Appendixes

Appendix A.—Proceedings of a Workshop on Wear Control to Achieve Product Durability*

BACKGROUND

The Office of Technology Assessment, U.S. Congress, is analyzing the potential for materials conservation in the manufacturing and use of products. This assessment will determine at which stages in the materials cycle materials can be conserved and the potential economic and other impacts of such conservation.

One possible strategy for conservation would be to increase product life through improved corrosion, wear, and fracture control. To explore the conservation potential of increased product life, a workshop was held in Washington, D. C., on the 23rd, 24th, and 25th of February 1976. This document presents the proceedings of that workshop. (See table A-1 for Agenda.)

Wear control was chosen as an example of a technology which can increase product durability. Experts from the field of wear along with representatives from industry discussed the status of wear control technology and its application in the design and maintenance of a range of products (railroad equipment, automobiles, aircraft, propulsion, naval aircraft structures, metal-cutting machinery and tools, and heavy construction equipment).

*Excerpted from Martin J. Devine, Editor, *Proceedings of a Workshop on Wear Control to Achieve Product Durability, 1977,* Analytical Rework/Service Life Project Office, Naval Air Development Center, Warminister, Pa. 18974. The workshop was sponsored by the Office of Technology Assessment, U.S. Congress.

Table A-1.—Agenda for the Workshop on Wear Reduction
(Sponsored by the Office of Technology Assessment, U.S. Congress, February 23-25, 1976)

Theme: "Materials Conservation—improved Product Durability by the-Application of Wear-Control Technology"

Morning Session, Monday, Feb. 23, 1976
Chairman— Dr. Elio Passaglia

Opening Remarks— Purpose
M.J. Devine
Office of Technology Assessment

Welcome
Emilio Q. Daddario, Director
Office of Technology Assessment

Materials Program Overview
A. E. Paladino
Office of Technology Assessment

Workshop Background
E. Passaglia
National Bureau of Standards

Session A.1

Session Chairman:
Dr. J. B. Wachtman, Jr.
National Bureau of Standards

Wear Technology
M. Peterson
Wear Sciences

Incentives for Longer Product Life
W. *Flanagan*
Center for Policy Alternatives
Massachusetts Institute of Technology

Manufacturing Technology for Materials Conservation
R. Matt
Aerojet General

Economic Factors in Product Durability
C. *H. Madden/R. S. Landry*
Chamber of Commerce of the United States

Technology for Estimating Product Durability
J. John
IRT Corporation

Financial and Taxation Implication of Equipment Replacement
P. Lerman
Fairleigh-Dickinson

Safety Aspects of Improved Product Durability
H. *Azzam*
Interrad Corporation

Automobile Durability
D. Barrett
Ford Motor Company

Economic impact of Tribology (U.K. Experience)
D. Scott
National Engineering Laboratory/ Wear Publications

Improved Product Durability Navy Program
A. Koury
Naval Air Systems Command

Bell Systems Wear Control Program
G. *Kitchen*
Bell Laboratories

Life-Cycle Costing
T. Brennan
Naval Air Development Center

National Science Foundation Tribology Program
M. Gaus
National Science Foundation

Advanced-Research Projects Agency Wear Program
E. Van RuethlR. Miller
Advanced Research Projects Office
Office of Naval Research

Maintenance Improvements Within the Airlines
T. Matteson
United Airlines

Session A-2 (Evening)

ASME Wear Control Handbook
W. *Wirier*
Georgia Institute of Technology

ASLE Replacement Costs Survey
R.L. Johnston
Rensselaer Polytechnic Institute

ASTM Wear Program
K.C. *Ludema*
University of Michigan

MFPG— Wear Control
E. Klaus
Pennsylvania State University

Session B—Seminars

1. Automobiles/automobile spare parts
2. Naval aircraft structures/ materials/components
3. Aircraft/aircraft propulsion systems
4. Metal cutting machinery and tools
5. Railroad rolling stock
6. Construction equipment
   a. Track-laying tractors
   b. Rubber-tired earth-moving equipment

SOURCE: OTA.

The workshop explored whether product life could be extended by improved wear control and what would be the cost and other consequences of such extension. These questions were explored from various viewpoints: 1) the status of technology to support increases in durability, 2) economic considerations, 3) current policies and programs, and 4) the methodology and information available.

