
```

by giving a steel a particular treatment and the subsequent minimum values of mechanical properties are considered as separate entities available for selection. For example, a 20 carbon steel, 070M20, if in the form of cold drawn bars from hot rolled condition, can be considered as four separate materials, because to achieve maximum ruling sections of 16, 40, 63 and 76 mm., four separate sets of mechanical values are associated with them. Similarly, in the normalised form, maximum ruling sections of 150 and 250 mm. can be attained with corresponding sets of mechanical properties. Thus, 20 carbon steel can be selected in one of the six forms and, for the purpose of the program, these are considered as six different materials.

The main program is stored in a file MATSEL and the information about the properties of materials is stored in a file called MATSELD. This information is read and stored in the computer in the form of two matrices, PROP (I,J) and KPROP (I,J).

Referring to Output 5.1 it can be seen that the properties matrix PROP (I,J) has 176 rows and 5 columns. The first two columns contain the material descriptions. The third column describes the treatment given to the steel. The following nomenclature is used:

CODR - Cold drawn from hot rolled condition
NORM - Normalised
HATE - Hardened and tempered
SOCO - Soaked and cold drawn
SOQE - Soaked and/or quenched.

The fourth column gives the British Standards specification number of the steel. The fifth column shows the price of the steel per tonne.[79]

The matrix KPROP (I,J) has 176 rows and 13 columns. For convenience, the information is stored in columns 6 to 13. These eight columns contain values of the properties described below:

6) TENS - Ultimate Tensile Strength in N/mm^2
7) YIEL - Yield Strength in N/mm^2
8) ELON - Percentage Elongation
9) IMPA - Impact Strength in N-m
10) MINS - Minimum Ruling Section in mm
11) MAXS - Maximum Ruling Section in mm
12) MINB - Minimum Brinell Hardness
13) MAXB - Maximum Brinell Hardness

For both matrices, the number of rows represent the number of steels available for selection.

The program held in file MATSEL, shown in Output 5.2 cannot be directly linked and operated on by a computer because it is written in a high-level source language (FORTRAN) which the central processing unit (CPU) cannot process directly. This source program is compiled or translated and stored in binary form in the file MATSELB. It is this binary program MATSELB which is executed by the CPU, using data from MATSELD, to give the output.

Whenever data is to be supplied at an intermediate

DOCUMENT   MATSEL

```
      MASTER
      DIMENSION PROP(180,5),USEFUL(180,5),USELES(180,5),NRECD(13),
     1VRECD(13),KPROP(180,13),KUSEFU(180,13),KUSELE(180,13)
      DO 99 I=1,176
      READ(3,10)(PROP(I,J),J=1,5),(KPROP(I,J),J=6,13)
   10 FORMAT(A8,A6,A4,A8,F7.2,6I5,2I4)
   99 CONTINUE
   17 K=0
      NPROP=0
   15 WRITE(2,20)
   20 FORMAT(15H WHAT PROPERTY?)
    C TENS=TENSILE STRENGTH,YIEL=YIELD STRENGTH,ELON=ELONGATION
    C HARD=MINIMUM HARDNESS,NES=MAXIMUM HARDNESS,IMPA=IMPACT STRENGTH
    C ALL PROPERTIES EXCEPT HARDNESS AND IMPACT STRENGTH IN SI UNITS
      NPROP=NPROP+1
      READ(1,30)NRECD(NPROP)
   30  FORMAT(I0)
      WRITE(2,40)
   40 FORMAT(7H.VALUE?)
      READ(1,50)VRECD(NPROP)
   50 FORMAT(F0.0)
      NMAT=176
      KMAX=KPROP(1,NRECD(NPROP))
      DO 60 I=1,NMAT
      IF(VRECD(NPROP).LE.KPROP(I,NRECD(NPROP))) GO TO 24
      IF(KMAX.LE.KPROP(I,NRECD(NPROP))) KMAX=KPROP(I,NRECD(NPROP))
   60 CONTINUE
      WRITE(2,70)KMAX
   70 FORMAT(14,12H WARNING     )
   24 WRITE(2,25)
   25  FORMAT(30H,IS THERE ANY OTHER PROPERTY?     )
    C FOR ANSWER YES,PUT N=1,FOR ANSWER NO PUT N=0
      READ(1,35)N
   35 FORMAT(I1)
      IF(N.EQ.1) GO TO 15
```

```
      IF (N.EQ.0) GO TO 45
   45 WRITE(2,72)(NRECD(I),I=1,NPROP)
   72 FORMAT(1H ,4I4)
      DO 55 I=1,NMAT
      IF(VRECD(1).LE.KPROP(I,NRECD(1)).AND.VRECD(2).LE.KPROP(I,NRECD(2))
     1.AND.VRECD(3).LE.KPROP(I,NRECD(3)).AND.VRECD(4).LE.KPROP(I,NRECD(4)
     2)))GO TO 51
      GO TO 55
   51 K=K+1
      USEFUL(K,5)=PROP(I,5)
      DO 33 J=6,13,1
      KUSEFU(K,J)=KPROP(I,J)
   33  CONTINUE
      N4=4
      N1=1
      N8=8
      CALL COPY(N4,USEFUL(K,3),N1,PROP(I,3),N1)
      CALL COPY(N8,USEFUL(K,4),N1,PROP(I,4),N1)
   55 CONTINUE
      IF(K.EQ.0)WRITE(2,96)
   96 FORMAT(22H NO SUITABLE MATERIALS      )
      DO 12 J=1,K-1,1
      DO 12 I=1,K-1,1
      IF(USEFUL(I,5).LT.USEFUL(I+1,5))GO TO 12
      DO 16 JA=6,13,1
      KUSELE(I,JA)=KUSEFU(I,JA)
      KUSEFU(I,JA)=KUSEFU(I+1,JA)
      KUSEFU(I+1,JA)=KUSELE(I,JA)
   16 CONTINUE
      JA=5
      USELES(I,JA)=USEFUL(I,JA)
      USEFUL(I,JA)=USEFUL(I+1,JA)
      USEFUL(I+1,JA)=USELES(I,JA)
      CALL COPY(N4,USELES(I,3),N1,USEFUL(I,3),N1)
      CALL COPY(N4,USEFUL(I,3),N1,USEFUL(I+1,3),N1)
      CALL COPY(N4,USEFUL(I+1,3),N1,USELES(I,3),N1)
```

```
      CALL COPY(N8,USELES(I,4),N1,USEFUL(I,4),N1)
      CALL COPY(N8,USEFUL(I,4),N1,USEFUL(I+1,4),N1)
      CALL COPY(N8,USEFUL(I+1,4),N1,USELES(I,4),N1)
   12  CONTINUE
      NR1=NRECD(1)
      NR2=NRECD(2)
      NR3=NRECD(3)
      NR4=NRECD(4)
      DO 27 I=1,3,1
      WRITE(2,78)USEFUL(I,3),USEFUL(I,4),KUSEFU(I,NR1),KUSEFU(I,NR2),
     1KUSEFU(I,NR3),KUSEFU(I,NR4),USEFUL(I,5)
   78 FORMAT(1H ,A4,3X,A8,3X,4I4,3X,F7.2)
   27  CONTINUE
      WRITE(2,44)
   44 FORMAT(13H MORE STEELS?    )
C     FOR ANSWER YES,PUT M=1,FOR ANSWER NO,PUT M=0
      READ(1,39)M
   39 FORMAT(I1)
      IF(M.EQ.1) GO TO 41
      IF (M.EQ.0) GO TO 56
   41 DO 29 I=4,6,1
      WRITE(2,73)USEFUL(I,3),USEFUL(I,4),KUSEFU(I,NR1),KUSEFU(I,NR2),
     1KUSEFU(I,NR3),KUSEFU(I,NR4),USEFUL(I,5)
   73 FORMAT(1H ,A4,3X,A8,3X,4I4,3X,F7.2)
   29 CONTINUE
   56 WRITE(2,57)
   57 FORMAT(10H MORE USE?    )
C     FOR ANSWER YES,PUT L=1,FOR ANSWER NO,PUT L=0
      READ(1,71)L
   71 FORMAT(I1)
      IF(L.EQ.1) GO TO 17
      STOP
      END
      FINISH
****
```

stage, an "invitation to type" is given and the data can then be keyed in. When the user has to supply information about a specific property or requirement , which he requires in his product or design, all he has to do is type the column number corresponding to that property. For example, if a user wants a certain value of yield strength for his application, he types 7 on the terminal and then types in the minimum required value. The program then compares this required minimum value with the corresponding values of all the available steels listed in MATSELD. If no steel has a value greater than that required, a warning will be issued and the highest available value of that particular property will be printed for the user to relax his requirement. This will enable him to pick up one of the steels if he decides to do so.

After all the constraints have been listed, the steels will be sorted and rearranged in increasing order of costs and the three cheapest steels will be listed with all the information about the properties in which the customer is interested. The customer is then again given the opportunity of knowing the next three cheapest steels in the list and/or carrying out a sensitivity analysis by relaxing or constricting a particular design constraint.

The program is simple to operate and communicates with the user by asking simple questions in English. Throughout the program, very simple conventions are followed. For example, to answer "yes" to any question, the user types "1" and to answer "no" he types "0". Any illegal or irrelevant information input by the user by mistake will be pointed out by the computer and the user will have the opportunity of correcting his mistakes in the same run.

5.7 THE COMAS PROGRAM

The theory outlined in Section 5.1 is the basis for the COmputerised MAterials Selector (COMAS) program. There are two variants of this program. The COMAS program is a batch program and produces a hard copy. Its variant the INCOMAS (INteractive COmputerised MAterials Selector) program is interactive but does not produce a hard copy unless extensive modifications are made to the program. For this reason most of the results analysed in the next chapter were produced by a COMAS program.

5.7.1 THE INPUT - COMASD

Thi input data for this program is stored in file COMASD and is shown in Output 5.3.

The first part of the input data consists of five matrices, A(I), B(I), X(I,J), LF(I,J) and M(J). The first two matrices A(I) and B(I) are alphameric matrices used for storing materials nomenclature. To facilitate handling of materials data, materials have been coded. There will be three letters separated from the standard nomenclature by a hyphen.

XXX - NAME

The first letter is either a "M" for metals or a"N" for non-metals. The second letter signifies the sub-class type like, ferrous, copper, plastics, etc. The third letter signifies the state of the material viz. casting, wrought, etc.

Example:

M F W - E N 3

Metal Ferrous Wrought Name of steel

N P C - H D P E

Non-metal Plastic Cast High Density Polythene

The third matrix X(I,J) is a two-dimensional matrix storing materials property values. It consists of I rows and J columns, where I is the number of materials under consideration and J is the number of properties in the list. Throughout this work the materials matrix X(I,J) will consist of around 53 rows for 53 materials and 8 columns for the 8 properties. The material at the top of the list is always the Basis Material and all other materials are in turn compared with this basis material. In Output 5.3 the Basis Material is Electrolytic Tough Pitch Copper.

The fifty-three materials in this list comprise some of the most common engineering materials. The fifty-three materials are divided as follows: 22 steels, 13 aluminium alloys, 9 plastics, 4 copper alloys, 3 kinds of timber, concrete and silver. The only reason why silver is included is because of its high electrical conductance.

The eight properties all in S.I. units are as follows:

1)	K	-	Cost	£/tonne
2)	S	-	Density	kg/m^3
3)	F	-	Fatigue Strength	MN/m^2
4)	E	-	Elastic Modulus	MN/m^2
5)	D	-	Design Strength	MN/m^2
6)	R	-	Rigidity Modulus	MN/m^2
7)	I	-	Impact Strength	N-m
8)	C	-	Electrical Conductance	IACS

All the quantities are stored in file COMASD as real numbers in free format; which is a technique of storing information without alignment within any particular group. This makes it easier for the user to edit the data at any later stage. It should be realised that there are no immediate constraints on the size of this data, and, that it can be extended in both dimensions.

The fourth matrix LF(IA,J) is a two-dimensional matrix which holds the weighting factors needed to weight the different characteristics. The difference between properties and characteristics needs a little explanation. Each material listed has eight properties, including cost and density. But since cost and density are mathematically treated differently from the remaining six engineering properties, for programming convenience these six properties are classed as characteristics.

```
DOCUMENT    COMASD

0  53 8 3 2 8
1                  K      S     F    E       D        R      I     C
2  MCW-ETP              820.0 8.9 97.3 110424.6 166.8 44015.4 47.5 100.0
3  MCW-OFHC            1150.0 8.9 117.37 110424.6 162.2 44015.4 61.01 100.0
4  MFW-EN 1            139.8 7.85 193.0 200750.0 125.0 77000.0 62.0 0.0
5  NAVAL BRASS          515.0 8.9 227.0 103500.0 284.0 38500.0 81.0 24.7
6  MAW-LM 2            308.0 2.7 77.0 69500.0 40.0 26254.8 2.15 31.0
7  MAW-LM 4            328.0 2.73 84.94 69500.0 106.6 44015.4 2.03 32.0
8  MAW-LM 6               438.0 2.65 68.0 69500.0 35.5 26254.8 8.13 37.0
9  MAW-EC              750.0 2.70 47.88 69500.0 49.4 26254.8 31.18 62.0
10 MAW-IC              712.0 2.7 47.88 69500.0 60.2 26254.8 31.18 58.0
11 MAW-N 3                475.0 2.73 61.78 69500.0 71.0 26254.8 28.47 41.0
12 MAW-N 4               507.0 2.68 123.55 69500.0 106.6 26254.8 28.47 35.0
13 MAW-N 5               500.0 2.64 123.55 69500.0 94.2 26254.8 28.47 31.0
14 MAW-H 9                 800.0 2.7 97.3 69500.0 137.5 26254.8 27.12 40.0
15 MAW-H 15            850.0 2.8 123.55 69500.0 211.6 26254.8 8.1 40.0
16 MAW-H 20              686.0 2.7 61.78 69500.0 91.1 26254.8 31.18 53.0
17 MAW-H 75            1000.0 2.8 155.98 69500.0 247.1 26254.8 8.13 30.0
18 ALUMINUM                310.0 2.7 50.0 62000.0 40.0 26254.8 30.0 65.0
19 COPPER              513.0 8.96 65.0 119000.0 75.0 48000.0 58.0 102.0
20 SILVER               30000.0 10.5 15.0 70000.0 70.0 30000.0 5.4 106.0
21 MFW-EN 2            132.8 7.87 233.0 200750.0 131.0 77000.0 63.5 0.0
22 MFW-EN 3               131.9 7.86 233.0 200750.0 215.0 77000.0 90.0 0.0
23 MFW-EN 4               133.0 7.86 193.0 200750.0 170.0 77000.0 95.0 0.0
24 MFW-EN 5                  133.0 7.85 233.0 200750.0 170.0 77000.0 65.0 0.0
25 MFW-EN 8            133.0 7.84 278.0 200750.0 215.0 77000.0 110.0 0.0
26 MFW-EN 9              133.1 7.85 293.0 200750.0 215.0 77000.0 27.0 0.0
27 MFW-EN 14             136.6 7.85 278.0 200750.0 210.0 77000.0 130.0 0.0
28 MFW-EN 15           136.6 7.85 320.0 200750.0 260.0 77000.0 41.5 0.0
29 MFW-EN 18             175.0 7.83 415.0 200750.0 310.0 77000.0 65.0 0.0
30 MFW-EN 22             230.0 7.85 425.0 200750.0 370.0 77000.0 80.0 0.0
```

```
 31 MFW-EN 24          211.8 7.83 495.0 200750.0 420.0 77000.0 65.0 0.0
 32 MFW-EN 56           180.0 7.72 386.0 200750.0 310.0 77000.0 100.0 0.0
 33 MFW-EN 100          200.0 7.85 510.0 200750.0 340.0 77000.0 40.0 0.0
 34 MFW-EN 110         211.8 7.84 750.0 200750.0 360.0 77000.0 40.0 0.0
 35 MFW-AISI 302       712.0 7.9 234.0 193000.0 130.0 86000.0 150.0 0.0
 36 MFW-AISI 309        1128.0 7.9 360.0 193000.0 140.0 86000.0 135.0 0.0
 37 MFW-AISI 317       1131.0 7.9 248.0 193000.0 140.0 86000.0 150.0 0.0
 38 MFW-AISI 410        311.0 7.9 278.0 193000.0 140.0 86000.0 27.0 0.0
 39 MFW-AISI 420         483.0 7.9 680.0 193000.0 670.0 86000.0 11.0 0.0
 40 MFW-AISI 430         483.0 7.7 320.0 193000.0 160.0 86000.0 20.0 0.0
 41 MFW-AISI 431          593.0 7.9 540.0 193000.0 530.0 86000.0 13.5 0.0
 42 NPC-HDPE           315.0 0.95 4.0 320.0 18.0 0.0 1.9 0.0
 43 NPC-NYLON 66        926.0 1.14 20.0 2100.0 60.0 0.0 3.4 0.0
 44 NPC-PP             325.0 0.9 7.5 1400.0 20.0 0.0 0.54 0.0
 45 NPC-PVC  (R)        240.0 1.4 12.0 960.0 50.0 0.0 0.6 0.0
 46 NPC-PS  (GP)       314.0 1.04 0.0 2800.0 48.0 0.0 0.27 0.0
 47 NPC-PROPATHENE      240.0 0.90 7.5 1500.0 34.0 0.0 0.5 0.0
 48 NPC-MARANYL A100   625.0 1.14 20.0 2900.0 80.0 0.0 3.5 0.0
 49 NPC-KEMETAL  AC    375.0 1.41 0.0 2800.0 60.0 0.0 3.5 0.0
 50 NPC-RIGIDEX 2000     210.0 0.95 4.0 320.0 28.0 0.0 13.0 0.0
 51 BEECH-WOOD        550.0 0.67 6.0 13500.0 15.4 5600.0 0.0 0.0
 52 TEAK-WOOD         1750.0 0.61 7.7 12750.0 17.5 5350.0 0.0 0.0
 53 OAK-WOOD           895.0 0.67 6.0 10750.0 14.0 4500.0 0.0 0.0
 54 NCC-1.2.4         23.0 2.45 1.1 30000.0 15.4 12250.0 0.0 0.0
 55  0 0 1 0 0 10
 56  0 0 5 0 0 10
 57  0 0 10 0 0 10
 58  30.0  80.0
 59                       COMPUTERISED  MATERIAL  SELECTION
 60                                   WEIGHTING
 61            FAT STR   ELA MOD   DES STR   RIG MOD   IMP STR   COND
 62                            BASIS  MATERIAL  =  MCW-ETP
 63 MIN CONDUCTANCE = 30 IACS
 64 MIN CONDUCTANCE = 30 IACS  AND  MIN DESIGN STRENGTH = 80 N/MM SQ
 65 ****
 66
```

Hence, if

NP = number of properties, and

NC = number of characteristics,

then,

NP = NC + 2.

Each characteristics needs a weighting hence there are six weighting factors, which comprise a set. But since weighting factors are subjective and not always exact, the program can be run for different sets of weighting factors, and these are stored in the matrix LF(IA,J). In the data file COMASD, shown in Output 5.3, there are three sets of weighting factors and the characteristics weighted are design strength and conductance.

The fifth and last matrix is the Control Matrix M(J). This matrix controls the entire program. It consists of five elements:

N - number of materials in the list

NP - number of properties = NC + 2

MF - number of sets of weighting factors.

MD - number of sets of design constraints

L - property loading number, the number of the property under consideration, the 'j' in Equation 3, Section 5.1.

In Output 5.3,

N = 53

NP = 8

MF = 3

MD = 2

L = 8 (Conductance)

The second section of the data consists of a Design Constraints matrix DC(K) and other minor alphameric matrices for storing the texts of the titles and headings. The design constraints take the form of minimum required values and if the property under consideration falls below this required minimum, computation is stopped and the statement "Properties below requirements" is printed.

For each set of weighting factors the program will work through all the design constraints imposed. Hence total number of print-outs will be MF * MD.

5.7.2 THE MAIN PROGRAM - COMAS

The program, as shown in Output 5.4, is divided into a Master segment and four subroutines. A subroutine is a self-contained section of a program which can be utilised by any other part of the program. The major reason for using subroutines is that certain sections of the program may be required at various points within the program. Writing these as subroutines will save the overheads of duplicating the sections throughout the program.

Subroutine INPUT 1

This subroutine reads and stores all the data. This includes the alphameric text and the numeric data. It prints out the Control Matrix M(J), the Materials Matrix X(I,J), the Weighting Factors Matrix LF(IA,J) and the single line heading for the properties.

Subroutine INPUT 2

This subroutine has only one function and that is to print the titles that appear on top of every page of the output. Unlike the previous subroutine INPUT 1, which is called only once during the entire program run, INPUT 2 is called MF*MD times.

Subroutine MAX

This subroutine scans the six columns of characteristics and picks out the maximum in each column. It then proceeds to calculate the six scaling factors as outlined in the theory in Section 5.1.

Subroutine SOLVE

At this stage of the program all the variables in equation 1, Section 5.1, are known and Subroutine SOLVE proceeds to compute the Cost per Unit Requirement (CUR) ratio for each material. After all the computations are complete the subroutine returns all these values to the Master segment for printing.

MASTER Segment

The MASTER Segment is the main body of the program. It executes the program the required number of times by means of do-loops and calls the four subroutines in the required order. The screening of the materials is done in the MASTER Segment by LP statements 15, 16 and 17. The statements are reproduced here for ease of reference.

```
15        GØ TØ (501, 502), K
16   501  IF (DC(K)-X(I,8)) 5, 5, 13
17   502  IF (DC(I).GT.X(I,8).ØR.DC(2).GT.X(I,5)) GØ TØ 13
```

Since these are only two design constraints, one for property number 8, conductance and the other for property number 5, design strength, K assumes two values, 1 and 2 for each constraint respectively. Entering statement 15 with K=1, the action of this computed go to statement would be to pass control to program statement 501 (line-printer statement 16). This statement compares the design constraint, which is the minimum value acceptable with property number 8 of material i. If this property in question is less than the design constraint, ie. the value within brackets is positive, control will be transferred to stop and "Properties below Requirements" will be printed thus eliminating the material from selection. If the property in question is greater than or equal to the design constraint, i.e. the value within the brackets is negative or zero, then control is transferred to program statement 5 which carries on with further computation.

Once the first design constraint is analysed the second constraint is taken into consideration. This second constraint is a combination of the minimum requirements of both the properties. Program statement 502 compares the first design constraint DC(1) with property number 8 and the second design constraint DC(2) with property number 5. Unless both are satisfied, control will transfer to statement 13 and the material will be eliminated from any further analysis. Both the tests, 501 and 502, are executed for every material and for every set of weighting factors. Since,

number of materials $N = 53$

and, number of sets of weighting factors, $MF = 3$

number of times both tests are executed $N * MF = 159$

The design constraints described are just one of the many complex combinations that can be incorporated with relative ease in the program.

The notation employed in the COMAS program is listed here for easy reference:

N - number of materials in list

NP - number of properties

NC - number of characteristics = NP-2

MF - number of sets of weighting factors

MD - number of design constraints imposed

L - property loading number, the 'j' in equation 3, Section 5.1

P(J) - one-dimensional array containing property titles

A(I)
B(I) } - alphameric one-dimensional array storing materials nomenclature in data bank

X(I,J) - main Materials Matrix containing property values

LF(IA,J) - Weighting Factors Matrix

M(J) - Control Matrix, controls the program by storing the major control variables

DC(K) - Design Constraints Matrix

AT(I) Alphameric one-dimensional arrays storing
BT(I) } - text of titles and headings to be printed
CT(K,I) on each page

AMAX(J) - array containing maximum value of each property

S(I) - Scaling Factors array

W(I) - Weighted Property Factors array for basis material 1

WPF(I) - Weighted Property Factors array for material i, i = 1 to N

RC(I) - Relative Cost array

CUR(I) - Cost per Unit Requirement array

5.7.3 THE OUTPUT - COMAS

As mentioned earlier the output consists of MF * MD print-outs. Each print-out starts at the top with a title, a list of characteristics above their weighting factors, the basis material and the minimum acceptable design values. This is then followed by the list of materials and the CUR ratios, with the basis material at the top of the list and any material unable to meet the requirements laid down, is automatically eliminated from further consideration. A more detailed analysis of the output under various constraints and boundary conditions is the subject of the next chapter.

```
DOCUMENT     COMAS

          MASTER
C         COMPUTERISED MATERIAL SELECTOR PROGRAM
          DIMENSION  UPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
         1P(10),LF(5,10),DC(9),AT(27),BT(9),CT(9,9),M(5),AMAX(10),S(9),B(55)
          COMMON RC,CUR,X,M,AMAX,S,NC,P,A,B,LF,DC,AT,BT,CT,MF,MD,L,N
          CALL INPUT1
          DO 12  IA=1,MF
          DO 12  K=1,MD
          CALL INPUT2(IA,K)
C         ALL PROPERTIES IN SI UNITS
C         F=FATIGUE STRENGTH     E=ELASTIC MODULUS     D=DESIGN STRENGTH
C         R=RIGIDITY MODULUS     I=IMPACT STRENGTH     C=CONDUCTIVITY
C         K=COST PER TONNE       S=SPECIFIC GRAVITY    N=NO OF MATERIALS
      500 DO  12  I=1,N
          GO TO (501,502), K
      501 IF (DC(1)-X(I,3)) 5, 5, 13
      502 IF (DC(1).GT.X(I,3).OR.DC(2).GT.X(I,5))  GO TO 13
        5 CALL MAX(N)
          CALL SOLVE(IA,I)
          GO  TO  70
       13 WRITE (2,203)  A(I), B(I)
      203 FORMAT (1X,2A8,10X,30H PROPERTIES BELOW REQUIREMENTS,/)
          GO  TO  12
       70 WRITE (2,202)  A(I), B(I), CUR(I)
      202 FORMAT (1X,2A8,18X,F10.4,/)
       12 CONTINUE
       99 WRITE (2,90)
       90 FORMAT (1H1)
          STOP
          END
```

```
      SUBROUTINE INPUT1
      DIMENSION  WPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AT(27),BT(9),CT(9,9),M(5),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,M,AMAX,S,NC,P,A,B,LF,DC,AT,BT,CT,MF,MD,L,N
      READ (1,112)  (M(J),J=1,5)
  112 FORMAT (5I0)
      N=M(1)
      NC=M(2)-2
      MF=M(3)
      MD=M(4)
      L=M(5)
      READ (1,105)  (P(J), J=1,9)
  105 FORMAT (1X,9A8)
      READ (1,100)  (A(I),B(I),(X(I,J),J=1,NC+2),I=1,N)
  100 FORMAT (2A8,8F0.0)
      READ (1,113)  ((LF(IA,J),J=1,NC),IA=1,MF)
  113 FORMAT (6I0)
      WRITE (2,106)   (P(J), J=1,9)
  106 FORMAT (1H1,9X,9A8,//)
      WRITE (2,111)  (A(I),B(I),(X(I,J),J=1,NC+2),I=1,N)
  111 FORMAT (1X,2A8,F7.1,F6.2,F7.2,F10.1,F7.1,F9.1,F7.1,F7.1,/)
      WRITE (2,114) ((LF(IA,J),J=1,NC),IA=1,MF)
  114 FORMAT (1H0,33X,I2,I8,I10,I7,2I8,/)
      WRITE(2,115)  (M(J),J=1,5)
  115 FORMAT (1H0,8X,5(10X,I5))
      READ (1,23)  (DC(K),K=1,MD)
   23 FORMAT (2F0.0)
      READ (1,51)  (AT(I),I=1,27)
   51 FORMAT (9A8)
      READ (1,52)  (BT(I),I=1,9)
```

```
 52   FORMAT (9A8)
      READ (1,53)  ((CT(K,I),I=1,9),K=1,MD)
 53   FORMAT (9A8)
      RETURN
      END

      SUBROUTINE INPUT2(IA,K)
      DIMENSION  UPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AT(27),BT(9),CT(9,9),M(5),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,M,AMAX,S,NC,P,A,B,LF,DC,AT,BT,CT,MF,MD,L,N
      WRITE (2,54)
  54  FORMAT (1H1)
      WRITE (2,109)  (AT(I),I=1,27)
 109  FORMAT (9A8,//)
      WRITE (2,101)  (LF(IA,J),J=1,NC)
 101  FORMAT (1H+,I4,5I10,//)
      WRITE (2,102)  (BT(I),I=1,9)
 102  FORMAT (9A8,/)
      WRITE (2,103)  (CT(K,I),I=1,9)
 103  FORMAT (1X,9A8,///)
      WRITE (2,104)
 104  FORMAT (9H MATERIAL,20X,26H COST PER UNIT REQUIREMENT,//)
      RETURN
      END

      SUBROUTINE MAX(N)
      DIMENSION  UPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AT(27),BT(9),CT(9,9),M(5),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,M,AMAX,S,NC,P,A,B,LF,DC,AT,BT,CT,MF,MD,L
      DO 14  J=3,8
```

```
      XMAX=0.0
      DO 14  I=1,N
      IF (X(I,J).GT.XMAX) XMAX=X(I,J)
      AMAX(J)=XMAX
   14 CONTINUE
      J=3
      DO 15  I=1,NC
      S(I)=100.0/AMAX(J)
      J=J+1
   15 CONTINUE
      RETURN
      END