The fact that only a few products were studied limits the conclusions. However, these products are sufficiently representative of a cross section of industry so that the question of product durability could, indeed, be qualitatively explored.

FINDINGS

Methodology of Economic Appraisal

A large amount of economic data was presented at the workshop establishing that the real cost of wear can be evaluated for a range of products and/or industries. Such information is essential to judge the need for and the significance of new technology.

No standard techniques for acquiring the real costs of wear are available. It is not apparent that a standard technique would suffice; each product might require its own separate analysis.

Standard methodologies are available for economic appraisals, and these could be applied to wear, corrosion, or any other degradation process. Some illustrative procedures are: 1) National Association of Corrosion Engineers (NACE) standards for corrosion economies, and 2) lifecycle costing.

Wear Costs and Consequences

It is clear from information provided during the presentations and seminars of the workshop that: 1) data on the cost of wear in several different product areas are available, and 2) that cost appraisal standards or techniques have been developed for this purpose. As expected, the greater part of this information is available from Government sources. However, further contacts with representatives from other product sectors are expected to yield additional cost data.

At the workshop, examples of specific cost data were presented. These data, if shown to be generally applicable, would in themselves provide strong economic incentives for improved product durability and therefore, for increased materials conservation. It is recommended that such data be collected. A major data source would be the military, which retains computerized malfunction maintenance records. Some examples of specific cost data discussed at the workshop include:

- **Data on Wear Costs in Naval Aircraft.** Data provided on the wear costs in naval aircraft show that the scheduled maintenance for wear for one aircraft amounted to $67 per flight hour, unscheduled maintenance $140 per flight hour, and overhaul $36.87 per flight hour. Thus, the total cost of wear is $243.87 per flight hour. This can be compared with the cost of fuel of $376 per flight hour. Data was also provided on the lifecycle costing of naval aircraft tires. The Navy uses 20,500 tires per year at a cost of $3.48 per landing for a total yearly cost of $1,853,200.
- **Data on Wear Cost of Diesel Engines.** Data provided on the diesel engine maintenance and repair for 20 ships (120 engines) indicated that wear costs were $38.92 per ship per hour. Fuel costs were $75.00 per ship hour.
- **Data on Wear Costs of Tools.** The purchased cost of high-speed steel tools (U. S. A.) was $470 million per year; carbide tools $435 million per year, It was also learned at the workshop that the best estimates of the cost of wear came from users rather than manufacturers of products. The relationship of these costs to manufacturing design decisions was not defined. However, where responsibility is divided between the user and the manufacturers the chief concern of the latter is marketability with durability being an indirect consideration.

It is clear from the data presented that ignorance as to the wear control costs a significant amount not only from the resultant necessity to overdesign but also from the discard of components. Another important factor regarding wear costs was that few product areas use lifecycle costing. And those areas that do use lifecycle costing employ it only at certain stages of decisionmaking. Also, there is little agreement as to how the appropriate interest rate should be calculated in order to compare different development and procurement plans from the present-worth point of view. Present high rates of interest tilt decisions to labor-intensive rather than capital-intensive projects, with a resulting loss in concern for product durability and hence wear control. The possibilities of technological obsolescence further aggravate the problem. Those responsible for development and procurement are frequently career people who will move on and whose current responsibility is to keep down capital cost, not to assure succeeding low-cost maintenance programs.

Thus, the above findings, which are but representative of the material that was covered during the workshop, all point to the fact that wear considerations cannot be isolated from the other considerations that go into the design of consumer products. Wear control simply does not appear to be a primary goal anywhere. Since responsibility for wear control changes hands as the product changes hands during its lifecycle, lifecycle costing will not be used. The heart of the analysis of wear and wear programs, or the lack of them, lies in the understanding of the objective functions of the producers and the consumers as well as the constraints under which they operate.

State of the Technology

It was pointed out at the workshop that tribology, the branch of science concerned chiefly with improvements in wear control for greater product durability, has not received sufficient attention in U.S. academic, industrial, and Government institutions. The benefits of increased emphasis have not been defined sufficiently by the scientists involved. Further research in the field of wear could result in improved techniques to control damage resulting from sources such as contamination, vibration, misalignment, etc. Thus, the most pressing need is for a centralized source of information on wear control technology which can be effectively used in product design.