      SUBROUTINE SOLVE(IA,I)
      DIMENSION  WPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AT(27),BT(9),CT(9,9),M(5),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,M,AMAX,S,NC,P,A,B,LF,DC,AT,BT,CT,MF,MD,L,N
C     CALCULATE WEIGHTED PROPERTY FACTORS
      W(I)   =((S(1)*LF(IA,1)*X(1,3))+(S(2)*LF(IA,2)*X(1,4))+(S(3)*LF
     1(IA,3)*X(1,5))+(S(4)*LF(IA,4)*X(1,6))+(S(5)*LF(IA,5)*X(1,7))+
     1(S(6)*LF(IA,6)*X(1,8)))
      WPF(I)   =((S(1)*LF(IA,1)*X(I,3))+(S(2)*LF(IA,2)*X(I,4))+(S(3)*LF
     1(IA,3)*X(I,5))+(S(4)*LF(IA,4)*X(I,6))+(S(5)*LF(IA,5)*X(I,7))+
     1(S(6)*LF(IA,6)*X(I,8)))
C     CALCULATE RELATIVE COST DEPENDING ON LOADING
      RC(I)=(X(1,L)/X(I,L))*(X(I,1)/X(1,1))*(X(I,2)/X(1,2))
C     CALCULATE  COST PER UNIT REQUIREMENT
      CUR(I)=(RC(I)/(WPF(I)/W(I)))
      RETURN
      END
      FINISH
****
```

5.8 THE INCOMAS PROGRAM

This program, INteractive COmputerised MAterials Selector, as the name suggests, is the interactive version of the COMAS program. To enable INCOMAS to operate in interactive mode on MOP, some modification of the COMAS program was necessary and a few explanations are in order.

Unlike the COMAS program, which had one channel of input, the COMASD program stored on file, and one output channel, the hard-copy on the line-printer, the INCOMAS program has two input channels and one output channel. The input channels are:

1. The INCOMASD data file shown in Output 5.5
2. The terminals (teletype or VDU), from which the user feeds in information on which depend the subsequent program control and output.

The output is confined to messages and information flashed on the VDU screen and thus without extensive modification to the program a hard-copy is difficult to obtain. A VDU hard-copy is shown in the next chapter.

The first input channel comprising INCOMASD consists of materials notation and properties. It is analogous to COMASD and when execution commences INCOMAS is coupled to INCOMASD. But again, unlike COMASD which contained all the information needed to run COMAS, extra information for INCOMAS is supplied by the user as and when requested via the terminals. It is this second channel which makes INCOMAS more powerful and truly interactive. The complete

INCOMAS program is shown in Output 5.6.

The program begins by flashing the letters:

N NC L

When permission to print is granted, the user prints in

N - the number of materials

NC - the number of characteristics

L - the property loading number

Similar requests are made for printing the weighting factors and the design constraints. Once all this primary information has been supplied the program computes and prints the CUR ratios for all the materials and flashes them on the screen. At the end of the computation the user is given the option of terminating the run or start all over again by feeding in new data. This is its main advantage over the COMAS program which is in batch mode. If the user is not satisfied with the design constraints or the weighting factors, the program can be started again and the new results compared with the old in a matter of minutes. This also enables the user to carry out a cost comparison exercise to relax or constrain parameters and observe their effect on cost, in general a whole range of sensitivity analyses can be performed.

Apart from its interactive nature, the INCOMAS program is similar to the COMAS program in structure and notation.

The program operates by asking simple questions in English and answers are fed in the conventional manner; to

DOCUMENT   INCOHAS

```
      MASTER
      DIMENSION WPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,AMAX,S,HC,P,A,B,LF,DC,L
      LL=0
   69 IA=1
      CALL INPUT(IA,N,LL)
C     ALL PROPERTIES IN SI UNITS
C     F=FATIGUE STRENGTH    E=ELASTIC MODULUS    D=DESIGN STRENGTH
C     R=RIGIDITY MODULUS    I=IMPACT STRENGTH    C=CONDUCTIVITY
C     K=COST PER TONNE      S=SPECIFIC GRAVITY   N=NO OF MATERIALS
  500 DO  12  I=1,N
  502 IF (DC(1).GT.X(I,3).OR.DC(2).GT.X(I,4).OR.DC(3).GT.X(I,5).
     1OR.DC(4).GT.X(I,6).OR.DC(5).GT.X(I,7).OR.DC(6).GT.X(I,8)) GO TO 13
    5 CALL MAX(N)
      CALL SOLVE(IA,I)
      GO  TO  70
   13 WRITE (2,203)  A(I), B(I)
  203 FORMAT (1X,2A8,8X,30H PROPERTIES BELOW REQUIREMENTS,/)
      GO TO 12
   70 WRITE (2,202)  A(I), B(I), CUR(I)
  202 FORMAT (1X,2A8,16X,F10.4,/)
   12 CONTINUE
  115 WRITE (2,24)
   24 FORMAT (1X,///,33H DO YOU WANT TO CHANGE WF OR DC ?,)
      READ (1,25) LL
   25 FORMAT (I0)
      IF (LL.EQ.1) GO TO 69
      WRITE (2,26)
   26 FORMAT (///,25X,15H END OF PROGRAM)
      STOP
      END

      SUBROUTINE INPUT(IA,N,LL)
      DIMENSION  WPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
```

```
     1P(10),LF(5,10),DC(9),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,AMAX,S,NC,P,A,B,LF,DC,L
      WRITE (2,109)
  109 FORMAT (/////,21X,31HCOMPUTERISED MATERIAL SELECTION,///)
      WRITE (2,113)
  113 FORMAT (28X,18HCONTROL PARAMETERS,//,5X,16HNO. OF MATERIALS,
     16X,22HNO. OF CHARACTERISTICS,6X,15HPROPERTY NUMBER,/)
      READ (1,112) N,NC,L
  112 FORMAT (3I0)
      IF (LL.EQ.1) GO TO 21
      READ (3,105)  (P(J),J=1,9)
  105 FORMAT (9A8)
      READ (3,100) (A(I),B(I),(X(I,J),J=1,NC+2),I=1,N)
  100 FORMAT (2A8,8F0.0)
   21 WRITE (2,11)
   11 FORMAT (/,27X,18H WEIGHTING FACTORS,/,9X,1HF,9X,1HE,9X,1HD,9X,1HR,
     19X,1HI,9X,1HC)
      READ (1,118) (LF(IA,J),J=1,NC)
  118 FORMAT (6I0)
      WRITE (2,3)
    3 FORMAT (/,27X,18HDESIGN CONSTRAINTS,/,9X,1HF,9X,1HE,9X,1HD,9X,1HR,
     19X,1HI,9X,1HC)
      READ (1,23)  (DC(K),K=1,NC)
   23 FORMAT (6F0.0)
      WRITE (2,102)  A(1),B(1)
  102 FORMAT (/,23X,19HBASIS MATERIAL  =  ,2A8,//)
      WRITE (2,104)
  104 FORMAT(/,9H MATERIAL,18X,26H COST PER UNIT REQUIREMENT,//)
      RETURN
      END

      SUBROUTINE MAX(N)
      DIMENSION  UPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AMAX(10),S(9),B(55)
```

```
      COMMON RC,CUR,X,AMAX,S,NC,P,A,B,LF,DC,L
      DO 14  J=3,8
      XMAX=0.0
      DO 14  I=1,N
      IF (X(I,J).GT.XMAX) XMAX=X(I,J)
      AMAX(J)=XMAX
   14 CONTINUE
      J=3
      DO 15  I=1,NC
      S(I)=100.0/AMAX(J)
      J=J+1
   15 CONTINUE
      RETURN
      END

      SUBROUTINE SOLVE(IA,I)
      DIMENSION  WPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,AMAX,S,NC,P,A,B,LF,DC,L
C     CALCULATE WEIGHTED PROPERTY FACTORS
      W(I)  =((S(1)*LF(IA,1)*X(1,3))+(S(2)*LF(IA,2)*X(1,4))+(S(3)*LF
     1(IA,3)*X(1,5))+(S(4)*LF(IA,4)*X(1,6))+(S(5)*LF(IA,5)*X(1,7))+
     1(S(6)*LF(IA,6)*X(1,8)))
      WPF(I)  =((S(1)*LF(IA,1)*X(I,3))+(S(2)*LF(IA,2)*X(I,4))+(S(3)*LF
     1(IA,3)*X(I,5))+(S(4)*LF(IA,4)*X(I,6))+(S(5)*LF(IA,5)*X(I,7))+
     1(S(6)*LF(IA,6)*X(I,8)))
C     CALCULATE RELATIVE COST DEPENDING ON LOADING
C     LOADING FOR DESIGN STRENGTH
      RC(I)=(X(1,L)/X(I,L))*(X(I,1)/X(1,1))*(X(I,2)/X(1,2))
C     CALCULATE  COST PER UNIT REQUIREMENT
      CUR(I)=(RC(I)/(WPF(I)/W(I)))
      RETURN
      END
      FINISH
****
```

answer 'yes' to any question, the user types '1' and to answer 'no' he types '0'. Any illegal or irrelevant information input by the user will cause the program to fail and the user will have to start at the beginning.

To overcome the problem of obtaining a VDU hard-copy, all messages input and output on the VDU have to be written in a file and then listed. A modified version of the INCOMAS program named TINCOMAS overcomes this problem and is listed in Output 5.7. It should be noted that this TINCOMAS program uses the same data as the INCOMAS program. Hence the data stored in data file INCOMASD is common to both these programs.

```
DOCUMENT     INCOMASD


 0                   K          S     F      E         D        R         I        C
 1 MFW-EN 1                   139.8 7.85 193.0 200750.0 125.0  77000.0 62.0 0.0
 2 MCW-ETP                     820.0 8.9 97.3 110424.6 166.8 44015.4 47.5 100.0
 3 MCW-OFHC                1150.0 8.9 117.37 110424.6 162.2 44015.4 61.01 100.0
 4 NAVAL BRASS                515.0 8.9 227.0 103500.0 284.0 38500.0 81.0 24.7
 5 MAW-LM 2                 308.0 2.7 77.0 69500.0 40.0 26254.8 2.15 31.0
 6 MAW-LM 4                 328.0 2.73 84.94 69500.0 106.6 44015.4 2.03 32.0
 7 MAW-LM 6                    438.0 2.65 68.0 69500.0 35.5 26254.8 8.13 37.0
 8 MAW-EC                    750.0 2.70 47.88 69500.0 49.4 26254.8 31.18 62.0
 9 MAW-IC                    712.0 2.7 47.88 69500.0 60.2 26254.8 31.18 58.0
10 MAW-N 3                     475.0 2.73 61.78 69500.0 71.0 26254.8 28.47 41.0
11 MAW-N 4                     507.0 2.68 123.55 69500.0 106.6 26254.8 28.47 35.0
12 MAW-N 5                     500.0 2.64 123.55 69500.0 94.2 26254.8 28.47 31.0
13 MAW-H 9                      800.0 2.7 97.3 69500.0 137.5 26254.8 27.12 40.0
14 MAW-H 15                   850.0 2.8 123.55 69500.0 211.6 26254.8 8.13 40.0
15 MAW-H 20                   686.0 2.7 61.78 69500.0 91.1 26254.8 31.18 53.0
16 MAW-H 75                   1000.0 2.8 155.98 69500.0 247.1 26254.8 8.13 30.0
17 ALUMINUM                     310.0 2.7 50.0 62000.0 40.0 26254.8 30.0 65.0
18 COPPER                     513.0 8.96 65.0 119000.0 75.0 48000.0 58.0 102.0
19 SILVER                       30000.0 10.5 15.0 70000.0 70.0 30000.0 5.4 106.0
20 MFW-EN 2                  132.8 7.87 233.0 200750.0 131.0 77000.0 63.5 0.0
21 MFW-EN 3                     131.9 7.86 233.0 200750.0 215.0 77000.0 90.0 0.0
22 MFW-EN 4                     133.0 7.86 193.0 200750.0 170.0 77000.0 95.0 0.0
23 MFW-EN 5                        133.0 7.85 233.0 200750.0 170.0 77000.0 65.0 0.0
24 MFW-EN 8                 133.0 7.84 278.0 200750.0 215.0 77000.0 110.0 0.0
25 MFW-EN 9                   133.1 7.85 293.0 200750.0 215.0 77000.0 27.0 0.0
26 MFW-EN 14                 136.6 7.85 278.0 200750.0 210.0 77000.0 130.0 0.0
27 MFW-EN 15                136.6 7.85 320.0 200750.0 260.0 77000.0 41.5 0.0
28 MFW-EN 18                 175.0 7.83 415.0 200750.0 310.0 77000.0 65.0 0.0
29 MFW-EN 22                   230.0 7.85 425.0 200750.0 370.0 77000.0 80.0 0.0
30 MFW-EN 24                   211.8 7.83 495.0 200750.0 420.0 77000.0 65.0 0.0
31 MFW-EN 56                     180.0 7.72 386.0 200750.0 310.0 77000.0 100.0 0.0
32 MFW-EN 100                    200.0 7.85 510.0 200750.0 340.0 77000.0 40.0 0.0
33 MFW-EN 110                 211.8 7.84 750.0 200750.0 360.0 77000.0 40.0 0.0
34 MFW-AISI 302                  712.0 7.9 234.0 193000.0 130.0 86000.0 150.0 0.0
35 MFW-AISI 309                  1128.0 7.9 360.0 193000.0 140.0 86000.0 135.0 0.0
36 MFW-AISI 317                  1131.0 7.9 248.0 193000.0 140.0 86000.0 150.0 0.0
37 MFW-AISI 410                311.0 7.9 278.0 193000.0 140.0 86000.0 27.0 0.0
38 MFW-AISI 420                  483.0 7.9 680.0 193000.0 670.0 86000.0 11.0 0.0
39 MFW-AISI 430                    483.0 7.7 320.0 193000.0 160.0 86000.0 20.0 0.0
40 MFW-AISI 431                  593.0 7.9 540.0 193000.0 530.0 86000.0 13.5 0.0
41 NPC-HDPE                   315.0 0.95 4.0 320.0 18.0 0.0 1.9 0.0
42 NPC-NYLON 66                 926.0 1.14 20.0 2100.0 60.0 0.0 3.4 0.0
43 NPC-PP                     325.0 0.9 7.5 1400.0 20.0 0.0 0.54 0.0
44 NPC-PVC  (R)                 240.0 1.4 12.0 960.0 50.0 0.0 0.6 0.0
45 NPC-PS  (GP)               314.0 1.04 0.0 2800.0 48.0 0.0 0.27 0.0
46 NPC-PROPATHENE              240.0 0.90 7.5 1500.0 34.0 0.0 0.5 0.0
47 NPC-MARANYL A100           625.0 1.14 20.0 2900.0 80.0 0.0 3.5 0.0
48 NPC-KEMETAL  AC             375.0 1.41 0.0 2800.0 60.0 0.0 3.5 0.0
49 NPC-RIGIDEX 2000               210.0 0.95 4.0 320.0 28.0 0.0 13.0 0.0
50 BEECH-WOOD               550.0 0.67 6.0 13500.0 15.4 5600.0 0.0 0.0
51 TEAK-WOOD                1750.0 0.61 7.7 12750.0 17.5 5350.0 0.0 0.0
52 OAK-WOOD                   895.0 0.67 6.0 10750.0 14.0 4500.0 0.0 0.0
53 NCC-1.2.4                23.0 2.45 1.1 30000.0 15.4 12250.0 0.0 0.0
54 ****
55
```

DOCUMENT   TINCOMAS

```
      MASTER
      DIMENSION WPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,AMAX,S,MC,P,A,B,LF,DC,L
      LL=0
   69 IA=1
      CALL INPUT(IA,N,LL)
C     ALL PROPERTIES IN SI UNITS
C     F=FATIGUE STRENGTH     E=ELASTIC MODULUS     D=DESIGN STRENGTH
C     R=RIGIDITY MODULUS     I=IMPACT STRENGTH     C=CONDUCTIVITY
C     K=COST PER TONNE       S=SPECIFIC GRAVITY    N=NO OF MATERIALS
  500 DO  12  I=1,N
  502 IF (DC(1).GT.X(I,3).OR.DC(2).GT.X(I,4).OR.DC(3).GT.X(I,5).
     1OR.DC(4).GT.X(I,6).OR.DC(5).GT.X(I,7).OR.DC(6).GT.X(I,8)) GO TO 13
    5 CALL MAX(N)
      CALL SOLVE(IA,I)
      GO  TO  70
   13 WRITE (2,203)  A(I), B(I)
      WRITE (6,203) A(I),B(I)
  203 FORMAT (1X,2A8,8X,30H PROPERTIES BELOW REQUIREMENTS,/)
      GO TO 12
   70 WRITE (2,202)  A(I), B(I), CUR(I)
      WRITE (6,202) A(I),B(I),CUR(I)
  202 FORMAT (1X,2A8,16X,F10.4,/)
   12 CONTINUE
  115 WRITE (2,24)
      WRITE (6,24)
   24 FORMAT (1X,///,33H DO YOU WANT TO CHANGE WF OR DC ?,)
      READ (1,25) LL
      WRITE (6,250) LL
  250 FORMAT (1H0,I4)
```

```
   25 FORMAT (I0)
      IF (LL.EQ.1) GO TO 69
      WRITE (2,26)
      WRITE (6,26)
   26 FORMAT (///,25X,15H END OF PROGRAM)
      STOP
      END

      SUBROUTINE INPUT(IA,N,LL)
      DIMENSION  UPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,AMAX,S,NC,P,A,B,LF,DC,L
      WRITE (2,109)
      WRITE (6,109)
  109 FORMAT (/////,22X,31HCOMPUTERISED MATERIALS SELECTION,///)
      WRITE (2,113)
      WRITE (6,113)
  113 FORMAT (28X,18HCONTROL PARAMETERS,//,5X,16HNO. OF MATERIALS,
     16X,22HNO. OF CHARACTERISTICS,6X,15HPROPERTY NUMBER,/)
      READ (1,112) N,NC,L
  112 FORMAT (3I0)
      WRITE (6,1120) N,NC,L
 1120 FORMAT (1H0,11X,I2,24X,I2,23X,I2)
      IF (LL.EQ.1) GO TO 21
      READ (3,105)  (P(J),J=1,9)
  105 FORMAT (9A8)
      READ (3,100) (A(I),B(I),(X(I,J),J=1,NC+2),I=1,N)
  100 FORMAT (2A8,8F0.0)
   21 WRITE (2,11)
      WRITE (6,11)
```

```
   11 FORMAT (/,27X,18H WEIGHTING FACTORS,/,9X,1HF,9X,1HE,9X,1HD,9X,1HR,
     19X,1HI,9X,1HC)
      READ (1,118) (LF(IA,J),J=1,NC)
  118 FORMAT (6I0)
      WRITE (6,1180) (LF(IA,J),J=1,NC)
 1180 FORMAT (1H0,6(8X,I2))
      WRITE (2,3)
      WRITE (6,3)
    3 FORMAT (/,27X,18HDESIGN CONSTRAINTS,/,9X,1HF,9X,1HE,9X,1HD,9X,1HR,
     19X,1HI,9X,1HC)
      READ (1,23)  (DC(K),K=1,NC)
   23 FORMAT (6F0.0)
      WRITE (6,230) (DC(K),K=1,NC)
  230 FORMAT (1H0,6(5X,F5.2))
      WRITE (2,102)  A(1),B(1)
      WRITE (6,102) A(1),B(1)
  102 FORMAT (/,23X,19HBASIS MATERIAL  =  ,2A8,//)
      WRITE (2,104)
      WRITE (6,104)
  104 FORMAT(/,9H MATERIAL,18X,26H COST PER UNIT REQUIREMENT,//)
      RETURN
      END

      SUBROUTINE MAX(N)
      DIMENSION  WPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,AMAX,S,NC,P,A,B,LF,DC,L
      DO 14  J=3,8
      XMAX=0.0
      DO 14  I=1,N
```

```
      IF (X(I,J).GT.XMAX) XMAX=X(I,J)
      AMAX(J)=XMAX
   14 CONTINUE
      J=3
      DO 15  I=1,NC
      S(I)=100.0/AMAX(J)
      J=J+1
   15 CONTINUE
      RETURN
      END

      SUBROUTINE SOLVE(IA,I)
      DIMENSION  WPF(55),RC(55),CUR(55),A(55),X(55,10),W(55),
     1P(10),LF(5,10),DC(9),AMAX(10),S(9),B(55)
      COMMON RC,CUR,X,AMAX,S,NC,P,A,B,LF,DC,L
C     CALCULATE WEIGHTED PROPERTY FACTORS
      W(I)   =((S(1)*LF(IA,1)*X(1,3))+(S(2)*LF(IA,2)*X(1,4))+(S(3)*LF
     1(IA,3)*X(1,5))+(S(4)*LF(IA,4)*X(1,6))+(S(5)*LF(IA,5)*X(1,7))+
     1(S(6)*LF(IA,6)*X(1,8)))
      WPF(I)   =((S(1)*LF(IA,1)*X(I,3))+(S(2)*LF(IA,2)*X(I,4))+(S(3)*LF
     1(IA,3)*X(I,5))+(S(4)*LF(IA,4)*X(I,6))+(S(5)*LF(IA,5)*X(I,7))+
     1(S(6)*LF(IA,6)*X(I,8)))
C     CALCULATE RELATIVE COST DEPENDING ON LOADING
C     LOADING FOR DESIGN STRENGTH
      RC(I)=(X(1,L)/X(I,L))*(X(I,1)/X(1,1))*(X(I,2)/X(1,2))
C     CALCULATE  COST PER UNIT REQUIREMENT
      CUR(I)=(RC(I)/(WPF(I)/W(I)))
      RETURN
      END
      FINISH
****
```

DOCUMENT   COMASP

```
  29 8 2 2 3
                      K           S         I          T            TM          FX        C       ST
HDPE                         265.0 0.98 20.0 30.0 800.0 20.0 0.0 50.0
LDPE                       205.0 0.92 25.0 10.0 250.0 0.0 0.0 30.0
PS   (GP)                    145.0 1.06 0.6 50.0 3000.0 75.0 110.0 85.0
PS   (HI)                  222.0 1.06 1.5 30.0 2500.0 40.0 110.0 80.0
SAN                        300.0 1.08 0.7 75.0 3700.0 100.0 120.0 80.0
ABS                          335.0 1.07 10.0 35.0 2000.0 65.0 75.0 105.0
C  ACETATE                 400.0 1.34 4.0 40.0 2000.0 45.0 75.0 45.0
C  PROPIONATE                620.0 1.23 6.0 30.0 1600.0 45.0 75.0 60.
C  NITRATE                 500.0 1.3 6.5 50.0 1500.0 65.0 95.0 60.0
ETHYL CELLULOSE              670.0 1.13 8.0 45.0 0.0 45.0 0.0 100.0
ACRYLIC                    505.0 1.19 0.4 70.0 2600.0 110.0 115.0 70.0
ACRYLIC (HI)               460.0 1.18 6.0 55.0 3100.0 80.0 80.0 70.0
PVC (R)                      160.0 1.58 3.0 50.0 2500.0 70.0 75.0 75.0
PVDC (R)                     500.0 1.54 1.0 60.0 3100.0 100.0 100.0 0.
NYLON 6                    920.0 1.14 3.0 80.0 3100.0 70.0 75.0 60.0
NYLON 66                     980.0 1.15 2.0 80.0 3000.0 70.0 90.0 70.0
ACETAL  HP                   650.0 1.42 2.0 70.0 3500.0 100.0 120.0 125.0
ACETAL  CP                   450.0 1.41 1.75 60.0 2800.0 90.0 30.0 110.0
POLYCARBONATE              1175.0 1.2 20.0 60.0 2500.0 90.0 80.0 135.
POLYIMIDE                    1000.0 1.4 1.0 70.0 3000.0 95.0 75.0 480.0
PTFCE                      650.0 2.15 4.0 40.0 2100.0 65.0 70.0 185.0
PTFE                       325.0 2.13 3.0 21.0 350.0 0.0 10.0 260.0
FEP                          960.0 2.14 15.0 22.0 550.0 0.0 10.0 200.0
POLYPROPYLENE HP           300.0 0.91 1.5 35.0 1400.0 50.0 70.0 50.0
POLYPROPYLENE CP           290.0 0.9 10.0 25.0 1000.0 40.0 65.0 50.0
POLYSULPHONE                 700.0 1.24 2.0 70.0 2400.0 100.0 100.0 150.0
PROPATHENE                 300.0 0.9 5.0 34.0 1500.0 0.0 0.0 50.0
KEMETAL AC                   450.0 1.41 0.5 60.0 2800.0 90.0 30.0 50.0
RIGIDEX 2000                 220.0 0.95 20.0 28.0 1000.0 20.0 0.0 50.0
 1 0 0 0 0 0
 2 0 0 0 0 1
 2.5 50.0
            COMPUTERISED  MATERIALS  SELECTION
                       WEIGHTING
  IMP STR   TEN STR   TEN MOD   FLX STR   COM STR   TEMP
                 BASIS  MATERIAL  =  HDPE
MIN IMPACT STRENGTH = 2.5 J
MIN IMPACT STRENGTH = 2.5 J  AND  MIN SERVICE TEMP = 50 C
****
```

CHAPTER 6

ANALYSIS OF COMPUTER OUTPUTS

This chapter analyses the results obtained from the computer under various input conditions. An attempt is also made to find any relationship between the weighting factors, the design constraints imposed and the final cost per unit requirement ratios. Each input is discussed separately and in detail, though some cross-referencing is necessary for full understanding.

6.1 OUTPUT 1

This is the output of the basic MATSEL program and illustrates the concept of sensitivity analysis that can be carried out. During the initial design stage, the designer would like a material with a tensile strength of 450 N/mm^2, an yield strength of 250 N/mm^2, an elongation of 20% and a ruling section of 60 mm.

When the designer or user is on-line to the computer and the program has been loaded, the following message is printed on the teletype "What Property?", and the user is invited to respond. The user then types in the number of the property he is interested in, in this case '6'. He is then given the option of considering more properties. If he is interested in considering more properties he keeps the program running by typing '1' and the whole sequence is repeated. When the number and the numerical values of all the relevant properties have been fed in, the user then ends this sequence by typing in a zero '0'. The computer then gives the solution by listing the numbers of the properties involved in the analysis and the three cheapest steels that satisfy the constraints. The user is then given the option of listing three more steels or to start the whole sequence again from the beginning by specifying different design constraints.

For the first set of constraints normalised 120M19 or hardened and tempered 216M28 or 212M36 would be the most appropriate steels for use. If good corrosion resistance is an additional requirement, martensitic 13% Cr steel, 410S21 can be used but considerable extra cost will have to be incurred. However, if the designer would like to see if, by modifying his design or changing the constraints, any other steel would be suitable, the program is continued with a different set of constraints. By increasing the tensile and yield strengths at the expense of elongation, an entirely new picture is obtained. The plain carbon steels like hardened and tempered 080M30 and 080M46 would also perform the same function.

```
          MZ 20000

13.04.01← UAFORTRAN LOAD MATSELB,*TR0 MATSELD,*CR0,*LP0,TIME 40

13.04.40 JOB IS NOW FULLY STARTED
DISPLAY: UAFORTRAN: TIME GIVEN TO OBJECT PROGRAM IS 40 SECONDS
13.04.49 0.14 CORE GIVEN 17344



WHAT PROPERTY?
← 6
VALUE?
← 450.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 7
VALUE?
← 250.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 8
VALUE?
← 20.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 11
VALUE?
← 60.
IS THERE ANY OTHER PROPERTY?
← 0


  6   7   8  11
NORM    120M19      490 295  20 100     154.40
HATE    212M36      620 340  20 100     171.80
HATE    216M28      620 355  20  63     171.80
MORE STEELS?
← 1

HATE    410S21      620 370  20 150     458.00
0000   00000000       0   0   0   0       0.00
0000   00000000       0   0   0   0       0.00
MORE USE?
← 1
```

```
WHAT PROPERTY?
← 6
VALUE?
← 550.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 7
VALUE?
← 300.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 8
VALUE?
← 15.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 11
VALUE?
← 60.
IS THERE ANY OTHER PROPERTY?
← 0


   6   7   8  11

NORM    120M36     570 340  16 250    154.90
NORM    120M36     590 355  15 150    154.90
HATE    080M30     620 355  18  63    167.30
MORE STEELS?
← 1


HATE    120M19     620 355  18 100    168.40
HATE    120M36     690 415  18 100    168.90
HATE    080M46     690 370  16 100    170.60
MORE USE?
← 0



13.17.40 FREE *TR0 ,176 TRANSFERS
13.17.47 FREE *CR0 ,28 TRANSFERS

13.17.53 FREE *LP0 ,43 TRANSFERS
0.20 :DELETED : 00
13.18.24 0.20 DELETED,CLOCKED 0.04
DISPLAY: UAFORTRAN: NORMAL EXIT
13.18.26←
```

6.2 OUTPUT 2

This output is also for the MATSEL program and shows the selection of a material for the shield screen in a nuclear application. The application is thought to require properties like a minimum ultimate tensile strength of 1000 N/mm^2, an yield strength around 900 N/mm^2 and a ruling section of around 200 mm.

The trial run with a very safe section of 275 mm fails to produce any suitable steels and a warning is issued that the maximum ruling section available from the list of materials is 250 mm.

A second run with a decrease in ruling section from 275 to 250 mm shows that there is still no material available that possesses all the three specified requirements.

However, it can be seen that, if the design can be changed or the screen can be fabricated with a modification in its shape, to perform the same function out of a ruling section of 200 mm and an yield strength of 900 N/mm^2,then one steel, 826M40 can be successfully used.

If a further reduction in ruling section to 150 mm is allowed, five steels satisfy the design constraints and thus give the designer more flexibility. The steels selected are the hardened and tempered Cr, Mo, medium carbon 826M40 and the Cr, Mo, high carbon 835M40.

The results include the nomenclature of the steel and the properties involved in the analysis. A drawback in this program is that upto a maximum of four properties can be considered at any one time. This number can be increased by program modification, but it should be mentioned that the programming language employed, Fortran, is not ideal for such non-mathematical search techniques.

```
            MZ 20000

13.29.19- UAFORTRAN LOAD MATSELB,*TR0 MATSELD,*CR0,*LP0,TIME 40

13.29.50 JOB IS NOW FULLY STARTED
DISPLAY: UAFORTRAN: TIME GIVEN TO OBJECT PROGRAM IS 40 SECONDS
13.29.56 0.31 CORE GIVEN 17344



WHAT PROPERTY?
- 6
VALUE?
- 1000.
IS THERE ANY OTHER PROPERTY?
- 1
WHAT PROPERTY?
- 7
VALUE?
- 950.
IS THERE ANY OTHER PROPERTY?
- 1
WHAT PROPERTY?
- 11
VALUE?
- 275.
250 WARNING
IS THERE ANY OTHER PROPERTY?
- 0


   6   7  11
NO SUITABLE MATERIALS
0000   00000000      0    0    0    0        0.00
0000   00000000      0    0    0    0        0.00
0000   00000000      0    0    0    0        0.00
MORE STEELS?
- 0

MORE USE?
- 1
```

```
WHAT PROPERTY?
← 6
VALUE?
← 1000.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 7
VALUE?
← 950.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 11
VALUE?
← 250.
IS THERE ANY OTHER PROPERTY?
← 0

   6    7   11
NO SUITABLE MATERIALS
0000    00000000       0    0    0    0       0.00
0000    00000000       0    0    0    0       0.00
0000    00000000       0    0    0    0       0.00
MORE STEELS?
← 0
MORE USE?
← 1

WHAT PROPERTY?
← 6
VALUE?
← 1000.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 7
VALUE?
← 900.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 11
VALUE?
← 200.
IS THERE ANY OTHER PROPERTY?
← 0

   6    7   11
0000    00000000       0    0    0    0       0.00
HATE     826M40     1160  925  250    0     285.40
0000    00000000       0    0    0    0       0.00
MORE STEELS?
← 1

0000    00000000       0    0    0    0       0.00
0000    00000000       0    0    0    0       0.00
0000    00000000       0    0    0    0       0.00
```

```
WHAT PROPERTY?
← 6
VALUE?
← 1000.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 7
VALUE?
← 900.
IS THERE ANY OTHER PROPERTY?
← 1
WHAT PROPERTY?
← 11
VALUE?
← 150.
IS THERE ANY OTHER PROPERTY?
← 0

   6    7  11
HATE     826M40     13101095 150    0     285.40
HATE     826M40     1160 925 2=0    0     285.40
HATE     826M40     11>0 940 150    0     285.40
MORE STEELS?
← 1

HATE     826M40     12401020 1=0    0     285.40
HATE     835M40     15401235 150    0     323.30
0000   00000000        0    0   0   0       0.00
MORE USE?
← 0




13.46.33 FREE *TR0 ,176 TRANSFERS
13.46.34 FREE *CR0 ,44 TRANSFERS

13.46.35 FREE *LP0 ,70 TRANSFERS
0.36 :DELETED : 00
13.46.36 0.36 DELETED,CLOCKED 0.03
DISPLAY: UAFORTRAN: NORMAL EXIT
13.46.42←


          LT
13.47.07 0.37 FINISHED : 0 LISTFILES
13.47.07 JOB COST 81P
13.47.09←
```

6.3 OUTPUT 3

This is the output of the COMAS program in its most elementary form. The program considers fifty-three engineering materials for analysis. The only criterion for selection is the design strength. The design strength is taken as half ultimate tensile strength for brittle materials, and taken equal to yield strength for ductile materials. Since only one property is under consideration its weighting factor can be any positive integer. The program computes the cost per unit strength for the basis material EN * 1 and the other fifty-two materials and prints the ratio. This calculation shows how much dearer or cheaper it is to buy a unit of strength for any material compared to EN * 1. From the print-out it can be observed that stainless steel EN 420 and alloy steel EN 24 (817M40) are nearly one seventh the price of ordinary low-carbon EN 1. The plastics and non-metals price themselves out of the competition. In the second section the same exercise is repeated but with a higher design strength requirement. Unless the design strength of the material is equal to or greater than 40 N/mm^2 the material is eliminated from consideration. Four out of nine plastics get eliminated and those that do get screened cost fifteen to twenty times as much as EN 24 or EN 420. Of the nine plastics covered the following are proprietory plastics: Propathene is an ICI polypropylene homopolymer, Maranyl is an ICI nylon, Kemetal is an AMCEL acetal copolymer and Rigidex is a BP high density polythene.

```
                    COMPUTERISED  MATERIALS  SELECTION

                              WEIGHTING

FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND

   0          0          1          0          0         0

                 BASIS  MATERIAL  =  MFW-EN 1

MIN.DESIGN STRENGTH = 15 N/MM SQ


MATERIAL                        COST PER UNIT REQUIREMENT

MFW-EN 1                                1.0000

MCW-ETP                                 3.7347

MCW-OFHC                                5.5390

NAVAL BRASS                             0.8091

MAW-LM 2                                7.4001

MAW-LM 4                                1.1219

MAW-LM 6                               13.1131

MAW-EC                                 11.8145

MAW-IC                                  7.5526

MAW-N 3                                 3.6625

MAW-N 4                                 1.7024

MAW-N 5                                 2.1179

MAW-H 9                                 1.6266

MAW-H 15                                0.7568

MAW-H 20                                3.1776

MAW-H 75                                0.6529

ALUMINUM                                7.4482

COPPER                                 11.6345

SILVER                                915.2878

MFW-EN 2                                0.8671

MFW-EN 3                                0.3193

MFW-EN 4                                0.5150

MFW-EN 5                                0.5144
```

```
MFW-EN 8                           0.3212
MFW-EN 9                           0.3218
MFW-EN 14                          0.3462
MFW-EN 15                          0.2258
MFW-EN 18                          0.2030
MFW-EN 22                          0.1878
MFW-EN 24                          0.1339
MFW-EN 56                          0.2059
MFW-EN 100                         0.1934
MFW-EN 110                         0.1824
MFW-AISI 302                       4.7387
MFW-AISI 309                       6.4733
MFW-AISI 317                       6.4905
MFW-AISI 410                       1.7847
MFW-AISI 420                       0.1210
MFW-AISI 430                       2.0684
MFW-AISI 431                       0.2375
NPC-HDPE                          13.1502
NPC-NYLON 66                       4.1750
NPC-PP                            10.4114
NPC-PVC  (R)                       1.9136
NPC-PS  (GP)                       2.0180
NPC-PROPATHENE                     2.6604
NPC-MARANYL A100                   1.5851
NPC-KEMETAL  AC                    2.0912
NPC-RIGIDEX 2000                   3.6230
BEECH-WOOD                        22.1228
TEAK-WOOD                         49.6289
OAK-WOOD                  PROPERTIES BELOW REQUIREMENTS
NCC-1.2.4                          3.3830
```

```
                COMPUTERISED  MATERIALS  SELECTION

                           WEIGHTING

FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND

   0          0          1          0          0         0

                BASIS  MATERIAL  =  MFW-EN 1

MIN DESIGN STRENGTH = 40 N/MM SQ


MATERIAL                        COST PER UNIT REQUIREMENT

MFW-EN 1                                 1.0000

MCW-ETP                                  3.7347

MCW-OFHC                                 5.5390

NAVAL BRASS                              0.8091

MAW-LM 2                                 7.4001

MAW-LM 4                                 1.1219

MAW-LM 6                       PROPERTIES BELOW REQUIREMENTS

MAW-EC                                  11.8145

MAW-IC                                   7.5526

MAW-N 3                                  3.6625

MAW-N 4                                  1.7024

MAW-N 5                                  2.1179

MAW-H 9                                  1.6266

MAW-H 15                                 0.7568

MAW-H 20                                 3.1776

MAW-H 75                                 0.6529

ALUMINUM                                 7.4482

COPPER                                  11.6345

SILVER                                 915.2878

MFW-EN 2                                 0.8671

MFW-EN 3                                 0.3193

MFW-EN 4                                 0.5150
```

```
MFW-EN 8                          0.3212
MFW-EN 9                          0.3218
MFW-EN 14                         0.3462
MFW-EN 15                         0.2258
MFW-EN 18                         0.2030
MFW-EN 22                         0.1878
MFW-EN 24                         0.1339
MFW-EN 56                         0.2059
MFW-EN 100                        0.1934
MFW-EN 110                        0.1824
MFW-AISI 302                      4.7387
MFW-AISI 309                      6.4733
MFW-AISI 317                      6.4905
MFW-AISI 410                      1.7847
MFW-AISI 420                      0.1210
MFW-AISI 430                      2.0684
MFW-AISI 431                      0.2375
NPC-HDPE                 PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66                      4.1750
NPC-PP                   PROPERTIES BELOW REQUIREMENTS
NPC-PVC  (R)                      1.9136
NPC-PS  (GP)                      2.0180
NPC-PROPATHENE           PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100                  1.5851
NPC-KEMETAL  AC                   2.0912
NPC-RIGIDEX 2000         PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD               PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD                PROPERTIES BELOW REQUIREMENTS
OAK-WOOD                 PROPERTIES BELOW REQUIREMENTS
NCC-1 2.4                PROPERTIES BELOW REQUIREMENTS
```

6.4 OUTPUT 4

This COMAS ouptut considers fifty-three materials on the basis of electrical conductance and design strength, with conductance being the primary requirement. The unit used for electrical conductance is the International Annealed Copper Standard (IACS). The resistance for an unit length (metre) and cross-sectional (sq. mm) area of annealed copper wire is 1.72 μΩ and this is given a rating of 100. All other electrical conductors are given ratings relative to this annealed copper standard. The output is divided into two major sections; each section corresponding to a set of weighting factors. Each section is further divided into two sub-sections; each sub-section corresponding to a set of design constraints. The first set of weighting factors (0 0 1 0 0 10) assigns conductance and design strength weightings of ten and one respectively, thus implying that for this application, conductance is ten times more important than strength. In the second set (0 0 5 0 0 10) the weightings are brought a little closer. The first design constraint is on conductance alone. Only if the material possesses a minimum conductance of 30 IACS is it selected. The second design constraint involves a combination of the two requirements. Unless conductance <u>and</u> strength are both above or equal to a certain minima the material will not be selected.

The basis material throughout this analysis is taken to be electrolytic tough pitch copper with an electrical conductance of 100 IACS. The service requirements are assumed for an overhead electrical conductor. The first section shows that the cheapest material to do the job would be aluminium, nearly one fourth the price. In the second sub-section when design strength is brought into consideration, aluminium like the steels and non-metals gets eliminated from consideration. The cheapest material under these conditions is the aluminium alloy H 20, an Al - Mg - Si alloy. In actual practice, the All Aluminium Conductor (AAC) is made from an alloy whose strength and electrical properties are similar to H 20.

The same situation holds in the third and fourth sub-sections where conductance is only twice as important as the strength.

An interesting observation is the shift of the Cost per Unit Requirement (CUR) ratio with the change in the weighting factors.

TABLE 6.1

WF		CUR			
COND	DS	ALUMINIUM	H 20	ETP	
10	1	0.2759	0.9028	1.0000	Case 1
10	5	0.2930	0.9003	1.0000	Case 2

A detailed calculation shows how the above values were arrived at and how they change.

TABLE 6.2

	Cost £/tonne	Density g/cm^3	Cond IACS	DS N/mm^2
Aluminium	310.0	2.7	65.0	40.0
H 20	686.0	2.7	53.0	91.1
ETP	820.0	8.9	100.0	166.8
Max Value			106.0	670.0

Case 1 (0 0 1 0 0 10)

$$WPF_{Al} = \frac{(65.0*10*\frac{100.0}{106.0}) + (40.0*1*\frac{100.0}{670.0})}{(10 + 1)} = 56.288$$

$$WPF_{H20} = \frac{(53.0*10*\frac{100.0}{106.0}) + (91.1*1*\frac{100.0}{670.0})}{(10 + 1)} = 46.690$$

$$WPF_{ETP} = \frac{(100.0*10*\frac{100.0}{106.0}) + (166.8*1*\frac{100.0}{670.0})}{(10 + 1)} = 88.026$$

$$RWPF_{Al} = \frac{WPF_{Al}}{WPF_{ETP}} = \frac{56.288}{88.026} = 0.6394$$

$$RWPF_{H20} = \frac{WPF_{H20}}{WPF_{ETP}} = \frac{46.690}{88.026} = 0.5304$$

Next calculate the Relative Cost.

$$RC_{Al} = \frac{P_{ETP}}{P_{Al}} * \frac{S_{Al}}{S_{ETP}} * \frac{K_{Al}}{K_{ETP}}$$

$$= \frac{100.0}{65.0} * \frac{2.7}{8.9} * \frac{310.0}{820.0} = 0.1764.$$

$$RC_{H20} = \frac{P_{ETP}}{P_{H20}} * \frac{S_{H20}}{S_{ETP}} * \frac{K_{H20}}{K_{ETP}}$$

$$= \frac{100.0}{53.0} * \frac{2.7}{8.9} * \frac{686.0}{820.0} = 0.4788$$

$$CUR_{Al} = \frac{RC_{Al}}{RWPF_{Al}} = \frac{0.1764}{0.6394} = 0.2759$$

and

$$CUR_{H2O} = \frac{RC_{H2O}}{RWPF_{H2O}} = \frac{0.4788}{0.5304} = 0.9028$$

Similar calculations have been carried out for CASE 2 (0 0 5 0 0 10) and the results are tabulated for comparison.

TABLE 6.3

	ALUMINIUM	H2O	ETP
WPF			
Case 1	56.288	46.690	88.026
Case 2	42.870	37.866	71.190
RWPF			
Case 1	0.6394	0.5304	1.0
Case 2	0.6022	0.5320	1.0
RC			
Case 1	0.1764	0.4788	1.0
Case 2	0.1764	0.4788	1.0
CUR			
Case 1	0.2759	0.9028	1.0
Case 2	0.2930	0.9000	1.0

As can be observed from Table 6.1, as the weighting factor of the secondary property increased from 1 to 5, the CUR ratio of aluminium increased while that of the alloy H2O decreased.

From the calculations for Case 1 it can be observed that in the numerator there are two very unequal brackets. For aluminium the brackets containing conductance have a much higher value than the brackets containing strength. Hence a relatively small change in the WF will not affect the numerator to a large extent while the denominator will increase. The same situation is very nearly true for ETP also. But the situation is quite different for H2O. The second bracket has a large quantity in strength (compared with conductance) and an increase in the WF decreases the overall value to a smaller extent than the other two. The extent of decrease in the WPF value directly affects the RWPF ratio as can be observed from Table 6.3. The WPF of the Alloy decreased to a lesser extent than the WPF of ETP. This in turn increased the RWPF, thus bringing the CUR down. With aluminium the effect was opposite, thus the CUR increased.

Thus it is very difficult to establish any formal relationship between the weighting factors and the cost per unit requirement ratio as there are too many external factors in the analysis.

```
                 COMPUTERISED  MATERIALS  SELECTION

                           WEIGHTING

FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND

   0          0          1          0          0        10

                 BASIS  MATERIAL  =  MCW-ETP

MIN CONDUCTANCE = 30 IACS


MATERIAL                          COST PER UNIT REQUIREMENT


MCW-ETP                                  1.0000

MFW-EN 1                        PROPERTIES BELOW REQUIREMENTS

MCW-OFHC                                 1.4034

NAVAL BRASS                     PROPERTIES BELOW REQUIREMENTS

MAW-LH 2                                 1.1927

MAW-LH 4                                 1.1683

MAW-LH 6                                 1.1746

MAW-EC                                   0.7317

MAW-IC                                   0.7907

MAW-N 3                                  1.0560

MAW-N 4                                  1.4883

MAW-N 5                                  1.8432

MAW-H 9                                  1.8007

MAW-H 15                                 1.9305

MAW-H 20                                 0.9028

MAW-H 75                                 3.8710

ALUMINUM                                 0.2759

COPPER                                   0.6142

SILVER                                  39.0205

MFW-EN 2                        PROPERTIES BELOW REQUIREMENTS

MFW-EN 3                        PROPERTIES BELOW REQUIREMENTS
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```
MFW-EN 4                     PROPERTIES BELOW REQUIREMENTS

MFW-EN 5                     PROPERTIES BELOW REQUIREMENTS

MFW-EN 8                     PROPERTIES BELOW REQUIREMENTS

MFW-EN 9                     PROPERTIES BELOW REQUIREMENTS

MFW-EN 14                    PROPERTIES BELOW REQUIREMENTS

MFW-EN 15                    PROPERTIES BELOW REQUIREMENTS

MFW-EN 18                    PROPERTIES BELOW REQUIREMENTS

MFW-EN 22                    PROPERTIES BELOW REQUIREMENTS

MFW-EN 26                    PROPERTIES BELOW REQUIREMENTS

MFW-EN 56                    PROPERTIES BELOW REQUIREMENTS

MFW-EN 100                   PROPERTIES BELOW REQUIREMENTS

MFW-EN 110                   PROPERTIES BELOW REQUIREMENTS

MFW-AISI 302                 PROPERTIES BELOW REQUIREMENTS

MFW-AISI 309                 PROPERTIES BELOW REQUIREMENTS

MFW-AISI 317                 PROPERTIES BELOW REQUIREMENTS

MFW-AISI 410                 PROPERTIES BELOW REQUIREMENTS

MFW-AISI 420                 PROPERTIES BELOW REQUIREMENTS

MFW-AISI 430                 PROPERTIES BELOW REQUIREMENTS

MFW-AISI 431                 PROPERTIES BELOW REQUIREMENTS

NPC-HDPE                     PROPERTIES BELOW REQUIREMENTS

NPC-NYLON 66                 PROPERTIES BELOW REQUIREMENTS

NPC-PP                       PROPERTIES BELOW REQUIREMENTS

NPC-PVC  (R)                 PROPERTIES BELOW REQUIREMENTS

NPC-PS  (GP)                 PROPERTIES BELOW REQUIREMENTS

NPC-PROPATHENE               PROPERTIES BELOW REQUIREMENTS

NPC-MARANYL A100             PROPERTIES BELOW REQUIREMENTS

NPC-KEMETAL  AC              PROPERTIES BELOW REQUIREMENTS

NPC-RIGIDEX 2000             PROPERTIES BELOW REQUIREMENTS

BEECH-WOOD                   PROPERTIES BELOW REQUIREMENTS

TEAK-WOOD                    PROPERTIES BELOW REQUIREMENTS

OAK-WOOD                     PROPERTIES BELOW REQUIREMENTS

NCC-1,2,4                    PROPERTIES BELOW REQUIREMENTS
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                    COMPUTERISED  MATERIALS  SELECTION

                              WEIGHTING

   FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND
      0          0          1          0          0        10

                    BASIS  MATERIAL  =  MCW-ETP
   MIN COND = 30 IACS  AND  MIN D.S. = 80 N/MM SQ


   MATERIAL
                              COST PER UNIT REQUIREMENT

   MCW-ETP                          1.0000
   MFW-EN 1                  PROPERTIES BELOW REQUIREMENTS
   MCW-OFHC                         1.4034
   NAVAL BRASS               PROPERTIES BELOW REQUIREMENTS
   MAW-LM 2                  PROPERTIES BELOW REQUIREMENTS
   MAW-LM 4                         1.1683
   MAW-LM 6                  PROPERTIES BELOW REQUIREMENTS
   MAW-EC                    PROPERTIES BELOW REQUIREMENTS
   MAW-IC                    PROPERTIES BELOW REQUIREMENTS
   MAW-N 3                   PROPERTIES BELOW REQUIREMENTS
   MAW-N 4                          1.4883
   MAW-N 5                          1.8432
   MAW-H 9                          1.8007
   MAW-H 15                         1.9305
   MAW-H 20                         0.9028
   MAW-H 75                         3.8710
   ALUMINUM                  PROPERTIES BELOW REQUIREMENTS
   COPPER                    PROPERTIES BELOW REQUIREMENTS
   SILVER                    PROPERTIES BELOW REQUIREMENTS
   MFW-EN 2                  PROPERTIES BELOW REQUIREMENTS
   MFW-EN 3                  PROPERTIES BELOW REQUIREMENTS
```

MFW-EN 4	PROPERTIES BELOW REQUIREMENTS
MFW-EN 5	PROPERTIES BELOW REQUIREMENTS
MFW-EN 8	PROPERTIES BELOW REQUIREMENTS
MFW-EN 9	PROPERTIES BELOW REQUIREMENTS
MFW-EN 14	PROPERTIES BELOW REQUIREMENTS
MFW-EN 15	PROPERTIES BELOW REQUIREMENTS
MFW-EN 18	PROPERTIES BELOW REQUIREMENTS
MFW-EN 22	PROPERTIES BELOW REQUIREMENTS
MFW-EN 24	PROPERTIES BELOW REQUIREMENTS
MFW-EN 56	PROPERTIES BELOW REQUIREMENTS
MFW-EN 100	PROPERTIES BELOW REQUIREMENTS
MFW-EN 110	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 302	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 309	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 317	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 410	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 420	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 430	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 431	PROPERTIES BELOW REQUIREMENTS
NPC-HDPE	PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66	PROPERTIES BELOW REQUIREMENTS
NPC-PP	PROPERTIES BELOW REQUIREMENTS
NPC-PVC (R)	PROPERTIES BELOW REQUIREMENTS
NPC-PS (GP)	PROPERTIES BELOW REQUIREMENTS
NPC-PROPATHENE	PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100	PROPERTIES BELOW REQUIREMENTS
NPC-KEMETAL AC	PROPERTIES BELOW REQUIREMENTS
NPC-RIGIDEX 2000	PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD	PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD	PROPERTIES BELOW REQUIREMENTS
OAK-WOOD	PROPERTIES BELOW REQUIREMENTS
MCC-1,2,4	PROPERTIES BELOW REQUIREMENTS

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                COMPUTERISED  MATERIALS  SELECTION

                          WEIGHTING

FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND

   0          0          5          0          0        10

                  BASIS  MATERIAL  =  MCW-ETP

MIN CONDUCTANCE = 30 IACS


MATERIAL                         COST PER UNIT REQUIREMENT


MCW-ETP                                 1.0000

MFW-EN 1                      PROPERTIES BELOW REQUIREMENTS

MCW-OFHC                                1.4070

NAVAL BRASS                   PROPERTIES BELOW REQUIREMENTS

MAW-LM 2                                1.2179

MAW-LM 4                                1.0734

MAW-LM 6                                1.2223

MAW-EC                                  0.7686

MAW-IC                                  0.8191

MAW-N 3                                 1.0523

MAW-N 4                                 1.3864

MAW-N 5                                 1.7176

MAW-H 9                                 1.6462

MAW-H 15                                1.6265

MAW-H 20                                0.9003

MAW-H 75                                2.9218

ALUMINUM                                0.2930

COPPER                                  0.6476

SILVER                                 41.3244

MFW-EN 2                      PROPERTIES BELOW REQUIREMENTS

MFW-EN 3                      PROPERTIES BELOW REQUIREMENTS
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```
MFW-EN 4                                  PROPERTIES BELOW REQUIREMENTS
MFW-EN 5                                  PROPERTIES BELOW REQUIREMENTS
MFW-EN 8                                  PROPERTIES BELOW REQUIREMENTS
MFW-EN 9                                  PROPERTIES BELOW REQUIREMENTS
MFW-EN 16                                 PROPERTIES BELOW REQUIREMENTS
MFW-EN 15                                 PROPERTIES BELOW REQUIREMENTS
MFW-EN 18                                 PROPERTIES BELOW REQUIREMENTS
MFW-EN 22                                 PROPERTIES BELOW REQUIREMENTS
MFW-EN 26                                 PROPERTIES BELOW REQUIREMENTS
MFW-EN 56                                 PROPERTIES BELOW REQUIREMENTS
MFW-EN 100                                PROPERTIES BELOW REQUIREMENTS
MFW-EN 110                                PROPERTIES BELOW REQUIREMENTS
MFW-AISI 302                              PROPERTIES BELOW REQUIREMENTS
MFW-AISI 309                              PROPERTIES BELOW REQUIREMENTS
MFW-AISI 317                              PROPERTIES BELOW REQUIREMENTS
MFW-AISI 410                              PROPERTIES BELOW REQUIREMENTS
MFW-AISI 420                              PROPERTIES BELOW REQUIREMENTS
MFW-AISI 430                              PROPERTIES BELOW REQUIREMENTS
MFW-AISI 431                              PROPERTIES BELOW REQUIREMENTS
NPC-HDPE                                  PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66                              PROPERTIES BELOW REQUIREMENTS
NPC-PP                                    PROPERTIES BELOW REQUIREMENTS
NPC-PVC  (R)                              PROPERTIES BELOW REQUIREMENTS
NPC-PS  (GP)                              PROPERTIES BELOW REQUIREMENTS
NPC-PROPATHENE                            PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100                          PROPERTIES BELOW REQUIREMENTS
NPC-KEMETAL  AC                           PROPERTIES BELOW REQUIREMENTS
NPC-RIGIDEX 2000                          PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD                                PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD                                 PROPERTIES BELOW REQUIREMENTS
OAK-WOOD                                  PROPERTIES BELOW REQUIREMENTS
NCC-1,2,4                                 PROPERTIES BELOW REQUIREMENTS
```

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              COMPUTERISED  MATERIALS  SELECTION

                        WEIGHTING

 FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND
    0          0          5          0          0        10

                 BASIS  MATERIAL  =  MCW-ETP
 MIN COND = 30 IACS  AND  MIN D.S. = 80 N/MM SQ


 MATERIAL                          COST PER UNIT REQUIREMENT

 MCW-ETP                                   1.0000
 MFW-EN 1                       PROPERTIES BELOW REQUIREMENTS
 MCW-OFHC                                  1.4070
 NAVAL BRASS                    PROPERTIES BELOW REQUIREMENTS
 MAW-LM 2                       PROPERTIES BELOW REQUIREMENTS
 MAW-LM 4                                  1.0734
 MAW-LM 6                       PROPERTIES BELOW REQUIREMENTS
 MAW-EC                         PROPERTIES BELOW REQUIREMENTS
 MAW-IC                         PROPERTIES BELOW REQUIREMENTS
 MAW-N 3                        PROPERTIES BELOW REQUIREMENTS
 MAW-N 4                                   1.3864
 MAW-N 5                                   1.7176
 MAW-H 9                                   1.6462
 MAW-H 15                                  1.6265
 MAW-H 20                                  0.9003
 MAW-H 75                                  2.9218
 ALUMINUM                       PROPERTIES BELOW REQUIREMENTS
 COPPER                         PROPERTIES BELOW REQUIREMENTS
 SILVER                         PROPERTIES BELOW REQUIREMENTS
 MFW-EN 2                       PROPERTIES BELOW REQUIREMENTS
 MFW-EN 3                       PROPERTIES BELOW REQUIREMENTS
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MFW-EN 4                 PROPERTIES BELOW REQUIREMENTS

MFW-EN 5                 PROPERTIES BELOW REQUIREMENTS

MFW-EN 8                 PROPERTIES BELOW REQUIREMENTS

MFW-EN 9                 PROPERTIES BELOW REQUIREMENTS

MFW-EN 16                PROPERTIES BELOW REQUIREMENTS

MFW-EN 15                PROPERTIES BELOW REQUIREMENTS

MFW-EN 18                PROPERTIES BELOW REQUIREMENTS

MFW-EN 22                PROPERTIES BELOW REQUIREMENTS

MFW-EN 26                PROPERTIES BELOW REQUIREMENTS

MFW-EN 56                PROPERTIES BELOW REQUIREMENTS

MFW-EN 100               PROPERTIES BELOW REQUIREMENTS

MFW-EN 110               PROPERTIES BELOW REQUIREMENTS

MFW-AISI 302             PROPERTIES BELOW REQUIREMENTS

MFW-AISI 309             PROPERTIES BELOW REQUIREMENTS

MFW-AISI 317             PROPERTIES BELOW REQUIREMENTS

MFW-AISI 410             PROPERTIES BELOW REQUIREMENTS

MFW-AISI 420             PROPERTIES BELOW REQUIREMENTS

MFW-AISI 430             PROPERTIES BELOW REQUIREMENTS

MFW-AISI 431             PROPERTIES BELOW REQUIREMENTS

NPC-HDPE                 PROPERTIES BELOW REQUIREMENTS

NPC-NYLON 66             PROPERTIES BELOW REQUIREMENTS

NPC-PP                   PROPERTIES BELOW REQUIREMENTS

NPC-PVC  (R)             PROPERTIES BELOW REQUIREMENTS

NPC-PS  (GP)             PROPERTIES BELOW REQUIREMENTS

NPC-PROPATHENE           PROPERTIES BELOW REQUIREMENTS

NPC-MARANYL A100         PROPERTIES BELOW REQUIREMENTS

NPC-KEMETAL  AC          PROPERTIES BELOW REQUIREMENTS

NPC-RIGIDEX 2000         PROPERTIES BELOW REQUIREMENTS

BEECH-WOOD               PROPERTIES BELOW REQUIREMENTS

TEAK-WOOD                PROPERTIES BELOW REQUIREMENTS

OAK-WOOD                 PROPERTIES BELOW REQUIREMENTS

NCC-1,2,4                PROPERTIES BELOW REQUIREMENTS
```

6.5 OUTPUT 5

In this output a comparison is made between present-day engineering materials and a future material. The property in question is electrical conductance and the comparison is made between available and commonly used electrical conductors and a fictitious high-strength conductor that comes onto the market.

For this marketing operation to be successful, two questions need to be answered.

1. What are the established materials it will have to compete with?
2. At what price should it be marketed?

Sometime in the 1930's, the cost effectiveness of aluminium, allowing for the difference in densities between aluminium and copper, overtook that of copper. It was during this period that the conversion of copper to aluminium took place for long-distance high-voltage overhead transmission lines. Since then, such lines have been aluminium with the exception of installations in sea coast areas where chloride corrosion militates against that material. This situation of aluminium replacing copper was shown in Output 4, where alloy H20 replaced ETP copper.

This situation is shown in a different format in the first section of the output with the aluminium alloy H20 replacing ETP copper as the basis material. This answers the first question. If a new material were to be introduced today, it will have to compete primarily with alloy H2O. The major characteristics of H2O are:

H 20

Design Strength	91	N/mm^2
Electrical Conductance	53	IACS
Density	2.7	g/cm^3
Market Price	686	£/tonne

Answering the second question to establish the cost is slightly more complex. First, the properties of this new alloy, called 'material X' have to be established. This comes under the fields of physical metallurgy and alloy design and assuming for this exercise that the alloy belongs to the copper family, its major characteristics are:

ALLOY X

Design Strength	175	N/mm^2
Electrical Conductance	75	IACS
Density	7.85	g/cm^3

Three factors which are outside the alloy designer's control are i) the production cost of the alloy; ii) the weighting which user's will assign to the two properties, and iii) the market price of the alloy.

For commerical reasons the market price is the dominant factor and is in turn controlled by the other two factors. The relationship between the production cost and the market price is fairly simple:- as long as the market price is greater than the production cost the product will make a contribution financially to the company. Hence, the market price must be, of necessity, greater than the production cost. The relationship between the property weightings and the market price is not so simple and is best illustrated by going through the second and third sections of Output 5.

The cost exercise is started by establishing the weighting factors. In this case, 10 for conductance and 1 for strength are assumed. Next, an arbitrary market price is assigned to X. This price is inserted into the data file COMASD; and the program run by coupling data file COMASD with the main program COMAS. If the CUR of all the other materials is greater than the CUR of X, then alloy X is the cheapest conductor for the job. If the CUR of X is not the least, decrease its price and run the program again. In interactive mode this running and re-running becomes quick and easy and the price of X is kept on decreasing (or increasing) till its CUR is the least. The second section shows alloy X as the basis material with the least CUR. This occurred at a price of £475/tonne, and hence, X can enter the market at any price upto £475/tonne and still be the cheapest.

The same exercise is conducted with a different set of weighting factors in the third section. Alloy X has a relatively high design strength compared with the other conductors and when the weighting for this secondary property is increased from 1 to 5, it has a favourable effect on X and the alloy can enter the market at £490/tonne and still be the cheapest conductor for the job.

Thus depending on the weighting of the requirements its utility to the user will change and this will be reflected in the price the user is willing to pay for the material. Thus, there is now an established relationship between market price and the weighting factors and this is summarised below.

ALLOY X

CONDUCTANCE	WF	STRENGTH	WF	PRICE
75	10	175	1	£475
75	10	175	5	£490

This is a simple illustration involving two properties only. The analysis can be extended further by introducing other properties which is usually the case in a real world situation. On the enhancement of a property like strength some other property like ductility may tend to suffer and in such complex situations this kind of computer analysis can help a company decide on its R and D, production and price-fixing policies.

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               COMPUTERISED  MATERIALS  SELECTION

                          WEIGHTING

FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND

   0          0          1          0          0        10

                 BASIS  MATERIAL  =  MAW-H 20

MIN CONDUCTANCE = 30 IACS  AND  MIN DESIGN STRENGTH = 80 N/MM SQ


MATERIAL                         COST PER UNIT REQUIREMENT


MAW-H 20                                  1.0000

MCW-OFHC                                  1.5545

MCW-ETP                                   1.1077

MFW-EN 1                      PROPERTIES BELOW REQUIREMENTS

NAVAL BRASS                   PROPERTIES BELOW REQUIREMENTS

MAW-LM 2                      PROPERTIES BELOW REQUIREMENTS

MAW-LM 4                                  1.2940

MAW-LM 6                      PROPERTIES BELOW REQUIREMENTS

MAW-EC                        PROPERTIES BELOW REQUIREMENTS

MAW-IC                        PROPERTIES BELOW REQUIREMENTS

MAW-N 3                       PROPERTIES BELOW REQUIREMENTS

MAW-N 4                                   1.6485

MAW-N 5                                   2.0416

MAW-H 9                                   1.9946

MAW-H 15                                  2.1383

MAW-H 75                                  4.2378

ALUMINUM                      PROPERTIES BELOW REQUIREMENTS

COPPER                        PROPERTIES BELOW REQUIREMENTS

SILVER                        PROPERTIES BELOW REQUIREMENTS

MFW-EN 2                      PROPERTIES BELOW REQUIREMENTS

                              PROPERTIES BELOW REQUIREMENTS
```

```
MFW-EN 4                       PROPERTIES BELOW REQUIREMENTS
MFW-EN 5                       PROPERTIES BELOW REQUIREMENTS
MFW-EN 8                       PROPERTIES BELOW REQUIREMENTS
MFW-EN 9                       PROPERTIES BELOW REQUIREMENTS
MFW-EN 14                      PROPERTIES BELOW REQUIREMENTS
MFW-EN 15                      PROPERTIES BELOW REQUIREMENTS
MFW-EN 18                      PROPERTIES BELOW REQUIREMENTS
MFW-EN 22                      PROPERTIES BELOW REQUIREMENTS
MFW-EN 24                      PROPERTIES BELOW REQUIREMENTS
MFW-EN 54                      PROPERTIES BELOW REQUIREMENTS
MFW-EN 100                     PROPERTIES BELOW REQUIREMENTS
MFW-EN 110                     PROPERTIES BELOW REQUIREMENTS
MFW-AISI 302                   PROPERTIES BELOW REQUIREMENTS
MFW-AISI 309                   PROPERTIES BELOW REQUIREMENTS
MFW-AISI 317                   PROPERTIES BELOW REQUIREMENTS
MFW-AISI 410                   PROPERTIES BELOW REQUIREMENTS
MFW-AISI 420                   PROPERTIES BELOW REQUIREMENTS
MFW-AISI 430                   PROPERTIES BELOW REQUIREMENTS
MFW-AISI 431                   PROPERTIES BELOW REQUIREMENTS
NPC-HDPE                       PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66                   PROPERTIES BELOW REQUIREMENTS
NPC-PP                         PROPERTIES BELOW REQUIREMENTS
NPC-PVC  (R)                   PROPERTIES BELOW REQUIREMENTS
NPC-PS  (GP)                   PROPERTIES BELOW REQUIREMENTS
NPC-PROPATHENE                 PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100               PROPERTIES BELOW REQUIREMENTS
NPC-KEMETAL  AC                PROPERTIES BELOW REQUIREMENTS
NPC-RIGIDEX 2000               PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD                     PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD                      PROPERTIES BELOW REQUIREMENTS
OAK-WOOD                       PROPERTIES BELOW REQUIREMENTS
MCC-1,2,4                      PROPERTIES BELOW REQUIREMENTS
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               COMPUTERISED  MATERIALS  SELECTION

                          WEIGHTING

  FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND
     0          0          1          0          0        10

               BASIS  MATERIAL  =  MATERIAL  X
  MIN CONDUCTANCE = 30 IACS  AND  MIN DESIGN STRENGTH = 80 N/MM SQ


  MATERIAL                       COST PER UNIT REQUIREMENT

  MATERIAL  X                          1.0000
  MCW-OFHC                             1.5609
  MCW-ETP                              1.1122
  MFW-EN 1                     PROPERTIES BELOW REQUIREMENTS
  NAVAL BRASS                  PROPERTIES BELOW REQUIREMENTS
  MAW-LM 2                     PROPERTIES BELOW REQUIREMENTS
  MAW-LM 4                             1.2994
  MAW-LM 6                     PROPERTIES BELOW REQUIREMENTS
  MAW-EC                       PROPERTIES BELOW REQUIREMENTS
  MAW-IC                       PROPERTIES BELOW REQUIREMENTS
  MAW-N 3                      PROPERTIES BELOW REQUIREMENTS
  MAW-N 4                              1.6553
  MAW-N 5                              2.0500
  MAW-H 9                              2.0028
  MAW-H 15                             2.1471
  MAW-H 20                             1.0041
  MAW-H 75                             4.3055
  ALUMINUM                     PROPERTIES BELOW REQUIREMENTS
  COPPER                       PROPERTIES BELOW REQUIREMENTS
  SILVER                       PROPERTIES BELOW REQUIREMENTS
  MFW-EN 2                     PROPERTIES BELOW REQUIREMENTS
  MFW-EN 3                     PROPERTIES BELOW REQUIREMENTS
```

MFW-EN 4	PROPERTIES BELOW REQUIREMENTS
MFW-EN 5	PROPERTIES BELOW REQUIREMENTS
MFW-EN 8	PROPERTIES BELOW REQUIREMENTS
MFW-EN 9	PROPERTIES BELOW REQUIREMENTS
MFW-EN 14	PROPERTIES BELOW REQUIREMENTS
MFW-EN 15	PROPERTIES BELOW REQUIREMENTS
MFW-EN 18	PROPERTIES BELOW REQUIREMENTS
MFW-EN 22	PROPERTIES BELOW REQUIREMENTS
MFW-EN 24	PROPERTIES BELOW REQUIREMENTS
MFW-EN 56	PROPERTIES BELOW REQUIREMENTS
MFW-EN 100	PROPERTIES BELOW REQUIREMENTS
MFW-EN 110	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 302	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 309	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 317	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 410	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 420	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 430	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 431	PROPERTIES BELOW REQUIREMENTS
NPC-HDPE	PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66	PROPERTIES BELOW REQUIREMENTS
NPC-PP	PROPERTIES BELOW REQUIREMENTS
NPC-PVC (R)	PROPERTIES BELOW REQUIREMENTS
NPC-PS (GP)	PROPERTIES BELOW REQUIREMENTS
NPC-PROPATHENE	PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100	PROPERTIES BELOW REQUIREMENTS
NPC-KEMETAL AC	PROPERTIES BELOW REQUIREMENTS
NPC-RIGIDEX 2000	PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD	PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD	PROPERTIES BELOW REQUIREMENTS
OAK-WOOD	PROPERTIES BELOW REQUIREMENTS
NCC-1,2,4	PROPERTIES BELOW REQUIREMENTS

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           COMPUTERISED  MATERIALS  SELECTION

                      WEIGHTING

FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND

   0          0          5          0          0        10

             BASIS  MATERIAL  =  MATERIAL  X

MIN CONDUCTANCE = 30 IACS  AND  MIN DESIGN STRENGTH = 80 N/MM SQ


MATERIAL                     COST PER UNIT REQUIREMENT

MATERIAL  X                          1.0000

MCW-OFHC                             1.5714

MCW-ETP                              1.1169

MFW-EN 1                  PROPERTIES BELOW REQUIREMENTS

NAVAL BRASS               PROPERTIES BELOW REQUIREMENTS

MAW-LM 2                  PROPERTIES BELOW REQUIREMENTS

MAW-LM 4                             1.1989

MAW-LM 6                  PROPERTIES BELOW REQUIREMENTS

MAW-EC                    PROPERTIES BELOW REQUIREMENTS

MAW-IC                    PROPERTIES BELOW REQUIREMENTS

MAW-N 3                   PROPERTIES BELOW REQUIREMENTS

MAW-N 4                              1.5484

MAW-N 5                              1.9183

MAW-H 9                              1.8386

MAW-H 15                             1.8166

MAW-H 20                             1.0055

MAW-H 75                             3.2632

ALUMINUM                  PROPERTIES BELOW REQUIREMENTS

COPPER                    PROPERTIES BELOW REQUIREMENTS

SILVER                    PROPERTIES BELOW REQUIREMENTS

MFW-EN 2                  PROPERTIES BELOW REQUIREMENTS
```

MFW-EN 4	PROPERTIES BELOW REQUIREMENTS
MFW-EN 5	PROPERTIES BELOW REQUIREMENTS
MFW-EN 8	PROPERTIES BELOW REQUIREMENTS
MFW-EN 9	PROPERTIES BELOW REQUIREMENTS
MFW-EN 16	PROPERTIES BELOW REQUIREMENTS
MFW-EN 15	PROPERTIES BELOW REQUIREMENTS
MFW-EN 18	PROPERTIES BELOW REQUIREMENTS
MFW-EN 22	PROPERTIES BELOW REQUIREMENTS
MFW-EN 26	PROPERTIES BELOW REQUIREMENTS
MFW-EN 56	PROPERTIES BELOW REQUIREMENTS
MFW-EN 100	PROPERTIES BELOW REQUIREMENTS
MFW-EN 110	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 302	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 309	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 317	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 410	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 420	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 430	PROPERTIES BELOW REQUIREMENTS
MFW-AISI 431	PROPERTIES BELOW REQUIREMENTS
NPC-HDPE	PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66	PROPERTIES BELOW REQUIREMENTS
NPC-PP	PROPERTIES BELOW REQUIREMENTS
NPC-PVC (R)	PROPERTIES BELOW REQUIREMENTS
NPC-PS (GP)	PROPERTIES BELOW REQUIREMENTS
NPC-PROPATHENE	PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100	PROPERTIES BELOW REQUIREMENTS
NPC-KEMETAL AC	PROPERTIES BELOW REQUIREMENTS
NPC-RIGIDEX 2000	PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD	PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD	PROPERTIES BELOW REQUIREMENTS
OAK-WOOD	PROPERTIES BELOW REQUIREMENTS
NCC-1,2,4	PROPERTIES BELOW REQUIREMENTS

6.6 OUTPUT 6

This is the output of a COMAS program selecting materials on the basis of design strength and elastic modulus. As the property weighting factors change it is interesting to note how the "batting order" changes.

In the first section design strength is the primary requirement and is given a weighting of 10. With a weighting of 1 for the elastic modulus, the cheapest materials are stainless steel 420 and 1.5% Ni-Cr-Mo steel EN24.

But if elastic modulus is made the primary requirement the situation changes completely. From the second section it can be observed that EN 24 and AISI 420 change order but neither of these steels is anywhere close to the cheapest steels which are mainly the carbon steels; EN3 the cheapest is a 20C steel, EN8 is a 40C steel and EN9 is a 55C steel.

The same exercise is repeated with the weightings brought a little closer and two new steels enter the picture. They are the C-Mn alloy steels EN14 and EN15.

Another interesting point to observe is how drastically the CUR values for the plastics change when the elastic modulus is made the major requirement.

Hence it is virtually important for the designer to be very accurate in his interpretation and definition of primary and secondary requirements as this has a major inpact on the

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              COMPUTERISED  MATERIALS  SELECTION

                        WEIGHTING

  FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND
     0          1          10         0          0         0

                BASIS  MATERIAL  =  MFW-EN 1
 MIN D.S. = 50 N/MM SQ  AND  MIN E.M. = 1000 N/MM SQ


 MATERIAL                      COST PER UNIT REQUIREMENT

 MFW-EN 1                              1.0000
 MCW-ETP                               4.6984
 MCW-OFHC                              6.9327
 NAVAL BRASS                           1.1080
 MAW-LM 2                      PROPERTIES BELOW REQUIREMENTS
 MAW-LM 4                              1.4153
 MAW-LM 6                      PROPERTIES BELOW REQUIREMENTS
 MAW-EC                        PROPERTIES BELOW REQUIREMENTS
 MAW-IC                                8.3741
 MAW-N 3                               4.2404
 MAW-N 4                               2.1476
 MAW-N 5                               2.6104
 MAW-H 9                               2.1379
 MAW-H 15                              1.0476
 MAW-H 20                              3.8902
 MAW-H 75                              0.9168
 ALUMINUM                      PROPERTIES BELOW REQUIREMENTS
 COPPER                               11.6835
 SILVER                             1054.0834
 MFW-EN 2                              0.8812
 MFW-EN 3                              0.3740
 MFW-EN 4                              0.5674
```

MFW-EN 8	0.3761
MFW-EN 9	0.3769
MFW-EN 14	0.4031
MFW-EN 15	0.2758
MFW-EN 18	0.2564
MFW-EN 22	0.2442
MFW-EN 24	0.1773
MFW-EN 56	0.2600
MFW-EN 100	0.2481
MFW-EN 110	0.2362
MFW-AISI 302	4.8671
MFW-AISI 309	6.8098
MFW-AISI 317	6.8279
MFW-AISI 410	1.8775
MFW-AISI 420	0.1696
MFW-AISI 430	2.2652
MFW-AISI 431	0.3252
NPC-HDPE	PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66	6.3388
NPC-PP	PROPERTIES BELOW REQUIREMENTS
NPC-PVC (R)	PROPERTIES BELOW REQUIREMENTS
NPC-PS (GP)	PROPERTIES BELOW REQUIREMENTS
NPC-PROPATHENE	PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100	2.4056
NPC-KEMETAL AC	3.1628
NPC-RIGIDEX 2000	PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD	PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD	PROPERTIES BELOW REQUIREMENTS
OAK-WOOD	PROPERTIES BELOW REQUIREMENTS
NCC-1.2.4	PROPERTIES BELOW REQUIREMENTS

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              COMPUTERISED  MATERIALS  SELECTION

                        WEIGHTING

FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND

   0         10          1          0          0         0

                BASIS  MATERIAL  =  MFW-EN 1

MIN D S = 50 N/MM SQ  AND  MIN E M = 1000 N/MM SQ


MATERIAL                      COST PER UNIT REQUIREMENT

MFW-EN 1                             1.0000

MCW-ETP                             21.4195

MCW-OFHC                            30.0755

NAVAL BRASS                         14.7899

MAW-LM 2                  PROPERTIES BELOW REQUIREMENTS

MAW-LM 4                             6.6300

MAW-LM 6                  PROPERTIES BELOW REQUIREMENTS

MAW-EC                    PROPERTIES BELOW REQUIREMENTS

MAW-IC                              14.5114

MAW-N 3                              9.7444

MAW-N 4                             10.0605

MAW-N 5                              9.8238

MAW-H 9                             15.7920

MAW-H 15                            16.8910

MAW-H 20                            13.8023

MAW-H 75                            19.5969

ALUMINUM                  PROPERTIES BELOW REQUIREMENTS

COPPER                              11.9171

SILVER                            2334.8292

MFW-EN 2                             0.9515

MFW-EN 3                             0.9324

MFW-EN 4                             0.9463
```

```
MFW-EN 8                          0.9378
MFW-EN 9                          0.9397
MFW-EN 14                         0.9651
MFW-EN 15                         0.9582
MFW-EN 18                         1.2156
MFW-EN 22                         1.5882
MFW-EN 24                         1.4486
MFW-EN 56                         1.2328
MFW-EN 100                        1.3869
MFW-EN 110                        1.4627
MFW-AISI 302                      5.5370
MFW-AISI 309                      8.7588
MFW-AISI 317                      8.7821
MFW-AISI 410                      2.4149
MFW-AISI 420                      3.4709
MFW-AISI 430                      3.6444
MFW-AISI 431                      4.3470
NPC-HDPE                PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66                   4824.4016
NPC-PP                  PROPERTIES BELOW REQUIREMENTS
NPC-PVC  (R)            PROPERTIES BELOW REQUIREMENTS
NPC-PS  (GP)            PROPERTIES BELOW REQUIREMENTS
NPC-PROPATHENE          PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100               1735.0732
NPC-KEMETAL  AC                1536.4133
NPC-RIGIDEX 2000        PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD              PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD               PROPERTIES BELOW REQUIREMENTS
OAK-WOOD                PROPERTIES BELOW REQUIREMENTS
NCC-1.2.4               PROPERTIES BELOW REQUIREMENTS
```

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                COMPUTERISED MATERIALS SELECTION

                          WEIGHTING

   FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND
      0          5          10         0          0         0

                  BASIS MATERIAL = MFW-EN 1
   MIN D.S. = 50 N/MM SQ  AND  MIN E.M. = 1000 N/MM SQ

   MATERIAL                       COST PER UNIT REQUIREMENT

   MFW-EN 1                              1.0000
   MCW-ETP                               6.5299
   MCW-OFHC                              9.5425
   NAVAL BRASS                           1.8515
   MAW-LM 2                     PROPERTIES BELOW REQUIREMENTS
   MAW-LM 4                              1.9774
   MAW-LM 6                     PROPERTIES BELOW REQUIREMENTS
   MAW-EC                       PROPERTIES BELOW REQUIREMENTS
   MAW-IC                                9.4970
   MAW-N 3                               5.1180
   MAW-N 4                               3.0005
   MAW-N 5                               3.4932
   MAW-H 9                               3.2472
   MAW-H 15                              1.7990
   MAW-H 20                              5.1443
   MAW-H 75                              1.6352
   ALUMINUM                     PROPERTIES BELOW REQUIREMENTS
   COPPER                               11.7374
   SILVER                             1262.1148
   MFW-EN 2                              0.8970
   MFW-EN 3                              0.4594
   MFW-EN 4                              0.6380
```

MFW-EN 8	0.4620
MFW-EN 9	0.4630
MFW-EN 14	0.4909
MFW-EN 15	0.3632
MFW-EN 18	0.3591
MFW-EN 22	0.3627
MFW-EN 24	0.2740
MFW-EN 56	0.3641
MFW-EN 100	0.3584
MFW-EN 110	0.3477
MFW-AISI 302	5.0148
MFW-AISI 309	7.2176
MFW-AISI 317	7.2368
MFW-AISI 410	1.9900
MFW-AISI 420	0.3008
MFW-AISI 430	2.5264
MFW-AISI 431	0.5435
NPC-HDPE	PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66	14.5162
NPC-PP	PROPERTIES BELOW REQUIREMENTS
NPC-PVC (R)	PROPERTIES BELOW REQUIREMENTS
NPC-PS (GP)	PROPERTIES BELOW REQUIREMENTS
NPC-PROPATHENE	PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100	5.5003
NPC-KEMETAL AC	7.1395
NPC-RIGIDEX 2000	PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD	PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD	PROPERTIES BELOW REQUIREMENTS
OAK-WOOD	PROPERTIES BELOW REQUIREMENTS
NCC-1.2.4	PROPERTIES BELOW REQUIREMENTS

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        COMPUTERISED  MATERIALS  SELECTION

                   WEIGHTING

FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND

   0          10         5          0          0         0

              BASIS  MATERIAL  =  MFW-EN 1

MIN D S = 50 N/MM SQ  AND  MIN E M = 1000 N/MM SQ


MATERIAL                        COST PER UNIT REQUIREMENT


MFW-EN 1                                  1.0000

MCW-ETP                                  19.5949

MCW-OFHC                                 27.6212

NAVAL BRASS                              12.1739

MAW-LM 2                      PROPERTIES BELOW REQUIREMENTS

MAW-LM 4                                  6.0521

MAW-LM 6                      PROPERTIES BELOW REQUIREMENTS

MAW-EC                        PROPERTIES BELOW REQUIREMENTS

MAW-IC                                   14.1434

MAW-N 3                                   9.3477

MAW-N 4                                   9.1836

MAW-N 5                                   9.1198

MAW-H 9                                  13.8489

MAW-H 15                                 13.5855

MAW-H 20                                 12.8682

MAW-H 75                                 15.1850

ALUMINUM                      PROPERTIES BELOW REQUIREMENTS

COPPER                                   11.9073

SILVER                                 2244.6788

MFW-EN 2                                  0.9485

MFW-EN 3                                  0.8900

MFW-EN 4                                  0.9242

                                          0.9230
```

MFW-EN 8	0.8952
MFW-EN 9	0.8970
MFW-EN 14	0.9235
MFW-EN 15	0.8947
MFW-EN 18	1.1086
MFW-EN 22	1.4095
MFW-EN 24	1.2579
MFW-EN 56	1.1243
MFW-EN 100	1.2475
MFW-EN 110	1.3039
MFW-AISI 302	5.5069
MFW-AISI 309	8.6633
MFW-AISI 317	8.6864
MFW-AISI 410	2.3886
MFW-AISI 420	2.7056
MFW-AISI 430	3.5657
MFW-AISI 431	3.5775
NPC-HDPE	PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66	1820.0313
NPC-PP	PROPERTIES BELOW REQUIREMENTS
NPC-PVC (R)	PROPERTIES BELOW REQUIREMENTS
NPC-PS (GP)	PROPERTIES BELOW REQUIREMENTS
NPC-PROPATHENE	PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100	662.6786
NPC-KEMETAL AC	643.1165
NPC-RIGIDEX 2000	PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD	PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD	PROPERTIES BELOW REQUIREMENTS
OAK-WOOD	PROPERTIES BELOW REQUIREMENTS
NCC-1.2.4	PROPERTIES BELOW REQUIREMENTS

6.7 OUTPUT 7

This output shows that the COMAS program can be very easily modified to accept a particular group of materials with special properties. In this output the program was run to work on a group of polymers listed in an United Nations publication.[41] Twenty-nine thermoplastics were selected for screening and the six properties considered were:

3	Impact Strength	ft.lb./in^2	BS	2782
4	Tensile Strength	MN/m^2	ASTM	D638
5	Tensile Modulus	MN/m^2	ASTM	D638
6	Flexural Strength	MN/m^2	ASTM	D790
7	Compressive Strength	MN/m^2	ASTM	D638
8	Service Temperature	^{o}C	ASTM	D648

As in previous outputs the first two properties cost and density are kept separate.

The first section shows the list screened to select the cheapest plastic with a minimum impact strength of 2.5 ft.lb./in^2. Nearly half the number listed satisfy this constraint but only two, LDPE and Rigidex 2000 are cheaper than the basis material which is High Density Polythene. Accordingly the material selected should be LDPE.

The second section is an extension of the first; there are now two constraints to be satisfied. A minimum impact strength of 2.5 ft.lb./in^2 is required along with a minimum service temperature of 50^{o}C. The number of plastics failing to satisfy this constraint now increases from the previous section, but the cheapest materials are still LDPE and Rigidex 2000 which is a BP high-density polythene.

```
         COMPUTERISED  MATERIALS  SELECTION

                     WEIGHTING

IMP STR   TEN STR   TEN MOD   FLX STR   COM STR   TEMP

   1         0         0         0         0        0

               BASIS  MATERIAL  =  HDPE

MIN IMPACT STRENGTH = 2.5 J


MATERIAL                      COST PER UNIT REQUIREMENT


HDPE                                  1.0000

LDPE                                  0.4648

PS   (GP)                  PROPERTIES BELOW REQUIREMENTS

PS   (HI)                  PROPERTIES BELOW REQUIREMENTS

SAN                        PROPERTIES BELOW REQUIREMENTS

ABS                                   5.5210

C  ACETATE                           51.5980

C  PROPIONATE                        32.6274
```

```
C  NITRATE                      23.6960

ETHYL CELLULOSE                 18.2205

ACRYLIC               PROPERTIES BELOW REQUIREMENTS

ACRYLIC (HI)                    23.2234

PVC (R)                         43.2636

PVDC (R)              PROPERTIES BELOW REQUIREMENTS

NYLON 6                        179.4892

NYLON 66              PROPERTIES BELOW REQUIREMENTS

ACETAL  HP            PROPERTIES BELOW REQUIREMENTS

ACETAL  CP            PROPERTIES BELOW REQUIREMENTS

POLYCARBONATE                    5.4293

POLYIMIDE             PROPERTIES BELOW REQUIREMENTS

PTFCE                          134.5302

PTFE                           118.4700

FEP                             14.0634

POLYPROPYLENE HP      PROPERTIES BELOW REQUIREMENTS

POLYPROPYLENE CP                 4.0200

POLYSULPHONE          PROPERTIES BELOW REQUIREMENTS

PROPATHENE                      16.6346

KEMETAL AC            PROPERTIES BELOW REQUIREMENTS

RIGIDEX 2000                     0.8048
```

```
          COMPUTERISED  MATERIALS  SELECTION

                   WEIGHTING

IMP STR   TEN STR   TEN MOD   FLX STR   COM STR   TEMP

   2         0         0         0         0        1

               BASIS  MATERIAL  =  HDPE

MIN IMPACT STRENGTH = 2.5 J  AND  MIN SERVICE TEMP = 50 C


MATERIAL                    COST PER UNIT REQUIREMENT

HDPE                              1.0000

LDPE                              0.4800

PS  (GP)                 PROPERTIES BELOW REQUIREMENTS

PS  (HI)                 PROPERTIES BELOW REQUIREMENTS

SAN.                     PROPERTIES BELOW REQUIREMENTS

ABS                               4.6178

C  ACETATE                        42.5047

C  PROPIONATE                     27.5715
```

```
C  NITRATE                          20.3475

ETHYL CELLULOSE          PROPERTIES BELOW REQUIREMENTS

ACRYLIC                  PROPERTIES BELOW REQUIREMENTS

ACRYLIC (HI)                        18.9714

PVC (R)                             27.9098

PVDC (R)                 PROPERTIES BELOW REQUIREMENTS

NYLON 6                            125.7039

NYLON 66                 PROPERTIES BELOW REQUIREMENTS

ACETAL  HP               PROPERTIES BELOW REQUIREMENTS

ACETAL  CP               PROPERTIES BELOW REQUIREMENTS

POLYCARBONATE                        4.9183

POLYIMIDE                PROPERTIES BELOW REQUIREMENTS

PTFCE                               65.0004

PTFE                                38.7427

FEP                                 11.1184

POLYPROPYLENE HP         PROPERTIES BELOW REQUIREMENTS

POLYPROPYLENE CP                     3.7885

POLYSULPHONE             PROPERTIES BELOW REQUIREMENTS

PROPATHENE                          14.0569

KEMETAL AC               PROPERTIES BELOW REQUIREMENTS

RIGIDEX 2000                         0.8048
```

6.8 OUTPUT 8

This is the interactive version of the COMAS program and one which provides a hard-copy or paper record of the output for later reference.

Once the job is begun, the titles and headings are printed and an invitation is issued to type in basic data on which the subsequent running of the program depends. This data is numeric in character and includes such information as the number of materials, the number of characteristics, the property loading number which identifies the primary property, the weighting factors and design constraints for each property. The program then takes over and within seconds the entire CUR table is flashed on the VDU screen. At the same time this output is being printed on the line-printer and a copy can be obtained for later use.

As soon as the CUR table comes to an end the user is then given the option of continuing or logging out. If he wishes to continue the program, to the question, 'Do you want to change WF or DC?' he types '1', if he wishes to log out he types '0'. In the former case the program starts again at the beginning giving the user the option to change his weighting factors and/or design constraints and analyse the new output or in the latter case, the statement 'End of Program' is printed and the program gets disconnected and taken off the on-line mode.

The output shows a TINCOMAS program run for a single property requirement. Design strength is kept at 75 N/mm^2

and any material falling short of this value is eliminated. Feeling that this value may be too high and wanting to compare the plastics with the metals, the user lowers the constraint to a design strength of 10 N/mm^2. Within seconds he has scanned through the data bank and has enough information for any further analyses.

In the beginning there is a wait of about 2-5 minutes as the program is made on-line, but thereafter the response time is of the order of 2-5 seconds. To produce an output of the size shown would normally take about 10 minutes on the VDU and about 15-20 minutes on the teletype.

```
DOCUMENT    OUTPUT8




                    COMPUTERISED MATERIAL SELECTION


                          CONTROL PARAMETERS

        NO. OF MATERIALS      NO. OF CHARACTERISTICS      PROPERTY NUMBER

               53                       6                         5

                          WEIGHTING FACTORS
              F         E         D         R         I         C

              0         0         1         0         0         0

                          DESIGN CONSTRAINTS
              F         E         D         R         I         C

            0.00      0.00     75.00      0.00      0.00      0.00

                     BASIS MATERIAL  =  MFW-EN 1


       MATERIAL                   COST PER UNIT REQUIREMENT

       MFW-EN 1                            1.0000
```

MCW-ETP	3.7347
MCW-OFHC	5.5390
NAVAL BRASS	0.8091
MAW-LM 2	PROPERTIES BELOW REQUIREMENTS
MAW-LM 4	1.1219
MAW-LM 6	PROPERTIES BELOW REQUIREMENTS
MAW-EC	PROPERTIES BELOW REQUIREMENTS
MAW-IC	PROPERTIES BELOW REQUIREMENTS
MAW-N 3	PROPERTIES BELOW REQUIREMENTS
MAW-N 4	1.7024
MAW-N 5	2.1179
MAW-H 9	1.6266
MAW-H 15	0.7568
MAW-H 20	3.1776
MAW-H 75	0.6529
ALUMINUM	PROPERTIES BELOW REQUIREMENTS
COPPER	11.6345
SILVER	PROPERTIES BELOW REQUIREMENTS
MFW-EN 2	0.8671
MFW-EN 3	0.3193
MFW-EN 4	0.5150
MFW-EN 5	0.5144
MFW-EN 8	0.3212
MFW-EN 9	0.3218
MFW-EN 14	0.3462
MFW-EN 15	0.2258
MFW-EN 18	0.2030
MFW-EN 22	0.1878

```
MFW-EN 24                              0.1339
MFW-EN 56                              0.2059
MFW-EN 100                             0.1934
MFW-EN 110                             0.1824
MFW-AISI 302                           4.7387
MFW-AISI 309                           6.4733
MFW-AISI 317                           6.4905
MFW-AISI 410                           1.7847
MFW-AISI 420                           0.1210
MFW-AISI 430                           2.0684
MFW-AISI 431                           0.2375
NPC-HDPE                    PROPERTIES BELOW REQUIREMENTS
NPC-NYLON 66                PROPERTIES BELOW REQUIREMENTS
NPC-PP                      PROPERTIES BELOW REQUIREMENTS
NPC-PVC  (R)                PROPERTIES BELOW REQUIREMENTS
NPC-PS  (GP)                PROPERTIES BELOW REQUIREMENTS
NPC-PROPATHENE              PROPERTIES BELOW REQUIREMENTS
NPC-MARANYL A100                       1.5851
NPC-KEMETAL  AC             PROPERTIES BELOW REQUIREMENTS
NPC-RIGIDEX 2000            PROPERTIES BELOW REQUIREMENTS
BEECH-WOOD                  PROPERTIES BELOW REQUIREMENTS
TEAK-WOOD                   PROPERTIES BELOW REQUIREMENTS
OAK-WOOD                    PROPERTIES BELOW REQUIREMENTS
NCC-1.2.4                   PROPERTIES BELOW REQUIREMENTS


DO YOU WANT TO CHANGE WF OR DC ?
  1
```

```
                    COMPUTERISED MATERIAL SELECTION


                          CONTROL PARAMETERS

      NO. OF MATERIALS       NO. OF CHARACTERISTICS       PROPERTY NUMBER


            53                           6                         5

                          WEIGHTING FACTORS
          F            E          D          R          I          C

           0            0          1          0          0          0

                          DESIGN CONSTRAINTS
          F            E          D          R          I          C

        0.00         0.00      10.00       0.00       0.00       0.00

                    BASIS MATERIAL  =  MFW-EN 1


    MATERIAL                   COST PER UNIT REQUIREMENT


    MFW-EN 1                          1.0000
```

MCW-ETP	3.7347
MCW-OFHC	5.5390
NAVAL BRASS	0.8091
MAW-LM 2	7.4001
MAW-LM 4	1.1219
MAW-LM 6	13.1131
MAW-EC	11.8145
MAW-IC	7.5526
MAW-N 3	3.6625
MAW-N 4	1.7024
MAW-N 5	2.1179
MAW-H 9	1.6266
MAW-H 15	0.7568
MAW-H 20	3.1776
MAW-H 75	0.6529
ALUMINUM	7.4482
COPPER	11.6345
SILVER	915.2878
MFW-EN 2	0.8671
MFW-EN 3	0.3193
MFW-EN 4	0.5150
MFW-EN 5	0.5144
MFW-EN 8	0.3212
MFW-EN 9	0.3218
MFW-EN 14	0.3462
MFW-EN 15	0.2258
MFW-EN 18	0.2030
MFW-EN 22	0.1878

```
MFW-EN 24                          0.1339

MFW-EN 56                          0.2059

MFW-EN 100                         0.1934

MFW-EN 110                         0.1824

MFW-AISI 302                       4.7387

MFW-AISI 309                       6.4733

MFW-AISI 317                       6.4905

MFW-AISI 410                       1.7847

MFW-AISI 420                       0.1210

MFW-AISI 430                       2.0684

MFW-AISI 431                       0.2375

NPC-HDPE                          13.1502

NPC-NYLON 66                       4.1750

NPC-PP                            10.4114

NPC-PVC  (R)                       1.9136

NPC-PS  (GP)                       2.0180

NPC-PROPATHENE                     2.6604

NPC-MARANYL A100                   1.5851

NPC-KEMETAL  AC                    2.0912

NPC-RIGIDEX 2000                   3.6230

BEECH-WOOD                        22.1228

TEAK-WOOD                         49.6289

OAK-WOOD                          43.5597

NCC-1.2.4                          3.3830


DO YOU WANT TO CHANGE WF OR DC ?

  0


                        END OF PROGRAM
```

6.9 OUTPUT 9

This is the interactive version of the COMAS program and is similar to Output 8 except that instead of the design constraints, the weighting factors are changed.

The operation and execution of the program was described in Output 8.

The materials are screened on the basis of three requirements. The first and primary requirement is a minimum design strength of 25 N/mm^2. The second is a minimum fatigue strength of 5 N/mm^2 and the third is a minimum impact strength of 2.5 Joules. The weightings are 10, 5 and 2 respectively. Most plastics get eliminated and the cheapest materials are the alloy steels, EN24 and AISI420.

When fatigue strength is made equally important with design strength, EN110 a low Ni-Cr-Mo steel also comes into the reckoning. The steels as usual are far superior on a cost basis to any other material in the list. This is true when strength in the dominant property. The situation will change when another property is made the design criterion.

```
DOCUMENT    OUTPUT9



                    COMPUTERISED MATERIAL SELECTION


                          CONTROL PARAMETERS

  NO. OF MATERIALS      NO. OF CHARACTERISTICS      PROPERTY NUMBER

        53                        6                        5

                          WEIGHTING FACTORS
     F         E         D         R         I         C

     5         0        10         0         2         0

                          DESIGN CONSTRAINTS
     F         E         D         R         I         C

   5.00      0.00     25.00      0.00      2.50      0.00

                    BASIS MATERIAL  =  MFW-EN 1


MATERIAL                   COST PER UNIT REQUIREMENT

MFW-EN 1                         1.0000
```

MCW-ETP	5.2577
MCW-OFHC	7.1197
NAVAL BRASS	1.0706
MAW-LM 2	PROPERTIES BELOW REQUIREMENTS
MAW-LM 4	PROPERTIES BELOW REQUIREMENTS
MAW-LM 6	13.5751
MAW-EC	12.6190
MAW-IC	8.8604
MAW-N 3	4.4716
MAW-N 4	2.0674
MAW-N 5	2.4340
MAW-H 9	2.3248
MAW-H 15	1.2463
MAW-H 20	4.2128
MAW-H 75	1.0619
ALUMINUM	7.1287
COPPER	11.9412
SILVER	1676.1370
MFW-EN 2	0.8302
MFW-EN 3	0.3665
MFW-EN 4	0.5475
MFW-EN 5	0.5615
MFW-EN 8	0.3367
MFW-EN 9	0.3988
MFW-EN 14	0.3443
MFW-EN 15	0.2846
MFW-EN 18	0.2425
MFW-EN 22	0.2347

```
MFW-EN 24                            0.1715

MFW-EN 56                            0.2381

MFW-EN 100                           0.2323

MFW-EN 110                           0.1917

MFW-AISI 302                         3.5652

MFW-AISI 309                         4.5867

MFW-AISI 317                         5.0366

MFW-AISI 410                         1.8484

MFW-AISI 420                         0.1758

MFW-AISI 430                         2.2002

MFW-AISI 431                         0.3427

NPC-HDPE                  PROPERTIES BELOW REQUIREMENTS

NPC-NYLON 66                         7.4232

NPC-PP                    PROPERTIES BELOW REQUIREMENTS

NPC-PVC  (R)              PROPERTIES BELOW REQUIREMENTS

NPC-PS  (GP)              PROPERTIES BELOW REQUIREMENTS

NPC-PROPATHENE            PROPERTIES BELOW REQUIREMENTS

NPC-MARANYL A100                     2.9377

NPC-KEMETAL  AC           PROPERTIES BELOW REQUIREMENTS

NPC-RIGIDEX 2000          PROPERTIES BELOW REQUIREMENTS

BEECH-WOOD                PROPERTIES BELOW REQUIREMENTS

TEAK-WOOD                 PROPERTIES BELOW REQUIREMENTS

OAK-WOOD                  PROPERTIES BELOW REQUIREMENTS

NCC-1.2.4                 PROPERTIES BELOW REQUIREMENTS



DO YOU WANT TO CHANGE WF OR DC ?

   1
```

```
                      COMPUTERISED MATERIAL SELECTION


                             CONTROL PARAMETERS

     NO. OF MATERIALS        NO. OF CHARACTERISTICS      PROPERTY NUMBER


            53                         6                         5

                              WEIGHTING FACTORS
         F          E          D          R          I          C

         10         0          10         0          2          0

                              DESIGN CONSTRAINTS
         F          E          D          R          I          C

        5.00       0.00      25.00       0.00       2.50       0.00

                        BASIS MATERIAL  =  MFW-EN 1


    MATERIAL                      COST PER UNIT REQUIREMENT

    MFW-EN 1                              1.0000
```

	0.2421
	0.2232
MCW-ETP	5.9368
MCW-OFHC	7.8858
NAVAL BRASS	1.1599
MAW-LM 2	PROPERTIES BELOW REQUIREMENTS
MAW-LM 4	PROPERTIES BELOW REQUIREMENTS
MAW-LM 6	12.6933
MAW-EC	13.7240
MAW-IC	9.8087
MAW-N 3	4.8405
MAW-N 4	2.1130
MAW-N 5	2.4482
MAW-H 9	2.5388
MAW-H 15	1.3728
MAW-H 20	4.6916
MAW-H 75	1.1566
ALUMINUM	7.5437
COPPER	13.3210
SILVER	2049.6869
MFW-EN 2	0.8099
MFW-EN 3	0.3848
MFW-EN 4	0.5783
MFW-EN 5	0.5658
MFW-EN 8	0.3470
MFW-EN 9	0.3899
MFW-EN 14	0.3572
MFW-EN 15	0.2843
MFW-EN 18	0.2404
MFW-EN 22	0.2388

```
MFW-EN 24                         0.1724

MFW-EN 56                         0.2421

MFW-EN 100                        0.2232

MFW-EN 110                        0.1739

MFW-AISI 302                      3.6756

MFW-AISI 309                      4.3934

MFW-AISI 317                      5.1753

MFW-AISI 410                      1.7097

MFW-AISI 420                      0.1778

MFW-AISI 430                      2.0142

MFW-AISI 431                      0.3467

NPC-HDPE                  PROPERTIES BELOW REQUIREMENTS

NPC-NYLON 66                      8.7389

NPC-PP                    PROPERTIES BELOW REQUIREMENTS

NPC-PVC  (R)              PROPERTIES BELOW REQUIREMENTS

NPC-PS  (GP)              PROPERTIES BELOW REQUIREMENTS

NPC-PROPATHENE            PROPERTIES BELOW REQUIREMENTS

NPC-MARANYL A100                  3.5438

NPC-KEMETAL  AC           PROPERTIES BELOW REQUIREMENTS

NPC-RIGIDEX 2000          PROPERTIES BELOW REQUIREMENTS

BEECH-WOOD                PROPERTIES BELOW REQUIREMENTS

TEAK-WOOD                 PROPERTIES BELOW REQUIREMENTS

OAK-WOOD                  PROPERTIES BELOW REQUIREMENTS

NCC-1.2.4                 PROPERTIES BELOW REQUIREMENTS



DO YOU WANT TO CHANGE WF OR DC ?

  0


                          END OF PROGRAM
```

CHAPTER 7

THE ENERGY COST OF MATERIALS

7.1 INTRODUCTION

A modern industrial society is built upon the tripod of materials, energy and information. All aspects of our culture involve a combination of these three basic ingredients. This chapter concentrates on the energy required to produce materials and there are a number of reasons why this is important.

Firstly, the materials production industries in the UK, comprise of the largest fuel consuming sector of the economy apart from the fuel industries themselves.

TABLE 7.1 (UK 1972)

SECTOR	Net Energy Used		Energy Overheads 10^9 kWh	Gross Energy Required	
	10^9 kWh	% of total primary energy		10^9 kWh	% of total
Industry	714.5	29	285.5	1000.0	41
Household	428.0	17	281.0	709.0	29
Transport	356.0	15	36.0	392.0	16
Other Users	214.0	9	140.0	354.0	14
Energy Industries	742.5	30	included under supply	included above	included above
Total primary energy	2455.0	100		2455.0	100

7.1.1 THE COST OF ENERGY

In the year 1970, approximately 25% of our total energy consumed was in the form of electric power, whereas by the year 2000, approximately 40% of the total will be electricity. This is an increase of approximately five times, which means that in the coming twenty-five years, five times the amount of generating capacity, transmission capacity and distribution capacity must be provided.[89]

Table 7.2 gives a comparison of some of the common and not so common electrical conductors in use today. This table compares the two most important characteristics, electrical resistivity and price, both of which one would like to be low. The cost effectiveness of a material as a conductor

TABLE 7.2

	Resistivity μΩ - cm	Conductance siemens	Density kg/m^3	Cost £/ tonne	Cost/ Conductance £/S/m^3	Relative Cost Equivalent Conductance
Cu	1.70	5.88*10^5	8.93	630	957*10^{-8}	1.00
Al	2.65	3.77	2.82	425	318	0.33
Ni	6.84	1.46	8.90	2000	12200	12.75
Ag	1.59	6.29	10.50	50000	83466	87.00
Na	4.20	2.38	0.97	215	88	0.09
Zn	6.20	1.61	7.20	250	2900	3.03

can be obtained by calculating the electrical conductance from the electrical resistivity. The cost per conductance is then obtained by dividing the cost density by the conductance. It is necessary to take account of density since electrical resistivity is a volume-based property and materials are usually sold by weight. Then by dividing all the figures by the one obtained for copper, a relative cost for equivalent conductance is obtained. It is immediately evident that nickel and silver are so cost ineffective, that except for very special applications they are eliminated from consideration. Sodium appears to have an inherent advantage over all of the other metals considered.

The properties of sodium give it a 10 to 1 cost effectiveness over copper. But, its melting point is low and it is highly reactive. The technique used to employ sodium as an electrical conductor is to manufacture polythene insulated sodium wire. Polythene insulation and sodium conductor are coextruded, then drawn to size together. This technique is not yet completely free from trouble and an important aspect that remains to be solved is that of making the connections.

Another cost factor which is usually over-looked is the energy overhead. The overheads comprise the energy used by the energy industries in converting the primary fuels to the forms required for delivery to the consumer together with some distribution losses and the energy costs for materials and construction (as opposed to fuels) that are required by the energy industries. Some preliminary estimates based on the 1968 Census of Production are given in Table 7.3 which shows the effects of all direct and indirect energy costs and system efficiencies for the energy industries.[80]

These overheads arise mainly from the up-grading of energy by the energy industries to forms that are essential or more convenient for their customer's requirements. In the case of petroleum the overheads are mainly from the up-grading done in refineries. The main part of the coal overheads arise from distribution losses. Energy overheads for the electrical industry include conversion losses, distribution losses and electricity used by the industry.

It should be emphasised that energy overheads are an essential part of the production of higher grade forms of

TABLE 7.3 (UK 1968)

	Gross Energy Input 10^9 kWh	Net Energy Output 10^9 kWh	Input/ Output Ratio	System's Energy Conversion Efficiency %
Coal	1210.4	1161.8	1.042	96.0
Coke	263.5	223.2	1.181	84.7
Gas	261.3	188.0	1.390	71.9
Petroleum	1290.2	1138.4	1.133	88.2
Electricity	766.7	182.6	4.198	23.8

energy. The annual rate of growth of primary energy in the UK has been 1.8% p.a. since 1960, but the delivered supply has grown at 1.2% p.a., thus indicating a faster rate of growth for energy overheads and showing that delivered energy is in a higher grade form now than in 1960.

As will be shown later materials production accounts for almost 30% of the delivered energy consumption in the UK and worldwide accounts for over 20% of world fuel consumption. These statistics indicate that savings in fuel consumption in these industries would have a substantial impact on total fuel demand.

Secondly, the materials industries are, together with the fuel industries, the most energy intensive industries. The energy intensity of an industry is determined by its ratio of direct fuel consumption to value added. In the UK the materials industries contribute 7% to the GNP but consume 30% of all fuels. This means that these industries are vulnerable to fuel price rises.

Thirdly, although the materials industries are energy intensive the fuel purchase only represent 20-30% of the total cost of producing materials. This means that the relative energy costs of materials may not be reflected in their relative financial costs. Consequently engineers and designers may unnecessarily increase total fuel consumption by choosing a material of higher energy cost, but lower or similar financial cost,than necessary. If energy conservation is to become part of good design than the energy cost of materials are necessary data.

7.2 ASSESSMENT OF ENERGY COSTS

One of the objectives of energy conservation is to find out whether energy can be saved by doing things differently. This requires an assessment of the energy costs associated with each option where the term 'energy costs' refers to the amount of energy used in a particular process, or in the manufacture of a certain product, or for some other specified purpose. Thus by energy audits one can seek to establish the energy costs for the manufacture of one tonne of aluminium ingot, or the energy costs for making an automobile, or the comparative energy costs of aluminium cans and plastic containers.

A knowledge of energy costs for a wide range of products and a wide variety of processes would be useful for the following purposes:

1. To assist in comparing efficiencies in the use of energy and indicate options for saving energy.

2. To help in assessing the economic impact on a process or product of a change in energy supply or energy prices, thus allowing better economic optimisation for the use of energy.

3. To help in forecasting changes in energy demand that would be consequent on changes in the pattern of production or of consumer demand.

4. To help in increasing the separation, collection and recycling of scrap and solid wastes.

Methods for assessing energy costs include:

1. Statistical Analysis - This can be used to give an idea of energy costs only in particular circumstances, for example in an industry where the product is reasonably homogenous and where the main energy-consuming production processes are covered by the aggregated statistical data. An example is given by the cement industry in the UK, which used in 1973 a net energy total of 134 million GJ to produce 20 million tonnes of cement, and one can deduce an approximate figure of 6.7 GJ/tonne (1.9 kWh/kg) as the energy cost for cement.

2. Input-Output Analysis - This is a standard technique in economics and it can provide a useful approximation for certain energy costs, and can readily be used to obtain either direct or indirect energy costs. Its limitations include: the high level of aggregation used in input-output

tables; the tables refer to financial costs of energy which cannot always be readily converted to physical quantities of energy since the energy prices are not always accurately known; also the efficiency of generation and usage differs between different energy forms; as well as yields of metals/materials in processing.

3. Process Analysis - This involves a series of approximations that successively enlarge the system that is associated with the manufacture of a given product. The chain of direct and indirect processes relating to the product needs to be specified and the energy costs identified and apportioned. The disadvantages of process analysis arise from the amount of detail required, which may involve wide variations between alternative methods of production and may not be available in the form required. Also many individual process steps are very difficult to assess for energy usage and yield factors.

Before going on to the actual energy costs of materials it is worth noting a few points:

1. Most of the energy cost figures were obtained by the Process Analysis method.
2. That energy costs differ from country to country depending on the yield and quality of the raw material input. Aggregated energy requirements may be very nearly equal and yet be the sums of quite different sets of disaggregated contributions.

For example, the energy requirements to convert bauxite ore to alumina vary markedly, with the US value by far the lowest. In contrast, the figures for electrolysis differ in the opposite direction.

Table 7.4 gives the average energy costs for the major materials in the UK.[80,81,82]

TABLE 7.4

ENERGY COST OF MATERIALS

	kWh/tonne
METALS	
Pig Iron	4000 - 6000
Crude Steel	8000 - 10000
Finished Steel	10000 - 16000
Aluminium	79000
Recycled Aluminium	3000 - 11000
Copper	16000
Recycled Copper	3000
Zinc	15000 - 20000
Lead	7000 - 14000
Magnesium	95000 - 115000
Titanium	155000
Tin	85000
PLASTICS	
Polypropylene	20000
Polythene L.D.	15000
Nylon 66	50000
PVC (R)	20000
Polyester Fibre	60000
BUILDING MATERIALS	
Glass	5000 - 15000
Timber	500
Concrete	2500
Bricks	500
Paper	7000

The total energy which is required to make tonnage metals and non-metals into forms utilisable by mankind differs very greatly and also differs through the varying process steps of working into a finished product.

The energy utilised at each of these stages is typically shown in Table 7.5.

TABLE 7.5

	kWh$_t$/tonne
STEEL	
Mining	500
Coke Ovens	850
Ore and Sinter Preparation	600
Blast Furnace	3800
Steelmaking (C steel)	1000
Fabrication (wire)	3000
Miscellaneous	1600
	11350
STEELMAKING - C Steel	1000
Alloy Steel	1700
Stainless Steel	4000
FABRICATION - Wire	3000
Forging	6000
ALUMINIUM	
Mining	1200
Bayer Process	13000
Anode Preparation	5500
Reduction	22000
Refining	22000
Fabrication	15000
	78700
COPPER	
Mining, Concentration and Extraction	7000

TABLE 7.5 Continued

	kWh_t/tonne
Refining	7000
Fabrication	2000
	16000
CEMENT	
Mining	200
Burden Preparation	400
Mix 'burnt' in kiln	1600
Fine Powder from Clinker and Gypsum	200
	2400
CONCRETE	
Cement, Sand Aggragated	2400
Mixing	100
	2500
TIMBER	
Felling, Logging, Shaping	500
POLYTHENE	
Crude Oil → Naptha	1500
Naptha → Ethylene	5700
Ethylene → Polythene	5100
Polythene → Film	3700
	16000
+ energy in feedstock	14000
	30000
POLYPROPYLENE	
Crude Oil → Propylene	9300
Propylene → Polypropylene	7800
Polypropylene → Crates	4800 (1300 films)
	21900
+ energy in feedstock	16000
	37900
PVC	
Crude Oil → Naptha	1500
Naptha → Ethylene	2700
Ethylene → PVC	14000
	18200
+ energy in feedstock	14000
	32200

Throughout the energy cost analysis, the energy consumed as electricity is treated separately. The reason for this is that one unit of electrical energy accounts for several units of fossil fuel energy consumption. The average efficiency of producing electricity in the UK is 23.85% which means that one kWh electrical (denoted kWh_e) is equivalent to 4.19 kWh thermal (denoted kWh_t). All energy cost figures shown in this work are in kWh thermal.

STEEL

There are several factors which make it difficult to arrive at an energy cost for steel. Firstly, different workers quote values for crude steel while others give values for finished steel. Furthermore the quantity of crude steel required to produce one tonne of finished steel varies between 1.2 and 1.5 tonnes of crude steel. Secondly the iron and steel sector sells energy, in the form of electricity and gas, to other sectors. Thirdly the output of the steel industry is not homogenous. A semi-finished slab of steel may have an energy cost as low as 8000 kWh/tonne whereas a thin sheet of specially treated alloy steel may have an energy cost as high as 50,000 kWh/tonne.

A number of American studies of the energy cost of steel give the following results:

15613 kWh/tonne[82], 14112 kWh/tonne[83], 16654 kWh/tonne[84].

Some of the improvements in the use of energy in the iron and steel industry include:

1. Increasing the use of high grade imported iron ore

with a 60% metallic content instead of UK ore with 28% metallic content. Laws[85] estimates a difference in energy requirements of about 3000 kWh per ingot tonne between a Basic Oxygen plant using all UK low grade ore and one using all imported ore.

2. Improvements in blast furnace operations through prereduction of iron ores and improved sinter and pellet preparation.

3. Replacing conventional methods using ingots, soaking pits and primary hot rolling mill by continuous casting operations.

4. Improvements in instrumentation and control method.

5. In the future nuclear power may lead to major changes in the pattern of steelmaking by providing direct heat via heat exchangers from advanced gas-cooled nuclear reactors.

ALUMINIUM

Most of the world's aluminium is produced from deposits containing 50% aluminium and alumina with open-pit bauxite mining. The crushed bauxite is converted to alumina in the Bayer process; the alumina is then reduced to aluminium in the Hall-Heroult electrolysis cell.

Some of the estimates for the energy costs of producing aluminium are listed below.

Makhijani and Lichtenberg[83] have used statistics published in the United States and arrive at a figure of 75250 kWh/tonne of rolled aluminium. Bravard et. al.,[82] using a process analysis approach obtained a value of 71950 kWh/tonne and Chapman[86] deduced a value of 72645 kWh/tonne. All these values are based on a conversion efficiency of electricity of 33% so that 1 kWh_e is equivalent to 3 kWh thermal. Using a conversion efficiency of 23.85% for the UK, Chapman reports an energy cost of 91133 kWh/tonne for aluminium.

Home scrap which is produced within a plant amounts to about 40% of the input. It is recycled so that essentially only the energy consumed for rolling or extrusion is involved. This figure ranges from 3000 kWh/tonne[87] to 11000 kWh/tonne[80].

No radical departure from the Hall-Heroult process has yet been achieved on an industrial scale but four new processes are being developed to the pilot plant stage and are compared in Table 7.6.[88]

TABLE 7.6 (Scale: 100000 tonnes per year)

	BAYER HALL	ALCOA	ALCAN	MONO CHLORIDE	TOTH
Fixed Capital Investment ($ per tonne of Al)	1700	- 5%	- 45%	-40%	- 40%
Direct Operating Costs ($ per tonne of Al)	350	+10%	0	-15%	+ 50%
Electrical Energy (kWh_e per tonne of Al)	14000	-20%	+ 80%	+ 5%	- 85%
Carbon Requirement (kg per tonne of Al)	450	-20%	+120%	+70%	+1000%

The above table compares study estimates of the probable capital and operating costs, energy and carbon requirements of the Alcoa, Alcan, Monochloride and Toth processes with the best available Bayer-Hall technology.

Assuming that the processes are feasible, the Alcoa Smelting Process seems to be the only one heading for full-scale development. It offers large energy savings and significant reductions in capital and operating costs if $AlCl_3$ can be produced directly from bauxite or clay.

COPPER

Open-pit mines account for more than half of the total world copper production and in the United States 83% of copper is obtained from open-pit mines. Most of the deposits worked in these large mines are sulphide ores of copper, and the energy costs are evaluated for open-pit mining of sulphide ores.

The energy cost of copper is highly dependent on the ore grade. Chapman[86] has derived an equation relating the energy cost to the ore grade.

$$E = \frac{11.8}{(G - 0.15)} + 7.5$$

E = energy cost, kWh/kg

G = ore grade, %Cu

$0.2 \leqslant G \leqslant 2.0$

For a 1% copper ore this is 22230 kWh/tonne and for a 0.5% ore gives 43140 kWh/tonne. At 23.85% efficiency for electrical generation Bravard et. al.[82] quote 15309 kWh/tonne and Makhijani and Lichtenberg[83] quote 23520 kWh/tonne. Using the U.S.A. conversion efficiency of 33%. Chapman's energy cost becomes 18789 kWh/tonne.

Copper recycling is of the order of 20% to 40% in the Western world. Chapman[87] has shown the overall energy cost of recycled copper, including refining, to be about 3000 kWh/tonne.

This average energy cost relates to the present level of recycling. If, in the future, the recovery of potential used scrap were increased, then the average energy cost would be expected to rise since presumably the scrap at present not recovered is inferior in quality or more difficult to collect.

There are several possibilities for reducing the overall energy costs of copper. New smelter designs may lower energy consumption and new leaching techniques may remove the necessity for any pyrometallurgical treatment. The theoretical energy required to extract copper from a sulphide ore is about -400 kWh/tonne,[82] indicating that it should be possible to get copper plus energy from the ore. In practice this is not realised because large amounts of energy have to be expended in liberating the mineral particles from the ore.

In the future the average energy cost of copper will rise due to the decreasing average grade of ore.

Down to an ore grade of about ·25%, copper is cheaper in energy cost than aluminium. An improvement in the energy efficiency of aluminium production seems possible, but a similar improvement for copper is not likely. On the basis of energy costs, it is unlikely to be worthwhile exploiting copper in sea-water since the production of 1 tonne of copper requires the processing of 10^8 tonnes of sea-water with an estimated energy cost of 560000 kWh.[86] This illustrates that, energy cost is a sensible factor for limiting the sources of a material to be counted in a resource base.

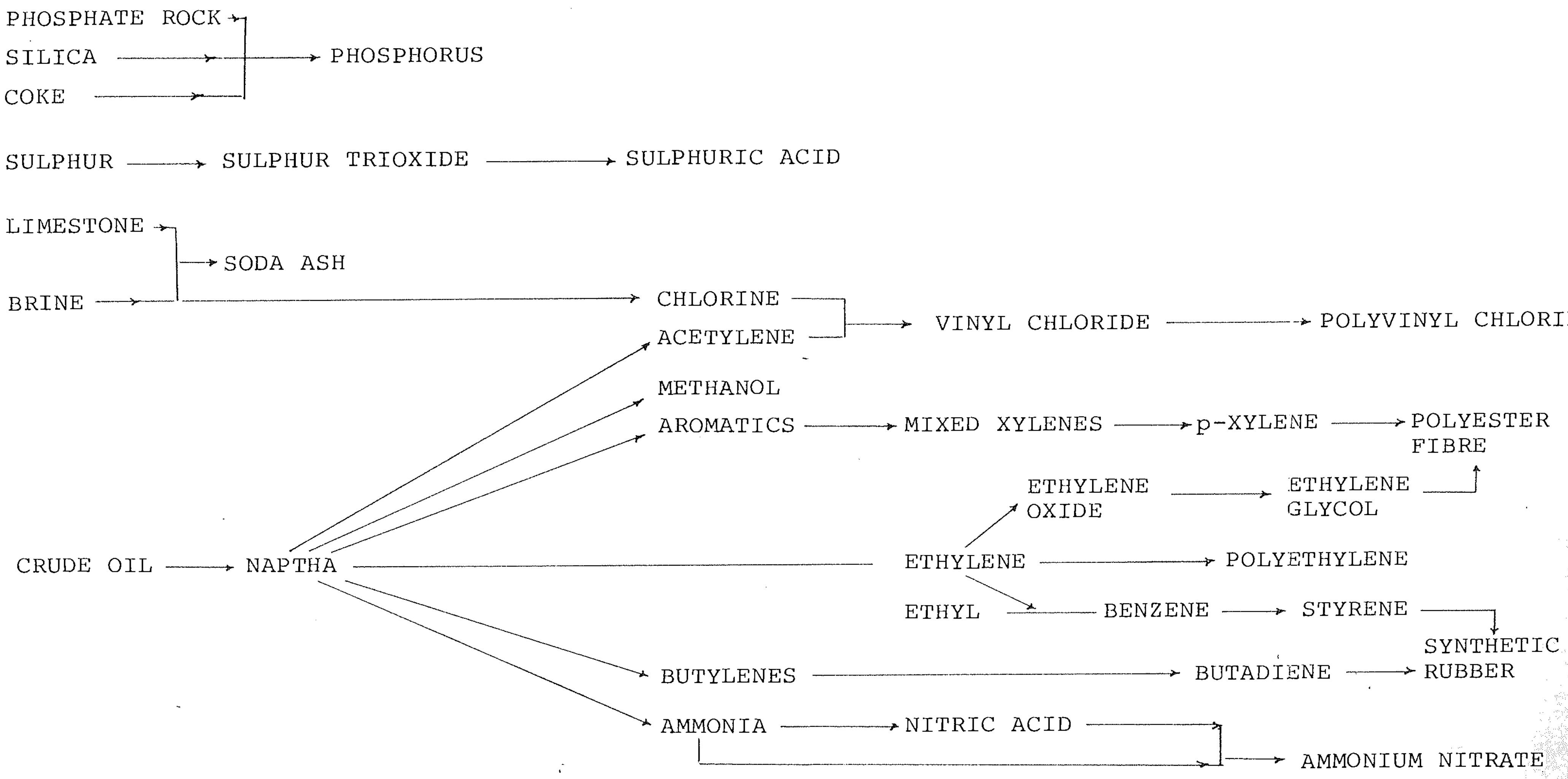
CHEMICALS

The energy cost of a chemical product is the energy required for its manufacture. This depends not only on the energy directly used by the chemical industry but also depends on the indirect energy required to provide the fuel used, the raw materials and the chemical plant and equipment. These direct and indirect energy costs have been calculated by Smith[89] for a variety of chemical products shown in Fig. 7.1.

The energy cost figures shown in Table 7.4 do not include the thermal content (heat of combustion) of the petrochemical feedstock required. This feedstock is mainly petroleum fuel at 0.1 kWh/kg or natural gas at 0.3 kWh/kg. According to the NEDO report[80] and Smith[89] the energy cost of the feedstock can be as high as twice

FIG. 7.1

ROUTES TO FINAL PRODUCTS



the energy required for its conversion to plastics. The energy required for the production of plastics accounted for 20% of the energy used by the chemicals industry in 1971. The production of plastics in the world has been increasing at about 10% per annum during the period 1970-75 and this rate of growth is expected to continue, especially in view of the relatively low use of plastics in the developing countries and in the UK compared with other industrialised countries. The future demand for energy, is therefore, likely to be dominated by an increase in plastics production, especially in the near future.

7.3 ENERGY COST, PRODUCTION, PRICE AND PROPERTIES OF MATERIALS

Energy costs by themselves do not mean much unless they are analysed in relation to materials production, market prices and engineering properties.

PRODUCTION

Using energy costs appropriate for primary production the total energy costs for these materials is $10800 * 10^9$ kWh, 21% of total world fuel consumption. The data in Table 7.7 does not include fuel consumed in the production of metals from scrap and chemicals since world production figures from these items are not available. Were these items included then the proportion of world fuel consumption for materials production might rise to around 25%.

TABLE 7.7

	1970 WORLD PRODUCTION 10^6 tonnes	ENERGY COST kWh/tonne	TOTAL ENERGY COST 10^9 kWh
Crude Steel	593.0	10000	5930
Concrete	567.0	2300	1304
Wood	200.0	500	100
Paper	125.0	7000	87
Plastics	30.0	45000	1350
Aluminium	9.6	79000	760
Copper	7.6	16000	122
Synthetic Rubber	5.0	41000	205
Zinc	4.8	20000	96
Lead	3.2	14000	45
TOTAL			$10800 * 10^9$

PRICE

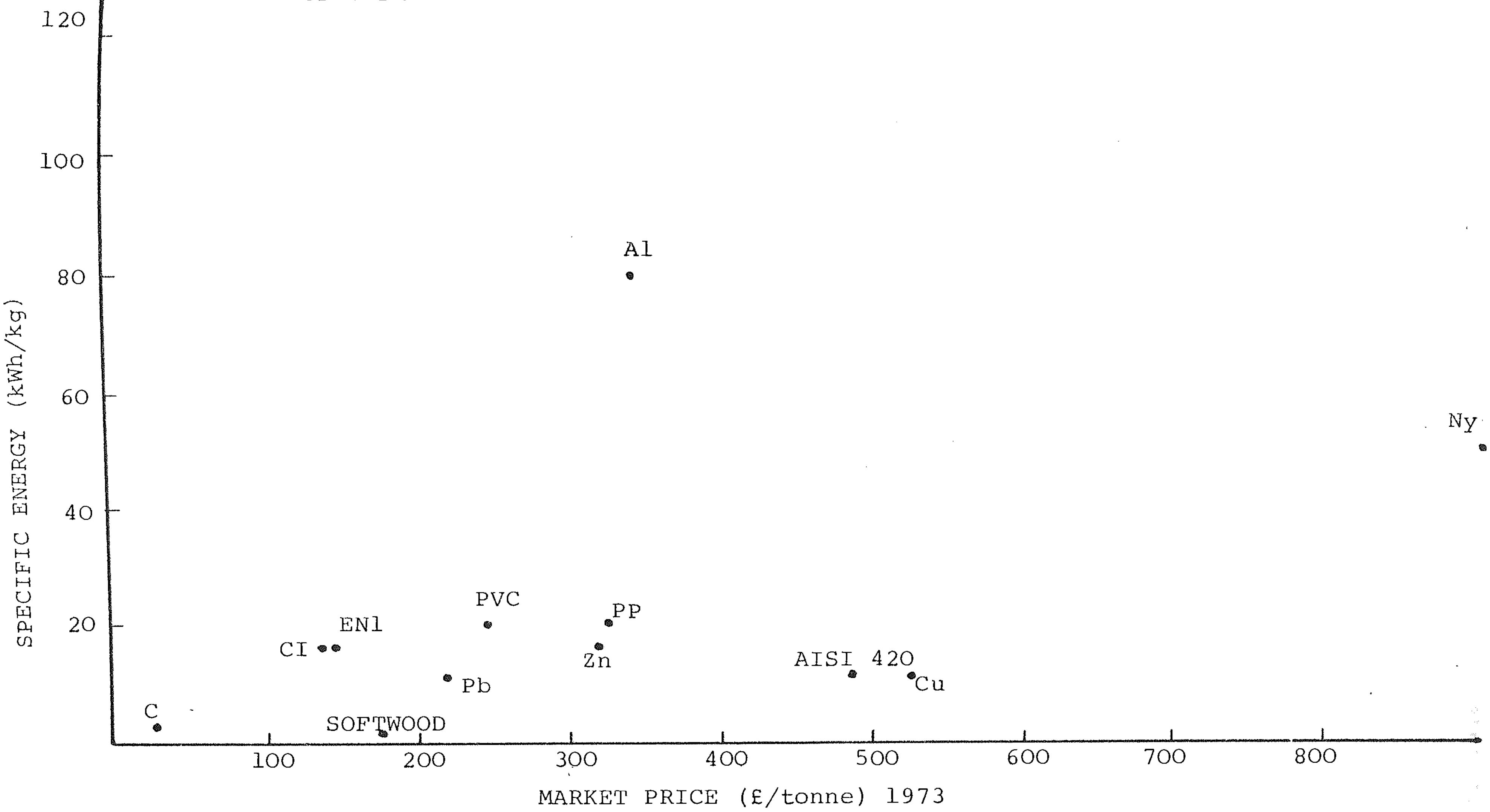
Market price reflects demand for a certain material. It also reflects the cost of the resources input towards the manufacture of the material. The major resources comprise capital equipment, raw materials, labour and energy. Analysing a broad spectrum of industries it is observed that the average breakdown of production costs is as follows:

Raw Materials	20 - 70 %
Energy and Power	10 - 35%
Labour	10 - 35%
Depreciation Maintenance Transport Overheads	10 - 20%

Fig. 7.2 is a graph of the specific energy plotted

FIG. 7.2

SPECIFIC ENERGY vs MARKET PRICE OF METALS AND MATERIALS



against the market price in 1973 for some common materials. It can be observed that for the majority of the materials, the specific energy falls within a narrow band of 15-25 kWh/kg, regardless of the type of material or its market price. For example, low carbon steel EN1 costs £140/tonne, low density polythene about £325/tonne and copper around £500/tonne but they all have a similar specific energy figure of 15 kWh/kg. Therefore it seems that there is no direct correlation between market price and specific energy and only in a few cases like aluminium, magnesium and titanium does specific energy affect price.

PROPERTIES

Though the total energy consumed per tonne of finished product can be evaluated, such information does not convey the inherent value of the product or material to the prospective user. The criterion of evaluating the range of engineering properties which the material possesses is of equal relevance.

The criterion of the cost per unit requirement was explained in the preceeding chapters and this approach can be readily associated with the energy cost concept as shown by Alexander and Appoo.[90] An outline of the information obtained by this approach is shown in Table 7.8. These figures are tentative, but an attempt has been made to unify them in the sense that if a fossil fuel has been used directly (such as coke in a blast furnace), that fuel has been converted directly into kWh of energy. If, however, a fossil fuel has

TABLE 7.8
ENERGY CONSUMPTION RELATED TO MATERIAL PROPERTIES

Material	Tensile Strength MN/m^2	Modulus of Rigidity MN/m^2	Fatigue Strength MN/m^2	Density kg/m^3	Specific Energy kWh/kg	Total Energy (KWh) per unit of		
						Tensile Strength	Modulus of Rigidity	Fatigue Strength
Cast Iron	400	35000	105	7300	16.0	293	3.34	1112
STEELS								
EN-1	250	77000	193	7850	16.0	502	1.63	651
EN-8M	600	77000	300	7830	16.0	209	1.63	418
EN-24	800	77000	495	7830	16.0	157	1.63	253
EN-56	1000	77000	280	7730	16.0	124	1.63	442
EN-58	700	77000	350	7900	16.0	181	1.63	361
AISI-309	600	86000	360	7900	16.0	210	1.47	351
AISI-420	600	86000	680	7900	16.0	210	1.47	186
Copper-Zinc Alloys	400	37300	140	8360	16.5-	345	3.70	985
Aluminium Alloys	300	26000	90	2700	79.0	710	8.2	2370
Magnesium Alloys	190	17500	95	1700	115.0	1029	11.17	2058
Titanium Alloys	960	45000	310	4510	155.0	730	15.53	2255
Polypropylene	30	-	7.5	900	20.0	600	-	2400
Propathene	35	-	7.5	900	20.0	515	-	2400
Polythene L.D.	13	-	3.25	920	15.0	1062	-	4246
Rigidex 2000	30	-	4.0	950	15.0	475	-	3560
Nylon 66	80	-	20.0	1360	50.0	850	-	3400
PVC (R)	50	-	12.5	1400	20.0	560	-	2240
R. Concrete	38	10000	23	2400	2.3	145	0.55	240
Softwood	5	2000	3	500	0.5	50	0.125	83

been used to generate electricity which has then been used at some intermediate stage in the processing of the material, then the value has been multiplied by a conversion factor of 3 to 4 to allow for the inefficiency of electrical generation direct from thermal power.

As would be anticipated, total energy criteria throw a different light on the values of some materials. For exmaple, timber needs far less energy for a given strength than any other material. Reinforced concrete is very attractive at 145, followed by the ferrous group at 125-300, these are followed by the plastics and the non-ferrous group of metals, all with values ranging from 600-800. All these figures quoted are in units of kWh/unit tensile strength. An important point to note is that the energy figures for plastics do not include the energy content of the feedstock (oil and gas), and if this were to be included the energy values would increase by a proportion of about 75%.

7.4 ENERGY COST AND THE COMPUTERISED SELECTION OF MATERIALS

In the previous chapters it was seen how a computer could help in assessing a large number of materials on the basis of cost. The same approach could be employed to store energy cost data and use it to select materials along the same principles.

Output E1 is a file called EØMASD (Energy Optimised Materials Selector - Data) containing the engineering properties of the materials. The contents of this file are

```
DOCUMENT     EOMASD

 0  52 8 1 2 5
 1                     KWH        S      F      E        D          R           I        C
 2 MFW-EN 1                 16.0 7.85 193.0 200750.0 125.0 77000.0 62.0 0.0
 3 MCW-ETP                  16.5 8.9 97.3 110424.6 166.8 44015.4 47.5 100.0
 4 MCW-OFHC               16.5 8.9 117.37 110424.6 162.2 44015.4 61.01 100.0
 5 NAVAL BRASS              16.5 8.9 227.0 103500.0 284.0 38500.0 81.0 24.7
 6 MAW-LM 2               79.0 2.7 77.0 69500.0 40.0 26254.8 2.15 31.0
 7 MAW-LM 4               79.0 2.73 84.94 69500.0 106.6 44015.4 2.03 32.0
 8 MAW-LM 6                   79.0 2.65 68.0 69500.0 35.5 26254.8 8.13 37.0
 9 MAW-EC                  79.0 2.70 47.88 69500.0 49.4 26254.8 31.18 62.0
10 MAW-IC                  79.0 2.7 47.88 69500.0 60.2 26254.8 31.18 58.0
11 MAW-N 3                   79.0 2.73 61.78 69500.0 71.0 26254.8 28.47 41.0
12 MAW-N 4                   79.0 2.68 123.55 69500.0 106.6 26254.8 28.47 35.0
13 MAW-N 5                   79.0 2.64 123.55 69500.0 94.2 26254.8 28.47 31.0
14 MAW-H 9                     79.0 2.7 97.3 69500.0 137.5 26254.8 27.12 40.0
15 MAW-H 15                79.0 2.8 123.55 69500.0 211.6 26254.8 8.13 40.0
16 MAW-H 20                79.0 2.7 61.78 69500.0 91.1 26254.8 31.18 53.0
17 MAW-H 75                  79.0 2.8 155.98 69500.0 247.1 26254.8 8.13 30.0
18 ALUMINUM                   79.0 2.7 50.0 62000.0 40.0 26254.8 30.0 65.0
19 COPPER                   16.5 8.96 65.0 119000.0 75.0 48000.0 58.0 102.0
20 MFW-EN 2               16.0 7.87 233.0 200750.0 131.0 77000.0 63.5 0.0
21 MFW-EN 3                  16.0 7.86 233.0 200750.0 215.0 77000.0 90.0 0.0
22 MFW-EN 4                  16.0 7.86 193.0 200750.0 170.0 77000.0 95.0 0.0
23 MFW-EN 5                     16.0 7.85 233.0 200750.0 170.0 77000.0 65.0 0.0
24 MFW-EN 8              16.0 7.84 278.0 200750.0 215.0 77000.0 110.0 0.0
25 MFW-EN 9                16.0 7.85 293.0 200750.0 215.0 77000.0 27.0 0.0
26 MFW-EN 14               16.0 7.85 278.0 200750.0 210.0 77000.0 130.0 0.0
27 MFW-EN 15             16.0 7.85 320.0 200750.0 260.0 77000.0 41.5 0.0
28 MFW-EN 18               16.0 7.83 415.0 200750.0 310.0 77000.0 65.0 0.0
29 MFW-EN 22                16.0 7.85 425.0 200750.0 370.0 77000.0 80.0 0.0
30 MFW-EN 24                16.0 7.83 495.0 200750.0 420.0 77000.0 65.0 0.0
31 MFW-EN 56                 16.0 7.72 386.0 200750.0 310.0 77000.0 100.0 0.0
32 MFW-EN 100                16.0 7.85 510.0 200750.0 340.0 77000.0 40.0 0.0
33 MFW-EN 110              16.0 7.84 750.0 200750.0 360.0 77000.0 40.0 0.0
34 MFW-AISI 302            16.0 7.9 234.0 193000.0 130.0 86000.0 150.0 0.0
35 MFW-AISI 309             16.0 7.9 360.0 193000.0 140.0 86000.0 135.0 0.0
36 MFW-AISI 317             16.0 7.9 248.0 193000.0 140.0 86000.0 150.0 0.0
37 MFW-AISI 410             16.0 7.9 278.0 193000.0 140.0 86000.0 27.0 0.0
38 MFW-AISI 420             16.0 7.9 680.0 193000.0 670.0 86000.0 11.0 0.0
39 MFW-AISI 430            16.0 7.7 320.0 193000.0 160.0 86000.0 20.0 0.0
40 MFW-AISI 431            16.0 7.9 540.0 193000.0 530.0 86000.0 13.5 0.0
41 NPC-HDPE                15.0 0.95 4.0 320.0 18.0 0.0 1.9 0.0
42 NPC-NYLON 66             50.0 1.14 20.0 2100.0 60.0 0.0 3.4 0.0
43 NPC-PP                  20.0 0.9 7.5 1400.0 20.0 0.0 0.54 0.0
44 NPC-PVC   (R)            20.0 1.4 12.0 960.0 50.0 0.0 0.6 0.0
45 NFC-PS   (GP)          40.0 1.04 0.0 2800.0 48.0 0.0 0.27 0.0
46 NPC-PROPATHENE           20.0 0.90 7.5 1500.0 34.0 0.0 0.5 0.0
47 NPC-MARANYL A100         50.0 1.14 20.0 2900.0 80.0 0.0 3.5 0.0
48 NPC-KEMETAL  AC          20.0 1.41 0.0 2800.0 60.0 0.0 3.5 0.0
49 NPC-RIGIDEX 2000           15.0 0.95 4.0 320.0 28.0 0.0 13.0 0.0
50 BEECH-WOOD             0.5 0.67 6.0 13500.0 15.4 5600.0 0.0 0.0
51 TEAK-WOOD                0.5 0.61 7.7 12750.0 17.5 5350.0 0.0 0.0
52 OAK-WOOD                 0.5 0.67 6.0 10750.0 14.0 4500.0 0.0 0.0
53 NCC-1.2.4             2.3 2.45 1.1 30000.0 15.4 12250.0 0.0 0.0
54  0 0 1 0 0 0
55  15.0  40.0
56
57            COMPUTERISED  MATERIALS  SELECTION
58                          WEIGHTING
59  FAT STR    ELA MOD   DES STR   RIG MOD   IMP STR   COND
60             BASIS  MATERIAL  =  MFW-EN 1
61 MIN DESIGN STRENGTH = 15 N/MM SQ
62 MIN DESIGN STRENGTH = 40 N/MM SQ
   ****
63
```

similar to CØMASD except for the first column. Instead of cost (£/tonne) in CØMASD, the first column in EØMASD is the specific energy, kWh/kg; and instead of cost per unit requirement (CUR), energy per unit requirement (EUR) is the selection parameter. The same theory of Chapter 5 is applicable in calculating the energy per unit requirement.

Output E2 is the computer print-out for the selection of a material on the basis of design strength only.

In the first section, the minimum design strength is kept at 15 N/mm^2. Any material not able to satisfy this requirement is automatically excluded from the analysis.

It is not surprising to note that the cheapest materials are the alloy steels with the non-ferrous and plastics group being about fifty times more expensive on the average.

In the second section when the minimum acceptable strength is increased some of the plastics and timber do not qualify.

It is interesting to compare this output with Output 3 in the previous chapter. Both select materials under the same design constraints, except that the basis of comparison is different. Output 3 selects on the basis of £/tonne while this program does it on kWh/kg.

The following table shows some interesting changes taking place from one output to another.

```
                  COMPUTERISED  MATERIALS  SELECTION

                              WEIGHTING

   FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND
      0          0          1          0          0         0

                BASIS  MATERIAL  =  MFW-EN 1
   MIN DESIGN STRENGTH = 15 N/MM SQ


   MATERIAL                         ENERGY PER UNIT REQUIREMENT

   MFW-EN 1                                   1.0000
   MCW-ETP                                    0.6566
   MCW-OFHC                                   0.6944
   NAVAL BRASS                                0.2265
   MAW-LM 2                                  16.5845
   MAW-LM 4                                   2.3611
   MAW-LM 6                                  20.6655
   MAW-EC                                    10.8734
   MAW-IC                                     7.3220
   MAW-N 3                                    5.3223
   MAW-N 4                                    2.3178
   MAW-N 5                                    2.9239
   MAW-H 9                                    1.4035
   MAW-H 15                                   0.6146
   MAW-H 20                                   3.1973
   MAW-H 75                                   0.4507
   ALUMINUM                                  16.5845
   COPPER                                     3.2696
   MFW-EN 2                                   0.9128
   MFW-EN 3                                   0.3385
   MFW-EN 4                                   0.5413
```

MFW-EN 5	0.5407
MFW-EN 8	0.3376
MFW-EN 9	0.3380
MFW-EN 14	0.3543
MFW-EN 15	0.2311
MFW-EN 18	0.1622
MFW-EN 22	0.1141
MFW-EN 24	0.0884
MFW-EN 56	0.1599
MFW-EN 100	0.1352
MFW-EN 110	0.1204
MFW-AISI 302	0.9304
MFW-AISI 309	0.8023
MFW-AISI 317	0.8023
MFW-AISI 410	0.8023
MFW-AISI 420	0.0350
MFW-AISI 430	0.5987
MFW-AISI 431	0.0560
NPC-HDPE	5.4714
NPC-NYLON 66	1.9697
NPC-PP	5.5981
NPC-PVC (R)	1.3933
NPC-PS (GP)	2.2462
NPC-PROPATHENE	1.9371
NPC-MARANYL A100	1.1080
NPC-KEMETAL AC	0.9745
NPC-RIGIDEX 2000	2.2611
BEECH-WOOD	0.1757
TEAK-WOOD	0.1239
OAK-WOOD	PROPERTIES BELOW REQUIREMENTS
NCC-1.2.4	2.9559

```
          COMPUTERISED  MATERIALS  SELECTION

                     WEIGHTING

FAT STR    ELA MOD    DES STR    RIG MOD    IMP STR    COND

   0          0          1          0          0         0

             BASIS  MATERIAL  =  MFW-EN 1

MIN DESIGN STRENGTH = 40 N/MM SQ


MATERIAL                      ENERGY PER UNIT REQUIREMENT


MFW-EN 1                              1.0000

MCW-ETP                               0.6566

MCW-OFHC                              0.6944

NAVAL BRASS                           0.2265

MAW-LM 2                             16.5845

MAW-LM 4                              2.3611

MAW-LM 6                      PROPERTIES BELOW REQUIREMENTS

MAW-EC                               10.8734

MAW-IC                                7.3220

MAW-N 3                               5.3223

MAW-N 4                               2.3178

MAW-N 5                               2.9239

MAW-H 9                               1.4035

MAW-H 15                              0.6146

MAW-H 20                              3.1973

MAW-H 75                              0.4507

ALUMINUM                             16.5845

COPPER                                3.2696

MFW-EN 2                              0.9128

MFW-EN 3                              0.3385

                                      0.5413
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MFW-EN 5                                      0.5407

MFW-EN 8                                      0.3376

MFW-EN 9                                      0.3380

MFW-EN 14                                     0.3543

MFW-EN 15                                     0.2311

MFW-EN 18                                     0.1622

MFW-EN 22                                     0.1141

MFW-EN 24                                     0.0884

MFW-EN 56                                     0.1599

MFW-EN 100                                    0.1352

MFW-EN 110                                    0.1204

MFW-AISI 302                                  0.9304

MFW-AISI 309                                  0.8023

MFW-AISI 317                                  0.8023

MFW-AISI 410                                  0.8023

MFW-AISI 420                                  0.0350

MFW-AISI 430                                  0.5987

MFW-AISI 431                                  0.0560

NPC-HDPE                           PROPERTIES BELOW REQUIREMENTS

NPC-NYLON 66                                  1.9697

NPC-PP                             PROPERTIES BELOW REQUIREMENTS

NPC-PVC  (R)                                  1.3933

NPC-PS  (GP)                                  2.2462

NPC-PROPATHENE                     PROPERTIES BELOW REQUIREMENTS

NPC-MARANYL A100                              1.1080

NPC-KEMETAL  AC                               0.9745

NPC-RIGIDEX 2000                   PROPERTIES BELOW REQUIREMENTS

BEECH-WOOD                         PROPERTIES BELOW REQUIREMENTS

TEAK-WOOD                          PROPERTIES BELOW REQUIREMENTS

OAK-WOOD                           PROPERTIES BELOW REQUIREMENTS

NCC-1.2.4                          PROPERTIES BELOW REQUIREMENTS
```

TABLE 7.9

MATERIAL	CUR £/ tonne	EUR kWh/kg
EN 1	1.0000	1.0000
ETP	3.7347	0.6566
ALUMINIUM	7.4482	16.5845
COPPER	11.6345	3.2696
EN 24	0.1339	0.0884
AISI 420	0.1210	0.0350
HDPE	13.1502	5.4714
TEAK WOOD	49.6289	0.1239

This shows very clearly how energy-intensive the plastics are and that timber is one of the cheapest materials from the total energy point of view. The table also reveals that steels, whether cost wise or energy wise, are one of the most all-round materials known to man.

The example illustrated is a simple approach to computerising energy optimised materials selection. Very rarely does a designer come across a real world problem in which design strength is the only requirement. In the majority of cases, as mentioned earlier, a combination of properties has to meet specified minimum criteria. This can very easily be incorporated into the program. The essential difference in the preceeding chapters, is that, instead of cost being the criteria for comparison, specific energy is used. The theory in Chapter 5 remains the same except that energy is substituted for cost in equation 3.

7.5 ENERGY CONSERVATION

In a period when fuel prices are rising, when fuel imports cause serious balance of payment problems and the supply of fuel is uncertain, energy conservation has become a major part of government policy in all industrial nations. The materials industries consume such a large proportion of total energy that attempts must be made to reduce the fuel consumed in this sector.

There are four major ways in which energy savings could be made in the materials sector, namely

1. improve the energy efficiency in industry;
2. substitute less energy intensive materials for more energy intensive ones;
3. increase recycling of materials;
4. consume less materials.

The last two sections are discussed in detail in the next chapter using the British Copper Industry as a model.

7.5.1 ENERGY EFFICIENCY

The meaning of energy efficiency depends on the context in which it is used; it depends on the system and it depends on the objective. Energy conservation is concerned with more efficient and more effective use of energy. It should not be limited to seeking methods for using less energy though this could be regarded as the first of several objectives. Thus it might appear desirable to save energy in one area but use more in another if such re-allocation brought sufficient benefits. Examples of this type of energy savings are seen in the aircraft industry where a group of heat-treatable aluminium alloys called Duralumin are used. These alloys contain around 95% Al, 4% Cu and 1% Mg. Two very energy intensive materials are employed, Al and Mg, but these metals by virtue of their high strength to weight ratio increase payload and decrease fuel consumption. A similar example is seen in the automobile industry where engine cylinder blocks are made from magnesium-aluminium alloys.

When discussing energy efficiency and conservation in the materials industries, it is necessary to divide these industries into those which are liable to resource scarcity and those which are not. Iron and steel, aluminium, concrete and timber are materials based upon relatively abundant natural resources and use high-grade sources of raw materials. For these materials, fuel efficiency can be achieved by better furnace or kiln design, recovery of more waste heat, utilising higher temperatures etc. In all these industries there has been a continuing technical improvement. British Steel Corporation's future energy planning is based on the estimate of a 10% reduction in the energy used per tonne of steel. In the aluminium industry there may be a similar improvement by continued technical advances or by the development of new technology such as the Alcoa process.

In contrast, the materials which are liable to resource shortages have shown a steadily increasing energy cost per tonne of product. This arises because as the rich sources are depleted more difficult and lower grade sources have to be worked. The best example of this type of material is copper, but metals such as lead, zinc and nickel are subject to similar increases in metal cost. Based on the analysis of change in energy cost with the ore grade[86] it is estimated that the energy cost of copper has risen by 50% over the past 25 years and will probably be twice today's value in another 25 years.

A different type of resource shortage faces the chemical industry. In this case the energy cost of suitable feedstocks is likely to rise as the easily recovered sources of hydrocarbons are depleted.

Hence it is apparent that resource constraints may increase energy costs for some materials faster than technical improvements can reduce energy costs. Eventually all materials will be subject to this type of constraint but for the next 20 years there may be significant savings in the energy consumed in producing materials.

7.5.2 MATERIALS SUBSTITUTION

The second method for conserving energy in the materials industries is to substitute materials with a low energy cost for those with a high energy cost. Unfortunately current trends are quite the opposite. Aluminium is displacing copper in a number of applications and plastics are replacing wood, paper and glass.

In comparing alternative materials allowance must be made for the energy cost per unit requirement or property. For example on a weight basis aluminium is twice as good a conductor as copper so only half a tonne of aluminium (40000 kWh) can replace one tonne of copper (16000 kWh). Similarly for milk containers, a plastic container may weigh only 0.012 kg (0.5 kWh) compared to a glass bottle of weight 0.36 kg (2.0 kWh) and a complete comparison must take into account the number of times each container is used.

In general there does not seem to be any evidence of the type of substitution required for energy saving, but rather trends in the opposite direction. There are many reasons for this and some common ones are vested interests and simply that the message has not got through.

CHAPTER 8

THE RECYCLING OF MATERIALS

8.1 THE SOLID WASTE PROBLEM

All industrialised countries have an urgent 'solid waste problem'. The problem, which is characterised by an ever-increasing solid waste generation rate, has two aspects: a pressing shortage of waste dumping areas and rising depletion of non-renewable natural resources. The situation is such that every person in the United States yearly discards around 90 kg of paper, 125 metal cans and 50 bottles and jars. On a national basis 7 million cars and 100 million tyres are discarded per year.[91] Americans who produce wastes at a rate reflecting an advanced Twentieth Century economy still dispose off it by Nineteenth Century techniques. Something must be done to stem this flow of the earth's natural resources into enormous junkyards of solid waste. Possible solutions for this problem are very few. It is desirable to slow down the consumption of natural resources and to reduce the rate of growth of waste dumps. Thus an approach like biodegradation of wastes is not a good solution. It only alleviates one half of the problem, the dump growth rate. In principle there is only one satisfactory approach, to reduce the rate at which natural resources are transformed into solid waste. It is the flow of materials from natural resources to solid waste which must be reduced.

To analyse and control this flow, a quantitative expression for its magnitude is needed. If,

the equilibrium number of products in use = P

the average lifetime of the product (ie. the time it is used) = L then,

the number of products discarded per unit time or the discard rate is = $\frac{P}{L}$

Assuming that the amount of waste in each product is W, the solid waste generation rate S is

$$S = \frac{PW}{L} \quad \text{tonne/year}$$

P = number of products (units)

W = waste per product (tonnes/unit)

L = product lifetime (years)

Thus there are in principle only three ways of reducing the solid waste generation rate:

1. Reduce P, the actual number of products in use;
2. Increase L, the product's lifetime;
3. Reduce W, the amount of waste in each product.

Since the material standard of living is related to the actual number of products in use per capita, (although the standard of well being may have almost nothing to do with P above threshold), the first approach implies a deliberate reduction of the average standard of living. This may be necessary in the long run but is probably not politically feasible at present.

Proposal two - to increase the useful lifetime of the products, represents an attempt at curbing the "throw away/ no return" and "planned obsolescence" tendencies of present day society. There are many ways in which the useful lifetime of a product could be increased. The most obvious way, of course, is to construct the product so that it lasts longer. But a second alternative is to design products to be easily and cheaply repaired or recycled.

The third alternative would be deliberate economic and social incentives inducing people to keep their products for longer periods than normal. But this may or may not have any impact, because products discarded by the primary user may be picked up and used by secondary and tertiary users until the product is completely useless. Inducing the primary user to hold the product longer might then decrease only the number of users and not increase product lifetime.

8.2 RECYCLING

There exists, however, another way of effectively reducing W which does not simultaneously result in changes in product lifetime. (The durability of a product may depend on the amount of raw material used in its construction. Hence, the lifetime L of the product may decrease when W decreases). This is to recycle the material in the discarded product. Because recycling can reduce the part of W which is actually thrown away to a small fraction, it can potentially reduce the solid waste generation rate substantially.

Even though society be engulfed by scrap, if the cost of recovery exceeds the market price of virgin metal then recycling is not a viable proposition. For example, it has been estimated that under New York city over 1500 tonnes of disused copper cable is going to waste because the collection costs are prohibitive.

Recycling involves scrap and scrap appears at three distinct stages of production and service.

1. Home Scrap - generated within the metal producing industry; collection and re-use is easy and complete.

2. New Scrap - produced during the manufacture of an article from the semi-manufactured sheet, bar, billet, casting, etc. although it has to be transported back to the metal producer for reprocessing, collection is reasonably straightforward and complete.

3. Old Scrap - scrap which has entered service, served its function and been discarded; collection is difficult and incomplete.

Fig. 8.1 shows the order of recycling of different types of scrap. As a rule, high quality home scrap and industrial scrap are recycled first. Then comes high-grade obsolete scrap such as battery lead and structural steel shapes. Lower grade obsolete scrap if not recycled is sent to disposal sites.

The line A-B between what is recycled and what is not shifts with changing market conditions. If the steel industry is booming, it may call for lower grades of scrap, shifting line A-B down. This shift usually is because industry is willing to pay prices that enable scrap dealers and processors to collect and improve the quality scrap for use, or that industry is willing to accept material of a grade it would normally shun. At all times, the decision on what is recycled is related to where it lies in relation to the line A-B.

Nearly all major materials are to some extent recycled, as shown in Table 8.1,[92] for the United States.

The recycling referred to is composed of new and old scrap. Home scrap is excluded. The typical level of recycling averages out at 25%. Building materials like cement, plaster, timber and the majority of plastics cannot be recycled, and for those plastics which could be recycled

FIG. 8.1

ORDER OF RECYCLING OF SCRAP

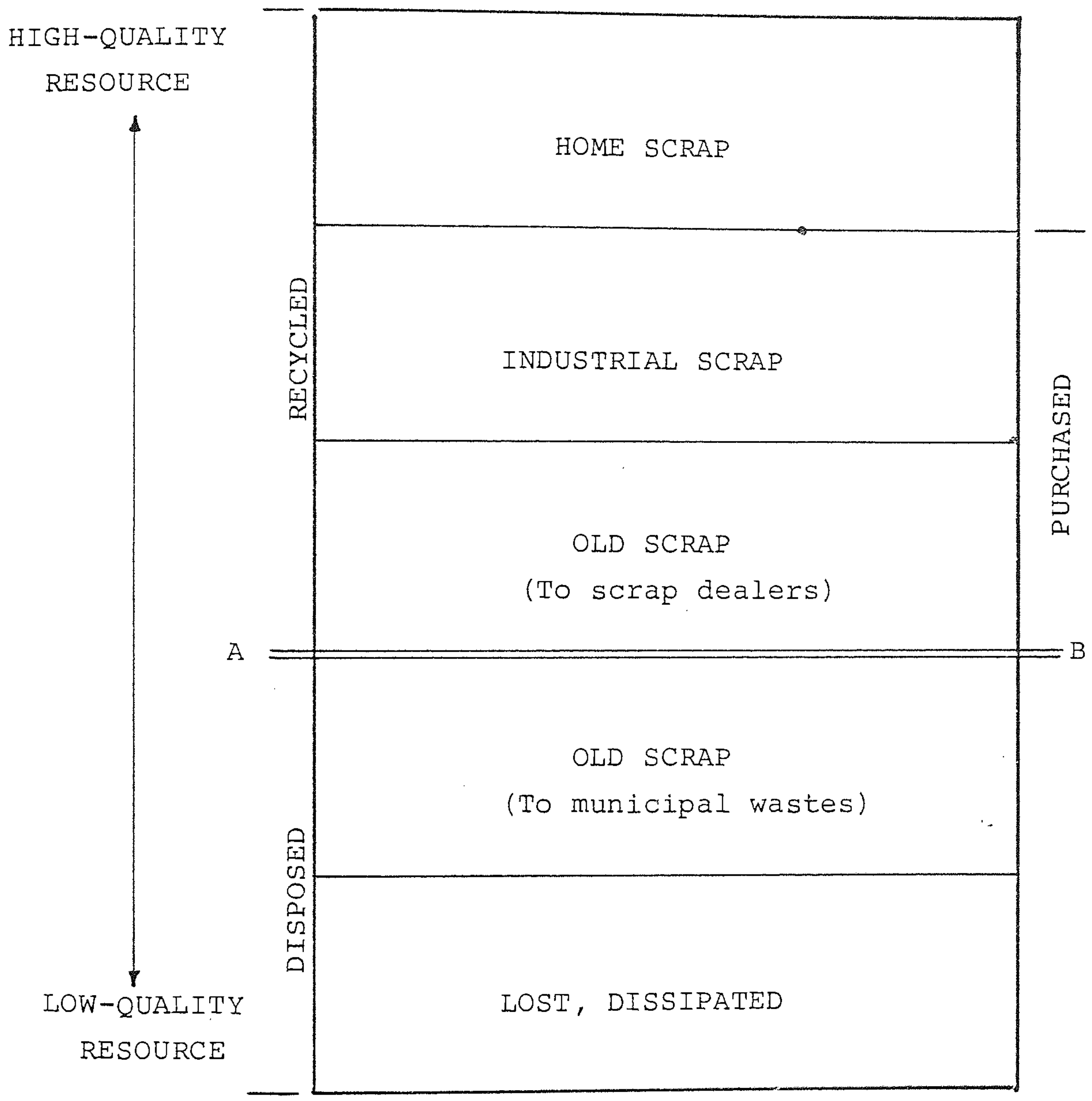


TABLE 8.1 (USA 1967)

MATERIAL	CONSUMPTION (million tons)	RECYCLED (million tons)	$\frac{\text{RECYCLED}}{\text{CONSUMPTION}}$ * 100
Iron and Steel	105.900	33.100	31.2
Paper	53.100	10.124	19.0
Glass	12.820	.600	4.7
Textiles	5.672	.246	4.3
Aluminium	4.009	.733	18.3
Rubber	3.943	1.032	26.2
Copper	2.913	1.447	49.7
Zinc	1.592	.201	12.6
Lead	1.261	.625	49.6
TOTAL	191.210	48.108	25.2

there is only limited room for improvement.

Recycling has a number of advantages. It conserves not only the metal being recycled, but energy as well. In a country with inadequate natural resources of its own, recycling reduces the dependence on imported ores. The inherent advantage over substitution is that no new manufacturing techniques need be developed and that the final products need not be changed.

This 376 billion kWh is about 2% of the industrial energy demand in 1968, the year the waste material would have been available in the United States.[92] A similar study conducted by Chapman[87] suggested a possible saving

TABLE 8.2 (USA 1967)

	ENERGY kWh/kg		Material Available For Recycling Million Tonnes	Energy Saved by Recycling kWh/tonne	Possible Energy Savings from Recycling kWh
	PRIMARY	SECONDARY			
Aluminium	79000	3500	1.0	75500	$75.5 * 10^9$
Steel	10000	6000	27.0	4000	$108.0 * 10^9$
Paper	7000	1500	35.0	5500	$192.5 * 10^9$
					$376.0 * 10^9$

of 16 billion kWh by proper recycling of copper and aluminium in the UK.

8.3 EFFECTIVENESS OF RECYCLING

Why is the recycled fraction so small? In the past raw materials were cheap and readily available; most still are. Investment in research and development has focussed on exploiting them. The market for recycled materials could be much larger if inequalities were eliminated from the marketplace. Some of these prejudices assure favourable tax treatment for virgin material producers. Freight rates for virgin material in the United States are less than rates for scrap. A traditional procurement bias by manufacturers consumers and the Government favours virgin material. Established production methods, long-term supply contracts, alloy specifications all tend to favour the present pattern of use and put recycling at a disadvantage. Other obstacles to recycling are collection, identification and separation costs, which are high because they are labour-intensive operations. Most industrial equipment has been designed and fabricated for virgin material.[93]

The economics of recycling are summarised in Fig. 8.2. The Figure shows the fluctuation in the market value of an article as a function of time.

When an article is manufactured and put on the market its retail price rises due to costs of labour, energy, marketing, etc. This is denoted by box X. Depending on the type of article under consideration, sometime between 0 to 50 years, it starts to wear out and is scrapped. Hence its value depreciates to scrap value. This is shown by box Y. Within about 5 to 10 years, the article is recycled to the original raw material. Due to the costs involved in collection, processing, etc. its value rises, to either A or B. If the recycled value is A, then reclamation cost exceeds market value, hence recycling runs at a loss (but only if subsidised or if market value is rising fast enough to justify storage). If the recycled value is B, then reclamation cost is less than market value, hence recycling runs at a profit, but can be vulnerable to market fluctuations.

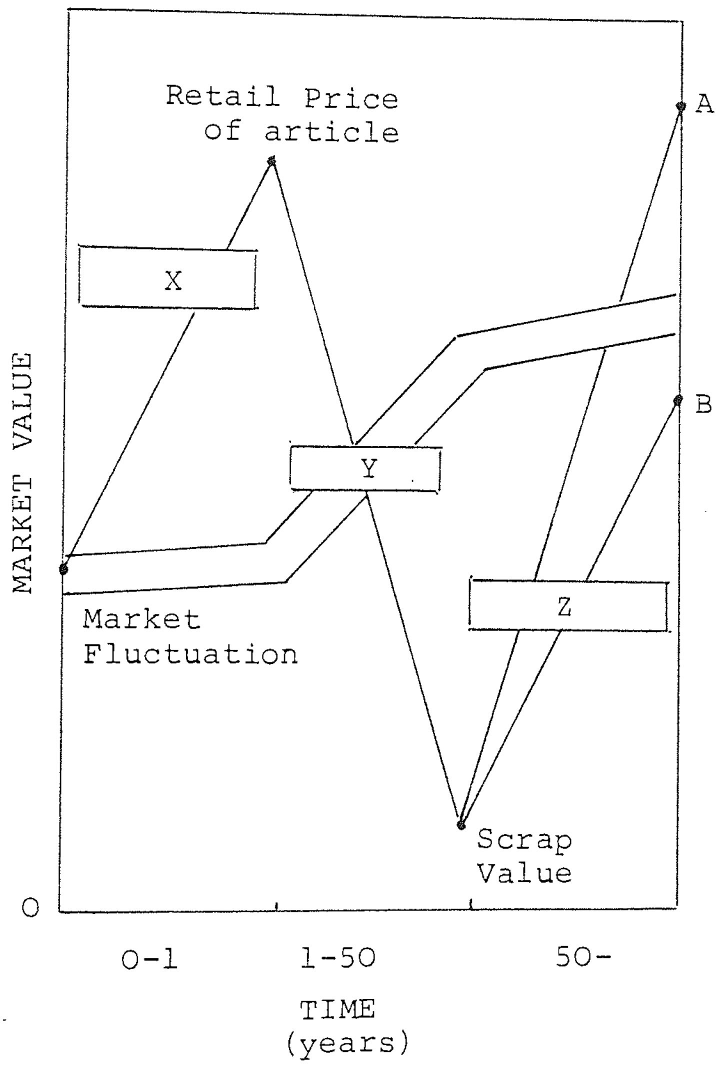
But it should also be realised that, although recycling has advantages, it does little to extend the life of the reserve base while growth continues at its present rate. This fact can be quantified and proved as follows:

Let,

Annual Growth Rate (material usage) = G%

FIG. 8.2

ECONOMICS OF RECYCLING



Base Annual Consumption in year 1 $= BAC$

Metal consumed at the end of the first year $= BAC(1+G)$

Metal consumed at the end of the second year $=$

$$= BAC(1+G)+BAC(1+G)G$$

$$= BAC(1+G)^2$$

By induction,

Total Metal consumed after X years is

(a) Without Recycling $(1+G)^X * BAC$

(b) With Recycling $(1+G)^X * BAC * (1-R)$

where R = fraction recycled in the period $1 \rightarrow X$

If without recycling, reserves are consumed within M years then,

$$\text{Reserves} = (1+\frac{G}{100})^M * BAC \qquad \text{i)}$$

and with recycling, if reserves are consumed within N years then,

$$\text{Reserves} = (1+\frac{G}{100})^N * BAC * (1-R) \qquad \text{ii)}$$

But Reserves being an independent physical quanitity is a constant, hence,

$$(1+\frac{G}{100})^M * BAC = (1+\frac{G}{100})^N * BAC * (1-R)$$

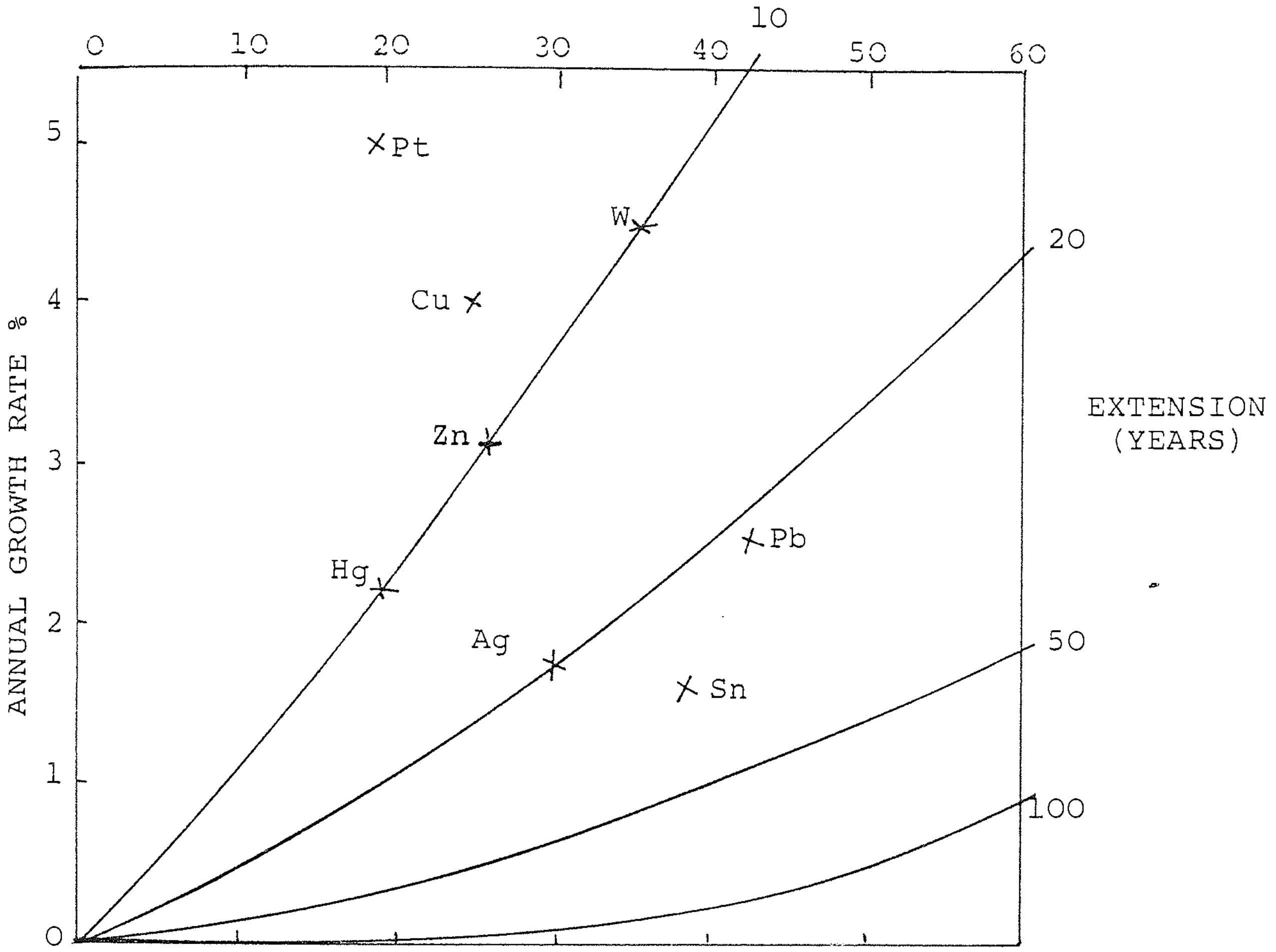
$$\text{Extension of Life, } (N-M) = \frac{\log(\frac{1}{1-R})}{\log(1+\frac{G}{100})} \qquad \text{iii)}$$

From equation iii) it is seen that the extension of the life of the reserve base is <u>independent of the size of the reserve base</u>.

Fig. 8.3 shows the extension of the reserve life as a function of growth rate and the fraction recycled.

FIG. 8.3

EFFECTIVENESS OF RECYCLING



% Currently Recycled

It shows that an increase in recycling usefully increases the reserve life only if the growth rate is low, say less than 1% per year. At current growth rates, typical recycling rates extend the life of the reserve base by a mere 15 years, and doubling them would only extend the life by a further 15 years. But if consumption growth were reduced to 0.5% per year, the life of the reserve base would be extended by over 100 years.

Once the effectiveness of recycling can be quantified, it should not be too difficult to set up a priority rating for recycling. The difficulty of assigning numerical ratings to involved problems is obvious, but it should be remembered that for the most part incentives to recycle have to be judged from an economic viewpoint, where numbers are the language. It is clear that this is just a start toward recognising more formal and rigorous techniques for setting up priority ratings and one should continue to explore methodology to refine these techniques.[94] A derivation of one such rating index is set out below.

Let,

D = disposal cost £/tonne
Vt = total tonnage disposed tonne
Vr = tonnage entering reuse cycle tonne
Vp = tonnage of products from reuse cycle tonne
M = manufacturing cost £/tonne
S = selling price of product £/tonne
I = incentive to recycle £/tonne
P = profit from reuse £
p = probability of success depending on recyclability
G = consumption growth rate
C = coefficient of self-sufficiency
N = MERIT RATING NUMBER

For recycling to be attractive:

P should be high
D*Vt should be low
p should be high.

Now,

$$P = \left|(S-M) * Vp + (I * Vr)\right| \qquad i)$$

and

$$N = \frac{P}{D * Vt} * p \qquad ii)$$

The total profit P from the recycling operation consists of the profit made in the actual manufacturing of the product plus an incentive. The manufacturing profit depends on the volume of products put on the market and the incentive depends on the volume of material entering the reuse cycle.

The Merit Rating Index, N shown in equation ii), deals only with the tonnage and the cost of the material. It does not consider important aspects like national reserves, strategic importance, population growth, demand and supply etc. This can be overcome by introducing two factors into equation ii).

G = consumption growth rate , %

C = coefficient of self-sufficiency = $(1- \frac{c\phi}{pr})$

$c\phi$ = annual consumption, tonnes

pr = annual production, tonnes

These two factors when incorporated into the formula, impart a sense of urgency to the merit rating.

The simple calculation shown in tabular form emphasises clearly how important it is for the UK to take steps to increase the recycling of copper.

COPPER

	G 1945-70	C	G * C
USA	2%	- 0.3	0.6
UK	2%	-1000.0	2000.0
THE WORLD	4%	- 0.12	0.48

Thus the final formula for the MERIT RATING INDEX is

$$N = \frac{P}{D * V_t} * p * G * C \qquad \text{iii)}$$

Some recent studies have shown that solid wastes are simply resources out of place, with few technical constraints in the way of recycling them. It has also been shown that a market exists for products obtained by efficient solid waste management.[95]

8.4 COPPER RECYCLING IN THE UK

In the preceeding sections general concepts and the state of the art of recycling were introduced and analysed. In this section an in-depth analysis of the consumption and losses of copper and copper alloys in the UK during the period 1920-70 is conducted.

8.4.1 INTRODUCTION

Throughout the world considerably more thought is being given to the need to increase the recycling of metals and materials as mentioned before. Although a lot of work is done in this field, nevertheless it was thought that one aspect which might repay greater study was to analyse the dissipative uses of some metals, in order to determine what significance these dissipative uses had on the overall recycling problem. It was also realised that, apart from the truly dissipative uses of metals, there is another great source of loss in that many metals in the form of old scrap were perhaps not recycled, or alternatively were lost in other ways, i.e. true dissipation. It was also appreciated that there might be difficulties in getting the appropriate statistics to cover such a detailed study.

For various reasons copper was selected as a suitable study to determine its "dissipative uses" and also to assess its apparent loss, or for want of a better title its "pseudo-dissipative loss".

Copper is one of the largest tonnage and oldest metals used in the world. It does not suffer from corrosion, being a noble metal losses into oxides, chlorides and sulphates are a minimum. Hence, when it is once extracted from its ores it must still exist in a metallic form somewhere on the face of the earth.

It was also decided to confine the study to one country, as it would be very difficult to make a comprehensive study covering the whole world, and also in the UK fairly reliable statistics, which go back fifty years were available.

It was therefore thought possible that an overall balance sheet of consumption would give a firm foundation on which to base the total availability of copper in the UK and against which could be balanced the scrap which was recycled.

Data on the truly dissipative uses of copper, normally in the form of fungicides and other chemical products, are readily available and show uses to be insignificant.

TABLE 8.3

(All Figures in Percentages)

	UK	USA		
	1965	1974	2000	
Electrical	51	54	72	Generators, transformers, motors, wiring
Construction	19	17	10	Plumbings, fittings, hardware
Industrial	12	12	7	Heat-exchangers, valves, plates
Transport	11	9	4	Heaters, bearings, radiators, wiring
Domestic	3	3	4	Washing machines, air-conditioners, radios, TV
Other	4	5	3	Chemicals, munitions, coins, pigments.

The statistics available from the World Bureau of Metal Statistics[96] and those drawn up by Ryder[97] give a fairly accurate indication of what the copper consumption of the UK had been since1920. Such consumption figures had been arrived at by taking the total production of the UK, adding imports of copper in the forms of semies etc., and subtracting the exports as semies and some finished goods. All these figures were converted to copper content and may involve some minor errors due to variations in alloy content. About 50% of all the copper refined in the UK as in most other countries, is utilised for electrical applications as high conductivity copper and is virtually 100% pure copper.

The statistics for the uses of copper are not broken down in a way that enables one to ascertain the qualities and conditions of copper and copper alloys used under the various categories. These categories are based on applications in the electrical, construction, industrial, transport and domestic consumer goods and appliances. Whereas for the electrical industry applications one can confidently anticipate that something of the order of 50% is used in the form of high purity copper, it is not easy to break down the remaining applications in the other areas into the various groups of copper and copper alloy specifications.

The dissipative uses of copper are extremely low, the main application being as fungicides and in most countries this varies where priority is given to agriculture in the total gross national product, but the consumption of copper for fully dissipated uses usually in the form of copper sulphate, is of the order of 1% per annum of UK consumption. This figure also covers the use of minor amounts of copper for other chemical compounds.

8.4.2 COPPER SCRAP

All producers and consumers of metal create scrap of one sort or another. The statistics for copper are more comprehensive than those for other metals and hence deserve examination.

The movement of copper scrap is extremely complicated and difficult to measure in statistical terms. It is possible to distinguish several main categories, which are as follows:

1. Scrap generated and consumed in the same plant.
2. Ashes and residues produced in mills and foundries and returned to smelters and refiners.
3. New scrap sold by the engineering industry back to the metal manufacturer. New scrap is produced at most stages of processing and fabrication. For example, nearly 5 tonnes of copper are cast to produce 3-4 tonnes of semi-manufactured goods; the balance is scrap. Some of this scrap may circulate entirely within a factory and hence will never appear in any statistics. And some of it may be recycled several times in one year, thus inflating the statistics by multiple accounting.
4. Old or used scrap which is collected by merchants and sold to smelters, refineries or fabricators. Old scrap arises from the breaking up of machinery, equipment, cars, ships, etc., from old cables and spent ammunition; from the plumbings and fittings of demolished buildings. Important sources of such

scrap are government departments, telephone companies, electricity supply boards, armed services and the railways.

In practice it is sometimes difficult to draw a line between old and new scrap and track them for accounting purposes. Thus cable scrap can originate as off-cuts in the cable-making plant (home scrap), as lengths of obsolete cable (old scrap), and as off-cuts of new cable during installation (new scrap). Is the last (which may be identical to the first) old or new scrap?

Some scrap, e.g. leady brasses, produced by the fabricators will always be sold to refiners because it cannot be used directly by the semi-manufacturers unless it is properly identifiable. It is part of the technique of the semi-manufacturers to use their scrap in the most effective and efficient manner.

In addition to the scrap produced in the fabricator's works, a large amount of scrap is produced by engineering companies. This consists largely of wire, rod, cables, swarf, cuttings, tube-ends and the like. It is all process or home scrap and the composition is usually known fairly accurately. Much of it is directly returned to the manufacturer of strip, tube or rod under some form of contra arrangement.

So much for new scrap which in many cases consists of more than 50% of all scrap return figures which are quoted later. From the point of view of conservation of metal once it has been mined, a far more significant and important figure to study is the data on old or used scrap.

There is no doubt that large quantities of old scrap are recovered every year. One of the virtues of copper, as was mentioned earlier, is that it is virtually indestructible and, apart from the chemical uses, most copper should be recoverable.

Old scrap follows a different cycle from new scrap. This is due essentially to the fact that old scrap is frequently not easily identifiable in its alloy content and is contaminated by iron and tin and so can only be used for producing ingots.

The main users of scrap are:

1. Refiners who use better and higher qualities of scrap to produce fire refined and electrolytic copper.
2. Smelters who use residues and low grade scrap for the recovery of blister copper.
3. Ingot makers who make specification ingots out of a variety of scrap.
4. Brass extrusion and rod mills who use a very large proportion of scrap in their products.
5. Foundries which use a very large proportion of scrap for production of castings.
6. Chemical complexes which use low grade scrap largely for production of copper sulphate but also for the production of a number of other chemicals.

Scrap not only flows back from the users of metal but there is also a trade in scrap and residues between the individual brass mills and between refiners.

8.4.3 COPPER RECYCLING

As indicated by Evans[98] and the International Wrought Copper Council (IWCC) 1968 report[99] current recycling fractions are about 16% old scrap of the total metal consumed in most Western countries, while new scrap recovered as a fraction of consumption is about 25%. Of the total old scrap recovered 50% is undoubtedly as pure copper from electrical applications. The remainder is a wide range of alloys containing zinc, tin, nickel, aluminium etc. Processing of such segregated and mixed scrap is now common in most industrial countries. It is not, therefore, anticipated that much can be done in the short term to improve such recycling once the metal has arrived at the scrap yards and has been identified.

The more serious matter is to locate old scrap which apparently, according to statistics is not, or may not, be coming up for recycling. No proper study has been made of the true life cycle of copper in all its individual applications, and thus it is impossible to state confidently what proportion of used copper has disappeared from the true recycling operation.

Data on the availability of scrap in the UK extended back to the 1920's, but all tonnages referred to were under the general heading of scrap. Further study revealed that the proportion of new or processed scrap, as compared with old or used scrap, needed further investigation. So far as the ultimate balance sheet was concerned it was essential to find out what was old scrap alone since new or processed scrap is irrelevant to the investigation. However, a very detailed investigation has been carried out by the IWCC covering the period 1960-65[99] in which a detailed study was made of the UK scrap situation in that period. The two major limitations of this report were that the figures were suspect in the apportionment of old scrap as compared with new scrap and the relatively short period of time over which the study was made.

Finally, another difficulty of such an overall study is the impossibility of accurately assessing the recycling time or useful life of any copper component. One has only to consider, for example, car radiators where the recycling time may be of the order of 5 to 10 years. With electrical cables it might be 30 years and with telephone cables recycling time may be as long as 40 years.

Clearly a proportion of the metals for all applications will be scrapped in a shorter time and in other cases in a very much longer time; and to get a fairly accurate assessment of the total situation one must attempt to average out what normal life expectancy is of copper or any of its alloys in various forms.

A weighted average gives a life cycle of 31 years. For the present analysis, life cycle times of 10 years, 20 years,

TABLE 8.4
(UK 1965)

	USAGE %	LIFE CYCLE YEARS
Electrical	51	25
Construction	19	40
Industrial	12	25
Transport	11	40
Domestic	3	10
Others	4	75

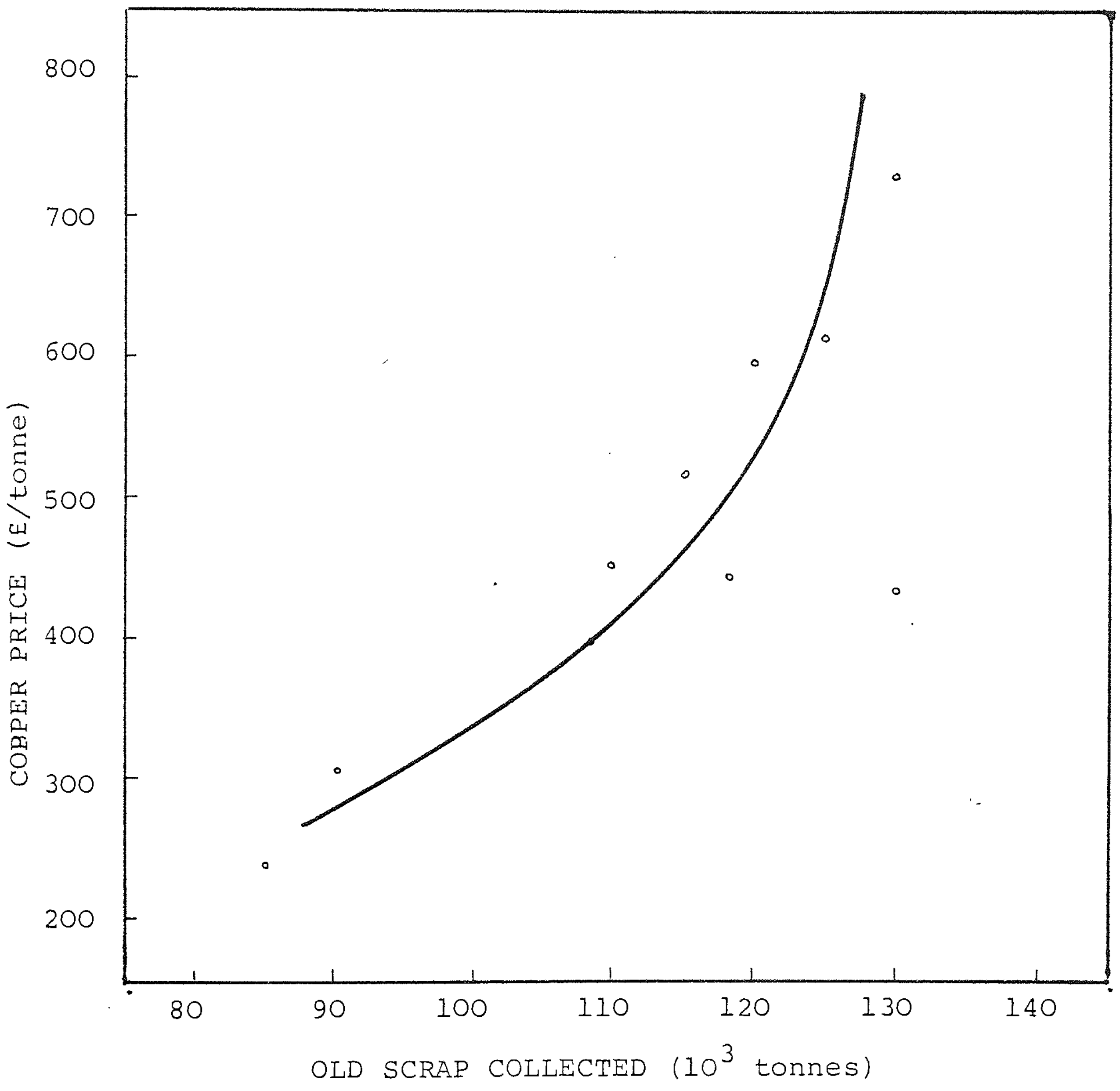
30 years and 40 years have been assumed for the average life of all copper and its alloys before they are recycled and used.

There is no doubt that considerable possibilities exist for increased recycling of copper and its alloys. At the present time the restrictions are mainly economic. It could be said that in the years ahead if the price of virgin metal stays constant beyond £1000 per tonne there will be additional incentive to recycle an increasing proportion of old copper scrap particularly since the additional margin between scrap metal value and the market value for virgin metal will have increased, though as a study of the past 20 years illustrates in Fig. 8.4, the rise in scrap collection did not increase significantly with a rise in LME metal price.

There is no technical reason why virtually 100% recycling of old scrap cannot be carried out. The reasons why it is

FIG. 8.4

OLD SCRAP COLLECTED vs REAL VALUE OF COPPER



not done at the moment are, firstly the question of recovery from its end use, secondly ready and accurate identification of composition and thirdly the whole economics of recycling. Obviously if identification of the various alloys etc. can be confidently made the whole added cost of going back to refining operations with attendant metal loss is eliminated, and the metal can simply be recycled as an alloy by remelting it into the appropriate alloy specification. If identification is confident and impurities are minimised there are no reasons why metallurgical recycling operations should not be conducted, if necessary, with as much as 90 to 95% efficiency.

8.4.4 BALANCE SHEET FOR COPPER CONSUMPTION

In this section an attempt has been made to draw up a balance sheet for the overall consumption of copper and copper alloys in the UK between the years 1920-1970.

Drawing up such a balance sheet for any one metal has rarely been attempted, but despite the difficulties outlined earlier it was thought worthwhile to make an attempt. The data were derived from the following considerations:

1. Consumption of metal in the UK on an annual basis. These values have been derived from figures of production, plus import of semies, less exports in the form of finished semies, ingots and castings.
2. The figures are more or less continuously recorded from 1920 to 1970 and beyond but the period 1937 to 1947 created some difficulties since statistics

were not available and these have been obtained from other records.[96,97]

3. The truly dissipative uses of copper have been estimated from figures which were available for certain years only between 1920-1970.

One of the greatest problems was that although figures of total scrap recycled were available it was found, that the proportion of new scrap to old scrap was not recorded. Furthermore there was considerable discrepancy even about recent figures, consequently recourse had to be made to direct inquiry to several of the copper refiners and secondary metal melters in the UK. This revealed that the figures of 85% new scrap and 15% old scrap assumed by the IWCC[99] were probably erroneous and, as far as the UK was concerned, the figures are more likely to be 50% new scrap to 50% old scrap. These proportions are supported by the paper on scrap metals by Evans.[98] In the final balance sheet, therefore, these figures are taken, although the figures may be optimistic for old scrap.

Discussions with the statisticians responsible for drawing up these figures at the British Non-Ferrous Metal Federation and the World Bureau of Metal Statistics have clearly revealed that in using the import and export figures of copper no account has been made of the balance of copper exported/imported as components of capital goods. Some years ago an estimate was made by the Non-Ferrous Bureau of Statistics on this problem and although they were not too confident of their methods they concluded that about 8% of the copper consumed in the UK was exported in the form of capital goods. Hence this percentage has been used to reduce the overall annual consumption of copper in the UK.

In addition a value of 3% of total consumption has been allowed for the dissipative uses. This is based on an average value extending back to 1920 and is probably a high figure covering the whole period. Thus Fig. 8.5 and Table 8.5 show total consumption value minus 11% (8% for capital exports and 3% for dissipative uses). Adjustments in the consumption are also made of the 0.1% copper lost as tramp element in the iron and steel manufacture in the UK. Again an optimistic value because for many years the tramp copper content of steels was kept well below 0.05% copper. The production of iron and steel in the UK has been of the order of 20 to 25 million tonnes per annum, and it can be seen from this, that if the amount of copper lost as tramp element is about 0.1% this would account for about 20000 tonnes per annum of copper almost completely lost for the copper recycling system.

8.4.5 ESTIMATE OF COPPER IN USE

To estimate the amount of copper in use, it is first necessary to break down usage into two main categories: 1) electrical and 11) non-electrical. It is a well-known fact that electrical applications account for nearly half the copper consumed in the UK. As a result of discussion with the CEGB, the various Area Boards of the UK, the Post

FIG. 8.5

COPPER SCRAP LOSS

$$NCC = 0.89A - TE$$

$$\% \text{ LOSS} = \frac{NCC - \&5}{NCC} \times 100$$

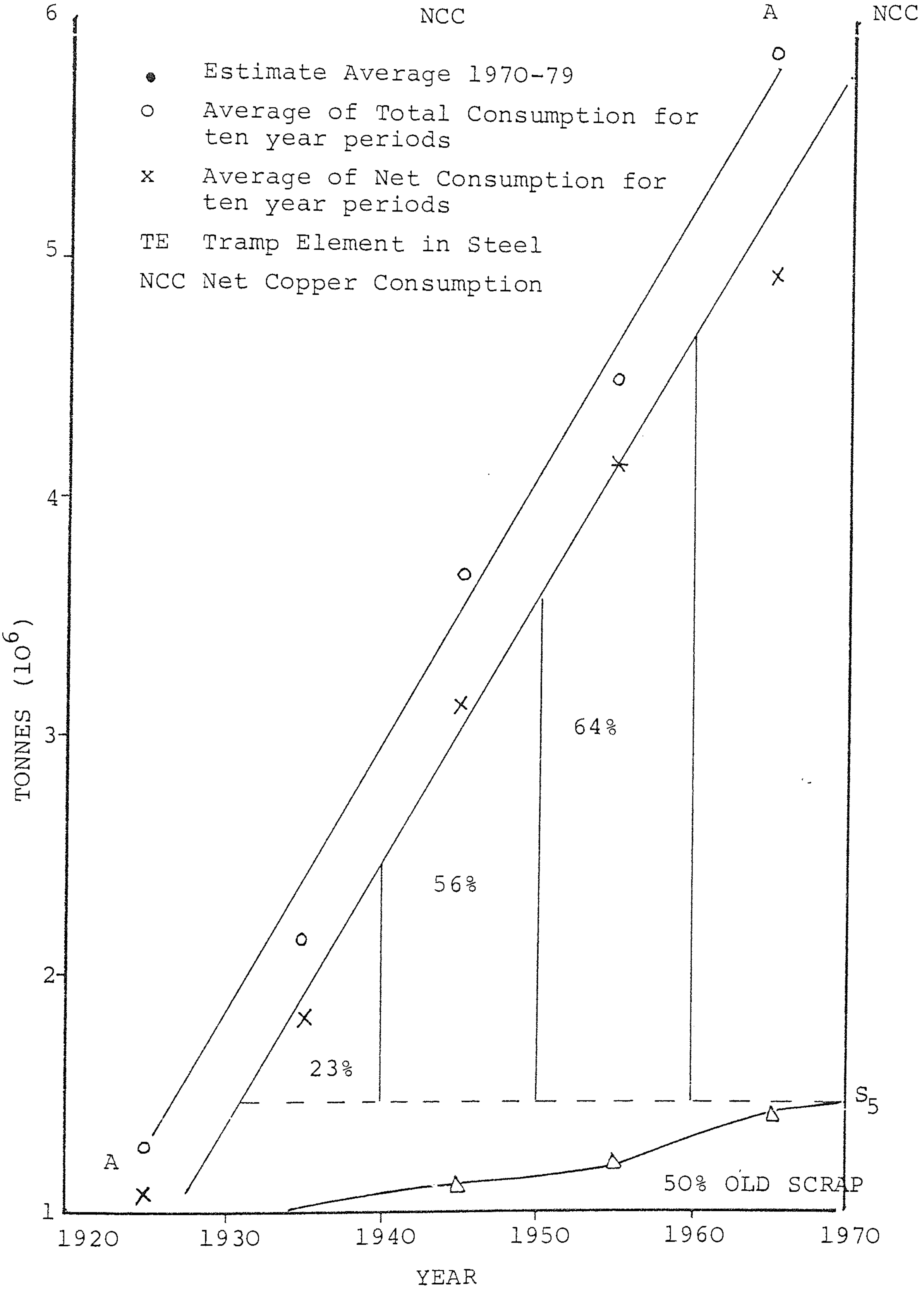


TABLE 8.5

Year	Copper Consumption A	Accumulating Total	Cu Lost as Tramp element in steel. TE	Net Copper Consumption B=0.89 x (A -TE)	Total Scrap	50% Old Scrap	50% Old Scrap Accumulating Total
1920 1929	1267100		90819	1036900	316775	158387	
1930 1939	2130810	3397910	105048	1791373	375300	187650	346037
1940 1949	3662605	7060515	139004	3120714	2172314	1086157	1436194
1950 1959	4485055	11545570	172308	3819391	2292528	1146264	2578458
1960 1969	5821494	17367064	223203	4957927	2765300	S_5 1382650	3961108
1920 1969	17367064		730382	14726305	7922217	3961108	

Office and industry, it is believed that the maximum and minimum figures given in Table 8.6 will adequately bracket copper in service.[100]

Referring back to Table 8.5, from 1920 to 1969 inclusive, 14,726,305 tonnes of copper entered use in the UK after adjusting for net trade, alloy composition etc. On the same basis, only around 3.96 million tonnes of old scrap were collected over the same period, (assuming 50% of all scrap collected was old scrap). Therefore, around 10.7 million tonnes remains in use as cable, tube, rolled copper and brass etc. All of this should, as the scrap trade puts it "come back one day". But this accumulation of metal unaccounted for leaves room for a large margin of doubt as to whether all of it is still working for its living as live cable or tube.

Thus the analysis in Table 8.6 shows that the electrical industry can account for only 3.2 million tonnes whereas nearly 5.35 million tonnes sould be in use. Thus in the electrical sector alone around 2.15 million tonnes of copper is unaccounted for. The non-electrical sector with its diverse uses in widely-scattered areas would have a loss comparable with the electrical sector. On the basis of this analysis it is therefore put forward that around 4.0 to 5.0 million tonnes of copper is unaccounted for in the UK.

8.4.6 ANALYSIS OF RESULTS

The statistical data was shown in Table 8.5. This is data relating to consumption, old scrap collected over the same period and other deductions like capital goods exported and psuedo-dissipative uses.

A more detailed analysis of copper loss is worked out as explained below.

Assume an average life cycle of 10 years. Then, the major portion of the copper consumed in the period 1950-59 should surface as old scrap. 10 years later, i.e. in the period 1960-69, hence:

$$B_{50-59} = S_5 + \text{LOSS}$$

$$3819391 = 1382650 + \text{LOSS}$$

$$\text{LOSS} = 2436741$$

and $\% \text{ LOSS} = \frac{\text{LOSS}}{B} * 100 = 64\%$

where B = net copper consumption (during decade indicated)

S_5 = old scrap available during 1960-69.

Similarly, at the other extreme, if life cycle is assumed equal to 40 years, then the net copper consumed in the period 1920-29, should surface 40 years later as old scrap, ie. in the period 1960-69. Therefore,

$$B_{20-29} = S_5 + \text{LOSS}$$

$$1036900 = 1382650 + \text{LOSS}$$

$$\text{LOSS} = -345750$$

and % LOSS = - 33%.

This negative loss suggests that not enough copper was consumed in 1920-29 to generate S_5 tonnes of old scrap which surfaced in 1960-69. Another way of looking at it is, if all the scrap is accounted for (zero loss), then the average life cycle is about 35 years.

These calculations have been summarised in Fig. 8.5 and Table 8.7. In Table 8.7 the percentage loss was calculated for different life cycles and for zero loss the life cycle is about 35 years. In Fig. 8.5 the line A-A is the total copper made available in the United Kingdom. Subtracting the copper lost as mentioned before, the net copper consumption is shown by line NCC. The curved line denoted by triangles shows old scrap recovered with S_5 being the amount of old scrap recovered in the period 1960-69.

There are two major assumptions in the logic behind the calculations shown. Firstly, that the amount of old scrap is about 50% of the total scrap recovered, and second, that there is zero loss in the transfer from copper in use to copper scrap over the years.

If this second assumption is valid then the average life cycle can be related to the percentage of old scrap in the total scrap produced. The calculations were also carried out with 25% and 75% old scrap values and the corresponding life cycles are shown below.

TABLE 8.6

Consumption NCC (1920-69)	14.7 million tonnes
Recycled as scrap (1920-69)	4.0 million tonnes
Therefore	
Cu in circulation (1970)	10.7 million tonnes
Assume	
50% in Electrical Industry	5.35 million tonnes
Non-Electrical	5.35 million tonnes
Maximum Cu accounted for in(i) Electrical Industry	3.20 million tonnes
Therefore	
Assumed lost	2.15 million tonnes
Maximum Cu accounted for in Non-Electrical Industry	?
Assumed Lost	?

(i) By correspondence from:

Electricity Council	1.6×10^6 tonnes
Area Boards	0.5 to 0.8×10^6 tonnes
Telecommunication Headquarters	0.8×10^6 tonnes

TABLE 8.7

LIFE IN YEARS	LOSS = $B - S_5$	$\% = \frac{\text{LOSS}}{B} \times 100$
40	- 345750	-33%
30	408723	23%
20	1738064	56%
10	2436741	64%

% Old Scrap ($\emptyset S$)	Life Cycle (years) (LC)
25	60
50	35
75	27

An approximate relationship exists between these two sets of figures and is quoted here for completeness.

$$LC = -2.0(\emptyset S) + 0.013(\emptyset S)^2 + 102$$

This equation is valid in the range $20\% \leqslant \emptyset S \leqslant 80\%$.

Since it was mentioned earlier that for the UK the proportion was about 50% old scrap to 50% new scrap, the minimum average life cycle for all copper products on the whole, would be around 35 years.

8.4.7 CONSERVATION POSSIBILITIES

Because copper and its alloys do not undergo any significant deterioration with time in service, two main objectives are all that are required of any design team in order to maximise conservation. The first criterion is to design to exploit the properties to their maximum, particularly electrical conductitivity and so use a minimum of metal. This also assumes the factors of safety are of a very low order and hence quality and reproducibility must be high. The second and probably more important requisite of a good design, in the light of what has been said earlier on pseudo-dissipative uses, is to ensure that all copper and its alloys can, at the end of their service, be easily dismounted, separated from other contaminating materials and recycled with a minimum expenditure of labour and energy.

For example, to revert to the automobile radiator one has only to realise that it has been developed into its present very sophisticated form over some fifty years of intensive work in Europe and United States. Its present performance in engineering heat transfer terms, bearing in mind its prime cost, is extremely efficient and effective. Having said this, it must now be said that it is not an ideal component to recycle. Similarly, and to a lesser extent, are all the other end uses of copper in automobiles. Is one to sacrifice present engineering design efficiency for the longer term and rather more nebulous concept of optimum recyclability?

On the question of design concepts for recycling, several points have to be mentioned. To begin with, copper and its alloys, because they are corrosion resistant, usually have a life or expected life longer than that of the unit in which they are assembled. It is a question therefore of designing the rest of the assembly for increased life which would improve conservation in the utilisation of copper and its alloys. To consider maintenance and repair, many of the uses are electrical and, if they are not, copper and its alloys can easily be joined by a variety of methods. It seems probable therefore that the metal cannot be improved significantly from the point of view of ease of maintenance and repair.

8.4.8 CONCLUSIONS

Although there is a paucity of data in some of the critical areas, and margins of error exist in some of the estimates, there appears to be a prima facie case that the pseudo-dissipative uses of copper, are very considerably higher than the truly dissipative uses. Furthermore the discrepancy between what has been consumed in the past years and what is now being recycled as old scrap appears to be of such a magnitude that a much more detailed study must be made of this loss or apparent loss. Alternative explanations may be:

i. to assume a much longer life cycle than seems reasonable;
ii. that the UK has lost considerable amounts of old scrap by exports in forms not recorded, and
iii. that the metal is so disseminated as to be irrecoverable.

It should also be noted that this study confirms (Fig. 8.6) that the copper consumption in the UK has been constant for the last 13 years, 1960-1973; and that exponential growth rates are not a reality.

CHAPTER 9

DISCUSSION

RESOURCES

Natural resources have traditionally formed the foundation for the economic development and growth of virtually all industrialised countries.

Considerations of the resource base - the actual total endowment of the earth rather than the anomalous endowments (i.e. ores) we have been accustomed to dealing with - would suggest that, instead of concern for resource scarcity, the world may be faced with a situation of abundance for the future. The combined effects of substitution and technological change have continuously allowed us to increase the known and economically usable range of resources, especially for our complex and flexible industrial societies. It is said that technology has increased our discovery potential. It is only fair to assert one shortcoming of the above argument, i.e. there is obviously a finite limit to the numbers of unexplored areas and there are a finite number of ore deposits. Geologic availability is the ultimate determinant of mineral potential and, as we reduce the number of unexplored areas, more intensive use will have to be made of marginal areas, which will result in increasing costs of production.

The strategic materials problem will be for the next few decades a continuing issue. The dependancy of a country on other countries for ores will be an important factor in future international relationships. Having an acceptable materials selection and utilisation program established can have considerable influence on the accuracy of decision making and on the reaction time when the need for change arises.

A methodology for resource assessment has been developed and shown here in the form of guidelines for future work.

1. <u>Examine resources/demand data</u>. Identify location and lifetime of resources.
2. <u>Extractive processes</u>. Analyse energy and environmental aspects. Is energy a large part of cost? How will energy cost changes alter price?
3. <u>Essential properties</u>. Analyse applications and the properties required. Check alternative materials.
4. <u>Conservation possibilities</u>. New resources. Minimising waste through increased recycling and improved

reliability. Increased durability through better mechanical and physical properties. Improved designing involving material saving and prolonged life. Explore methods of standardisation.

5. Substitution possibilities. Identification of properties and uses. Use of cost per unit requirement (CUR) and energy per unit requirement (EUR) as criteria for choice of substitutes. Analyse non-conventional alternatives.
6. Formulation of long-term research aims. Particularly those which have little economic incentive.
    a) Resource - assessment techniques.
    b) Extraction techniques.
    c) Recycling techniques.

ENERGY

To be rich is to consume energy; and to consume energy is to be rich. The industrial and post-industrial societies of the world have emerged because fuel energy is cheaper than human energy. If the balance is allowed to go the other way, incomes per head will regress towards the level that unsupported human energy can achieve.

In the poor countries of the world the items that go to make up a "good" standard of living are in scarce supply. Simultaneously, the per capita energy consumption in underdeveloped countries is low compared to that of the developed countries. One concludes, therefore, that energy consumption and provision for human needs and comforts are roughly related.

But, in comparing the developed countries, in which the spread in the GNP is less, there is much less correlation of GNP and energy consumption.

TABLE 9.1

	GNP dollars per capita	Energy Consumption kWh per capita
N. Zealand	1500	11880
France	1500	15840
Denmark	1500	19800
Australia	1500	23760
U.K.	1500	29040

In the light of the above observation, it can be seen that at least for developed countries, the statement is not correct. Large variations in energy consumption seem to occur without corresponding differences in standard of living.

Hence in principle it should be possible for a developed country to reduce its energy consumption without an accompanying reduction in the standard of living.

RECYCLING

Recycling of scrap is so often cited these days as a cure for the material and energy shortages that we face, that one is likely to picture recycling as a new industry to be developed.

The recycling industry - or secondary metal industry, as it is frequently called - lacks the glamour of the primary metal industry. It is an industry that recycles more than 50 million tonnes of metal each year in the United States. Almost one-third of the enormous requirement for raw steel in that country is supplied by recycled scrap.

Of increasing importance is the concept of 'recyclability'. Is the material capable of being recycled indefinitely in a primary cycle? Or can it be processed through one or several secondary cycles of increasing degradation and be dissipated?

Of the various groups of materials, metals are pre-eminent for recyclability in that, assuming they are collected and properly segregated, there is no reason why the majority of them should not be 100% recycled as old scrap in the primary cycle, i.e. as metals or alloys without degrading their specified properties. Timber might be reclaimed but for degraded products. Concrete can only be used as hard-fill and reinforcing steel rod reclaimed. Plastics are recyclable only with difficulty and hence the major part of the total energy which is used to manufacture plastics is ultimately wasted.

If recycling of materials is to be optimised in industry, one must be able to interchange the concepts of waste and ore. Namely, a waste, where possible, must be identified as an ore for some product or material wherever it exists in our technical universe. In order to do this three main categories come to mind in classification for recycling. The system would be:

a) Economically feasible and in operation;

b) Technically feasible but currently economically unattractive;

c) Potential unknown.

Most metals are on the border line between a) and b). In the previous chapter it was shown that roughly 2 million tonnes of copper is missing in the U.K. If this copper was made available, it would amount to four years U.K. consumption and nearly

$$(2 * 10^6) * (16000 - 3000) = 26 * 10^9 \text{ kWh}$$

of energy could be saved.

COMPUTERISATION

The 1960's produced a snowstorm of mineral data, scattered through the literature and in private and public files. Although data are available within various governmental and commercial files to create a national data base, these data are not in a computerised storage and retrieval form which would allow for their utilisation. In addition, no one has attempted to conceptualise how the data might be organised for a national information service; what it would cost; and who its clientele might be.

To be useful, data must be accurate, timely and complete before processing. The basic task is to establish standard terms and parameters, methods of collecting data based on those standards and systems for organising or filing the data so that programs for processing or analysing it may be founded on reality.

A data bank on resources will point to areas for developing and producing material resources which a country needs to import; specify alternative sources of supply; and indicate when reserves may become depleted. The bank would serve as a source of historical data for interdisciplinary studies of the availability, depletion and utilsation rates of resources.

The data bank would continually update information and allow for instant integration of the latest reports. In addition, it would project trends and probable courses of action.

Another apsect of computerisation is the kind of work described in this thesis, whereby complex analysis is carried out on materials selection.

CHAPTER 10

CONCLUSIONS

Selection of engineering materials is often an extremely difficult task. The engineer or designer tends either to become specialised in a given materials field or he tends to use familiar materials.

Consider, for instance, the breakdown given in Table 10.1, as given in the Materials Selector Handbooks.[29,30]

With an approximate minimum of 10 properties for each material, there are therefore over 15,000 units of material data with which to cope. Further, the data are given for representative materials only and do not reflect, for instance, all possible heat treatments, composition variations or a wide variety of material supply sources. Allowing factors of 10^2 - 10^3 for other data sources, in all, there may be 2-to 20- million pieces of engineering material data.

TABLE 10.1

Types and quantities of engineering materials. (1971)

Class of Material	Number of subclasses
Iron and steels	360
Nonferrous metals	375
Plastics	200
Composites	150
Rubbers and elastomers	40
Ceramics, glass, mica	65
Fibres, wood, paper	150
Finishes and coatings	220
TOTAL	1560

Confronted with evaluating an almost endless number of materials, often covering a wide range of properties, use of a computer is the only logical answer.

The system developed at Aston uses the computer in three steps to analyse materials selection problems.

The first step is information retrieval and storage, without which no materials selection policy would work. Thus, the computer is used as a high-speed storage device, storing masses of information relating to materials data. The data has high-speed transfer capability, ease of access and is easy to up-date and edit.

The second step involes the computation. The materials property data is subjected to certain set mathematical and logical conditions and the results are stored for output.

The programs contained in the system are small compared to commercial and industrial programs and thus require very little computer power for operation.

The third step is also part of information retrieval and storage. The final function of the computer is to print the results to create a permanent record. The system can also be made to give any information relating to the overall materials selection program.

The system enables programs to be run in both, batch and interactive mode. In the interactive mode, inputing the properties sought along with the weighting coefficients and design constraints,enables the program to list within seconds the best candidates according to the chosen selection criteria.

The program output ultimately depends for its accuracy and usefulness on the input data. Hence, it is vitally important that the input data be absolutely accurate and up-dated. This has particular relevance to the price data; as market prices for materials fluctuate, it should be possible to up-date the price data without much modification. The data files are structured in a manner which make price data up-dating easy and fast.

The program with modification can also handle such diverse variables as location and quantity of mineral resources, alternative sources of supply, energy cost of materials and depletion and utilisation rates of strategic materials.

The programs are written in FØRTRAN for the ICL 1900 series computers. For use on other machines the programs will need slight modifications. The programs operate in single-user mode and require at least 8K core store.

The major significance of the results from this study is four-fold:

1. It forces the designer to define first the properties he is seeking.
2. It allows the materials engineer to optimise the selection of materials; taking into consideration variables such as, availability, energy cost, ease of manufacture etc.
3. It allows the designer to consider the properties relative importance.
4. With the aid of the programs he can rethink his choices and consider trade-offs. Judgment superposed on this approach thereby permits selection of the best candidate materials, so that detailed design work can proceed with a fair chance that the cheapest product will be made.

Materials selection by the interactive use of a computer can be successfully carried out for considerable financial gains by organisations which

1) already have their own computers with interactive facilities.

2) are in a position to rent interactive facilities from other computing agencies. This is possible due

to the low operating cost of this system.

This interactive system would be particularly beneficial for:

1) organisations carrying out a repeated search for new materials and products;

2) stockholding firms dealing with materials in an extremely unstable situation of supply, demand and prices;

3) design and materials consultants frequently associated with problems in product design and service;

4) materials manufacturers providing a customer-oriented technical service;

5) educational institutions providing courses in materials engineering;

6) research organisations to assess the techno-economics for any potentially new alloy or material.

This system of programs would not be economical for:

1) organisationa dealing with materials selection problems only occasionally;

2) organisations which hold criteria like reliability more important than costs and when the number of materials involved is few; unless extensive modifications are made to the programs.

Finally, the rationale and tools discussed in this thesis are effective in lowering production costs without sacrificing quality. The concept, though, is important as an on-going philosophy in terms of efficiency in materials selection, preparedness for change and conservation of strategic materials.

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APPENDIX 1

RELATIVE COST EQUATION

The equation is derived for solid cylinders in tension or compression.

Basic Strength Equation

Stress $Q = \frac{\text{LOAD}}{\text{AREA}} = \frac{W}{\frac{\pi D^2}{4}}$ W = load,   D = diameter

i.e. $D = \left(\frac{4W}{\pi Q} \right)^{\frac{1}{2}}$

For constant load, $D \propto \left(\frac{1}{Q}\right)^{\frac{1}{2}}$

Relative Diameter, $RD = \frac{D_2}{D_1} = \left(\frac{Q_1}{Q_2}\right)^{\frac{1}{2}}$

Assuming the stress in question is the Yield Stress, ys

Then, $RD = \left(\frac{ys_1}{ys_2} \right)^{\frac{1}{2}}$

Now, Volume = Area * Length

$$= \left(\frac{\pi D^2}{4}\right) * L$$

For constant L, $V \propto D^2$

Relative Volume, $RV = (RD)^2 = \left(\frac{ys_1}{ys_2}\right)$

Now, Relative Weight, $RW = RV * \left(\frac{S_2}{S_1}\right)$ S = density

$$= \left(\frac{ys_1}{ys_2}\right) * \left(\frac{S_2}{S_1}\right)$$

Relative Cost, $RC = RW * \left(\frac{K_2}{K_1}\right)$ K = cost

$$= \left(\frac{ys_1}{ys_2}\right) * \left(\frac{S_2}{S_1}\right) * \left(\frac{K_2}{K_1}\right) \qquad \ldots\ldots (1)$$

Basic Stiffness Equation

Modulus of Elasticity $E = \frac{\text{Stress}}{\text{Strain}}$

Stress $= \frac{W}{\frac{\pi D^2}{4}}$, Strain $= \frac{\Delta L}{L}$

$$E = \left(\frac{W}{\frac{\pi D^2}{4}}\right) * \frac{L}{\Delta L}.$$

i.e. $D \propto \left(\frac{1}{E}\right)^{\frac{1}{2}}$ for constant W and L

$$RD = \frac{D_2}{D_1} = \left(\frac{E_1}{E_2}\right)^{\frac{1}{2}}$$

and $RV = (RD)^2 = \left(\frac{E_1}{E_2}\right)$

and $RW = RV * \left(\frac{S_2}{S_1}\right) = \left(\frac{E_1}{E_2}\right) * \left(\frac{S_2}{S_1}\right)$

Relative Cost $RC = \left(\frac{E_1}{E_2}\right) * \left(\frac{S_2}{S_1}\right) * \left(\frac{K_2}{K_1}\right)$ . . . . (11)

Formulae for other loading conditions can be derived in a similar manner as above.

Hence, generalising, if

P = property of material

S = density of material

K = cost of material

$$RC_2 = \left(\frac{P_1}{P_2}\right) * \left(\frac{S_2}{S_1}\right) * \left(\frac{K_2}{K_1}\right)$$

APPENDIX 2

COMAS

APPENDIX 3

ENERGY CONTENT: A VITAL FACTOR IN ASSESSING MATERIALS DEMAND AND USE

Computer analysis speeds assessment of engineering materials

Copper and copper alloys in the UK

Consumption and losses, 1920-70

W.O. Alexander and P.M. Appoo