At the same time, technology does not limit product durability, since many newly developed techniques are now currently used by industry. implementation of this technology in design and maintenance varies from one product to another and one industry to another and is generally limited by many other factors such as cost-effectiveness.

At present, several professional and technical societies sponsor activities which contribute to and facilitate efforts to control wear. Some examples of these societies are as follows:

- American Society of Lubrication Engineers (ASLE) documentation of wear and failure costs;
- American Society for Testing and Materials (ASTM) Committee G-2 on erosion and wear;
- Mechanical Failure Prevention Group (MFPG) sponsored by the National Bureau of Standards; and
- American Society of Mechanical Engineers (ASME) Lubrication Division and Research Committee on Lubrication.

Existing technology is shared by various manufacturers or industries by communication with each other through these societies.

It was also noted that support programs oriented toward tribology and wear control are sponsored by the National Science Foundation, the Advanced Research Projects Agency of the Department of Defense, the Office of Naval Research, the National Bureau of Standards, and the National Aeronautics and Space Administration.

Product Durability

Concise definitions of product durability are not available; however, it relates both to the maximum life achieved and the ability of the product to survive both normal and abnormal usage. High product durability appears desirable from the point of view of reliability and materials conservation. In practice this is usually achieved at a higher purchase price. Secondly, longer life products may have a tendency to reduce the application of technical innovations.

The conclusions of this workshop indicate that considerable improvement in the durability of some products can be achieved if desired. The question which ultimately must be answered is whether increased durability *is worth the added costs* to the consumer and whether it *can be effectively achieved*. Product durability is the prerogative of the consumer. It is available if he wants and demands it.

During the workshop several different actions were discussed which could lead to improved durability.

- Industries with close working relationships between manufacturer and user, e.g., the Bell System and the heavy construction equipment industry, could provide an active feedback system yielding improved durability of products.

- Inspection requirements and inspection frequency may be utilized to achieve increased useful life of products, e.g., based on data from Sweden, and comparison of States in the United States, with and without periodic motor vehicle inspection (PMVI), median car life was shown to be extended as a result of PMVI programs.

- At the workshop, active product-durability programs were reported by the Navy Department. These programs, which have been designated the analytical-rework and service-life programs (ARP), are concerned with: 1) reducing the cost of aircraft maintenance; 2) applying new technology to aircraft repair-rework aimed at increasing service life and improving performance/safety /quality; 3) conducting the optimum strategy for a more efficient application of materials and processes generated under ARP; and 4) increasing component and product durability through the application of the rapid and precise nondestructive inspection techniques (with the minimum disassembly of components) currently available.

However, product life is often not limited by product durability. For example, many products are removed from service which still have some remaining useful life, Among the reasons for early product retirement are: 1) cost of operation or repair, 2) productivity or functionality, 3) esthetics, 4) accidents, 5) physical loss, and 6) style preferences. Nevertheless, the extent to which useful product life can be extended without decreased product durability is not known. The primary factors that can affect useful product life are: 1) use, 2) environment, 3) maintenance, 4) procedures, 5) personnel qualifications, 6) inherent durability, 7) design, 8) manufacturing process, and 9) material characteristics.

In addition, product durability is only one approach to materials conservation. Due consideration should be given to other approaches. At this workshop, reducing materials wastage in manufacturing was frequently cited as one means of achieving materials conservation and should be investigated.

Capital and Labor

From the manufacturer's point of view there are many factors in the development of a product: performance, safety, development cost, schedule, energy consumption, maintenance costs, first costs, appearance, styling, and durability. These factors must be balanced in such a way as to find widespread consumer acceptance. Where durability has a high value to the consumer, that attribute will be accentuated in the product. Even without this demand, the manufacturer has compelling reasons for maintaining high durability standards. First and foremost, a good service record for durability helps to *ensure* that the *customer will return.* This is particularly true for industrial consumers who maintain detailed maintenance records and perform component evaluations.

The manufacturers in general cannot design for a given product life. However, they do know and keep records of service problems (warranty or otherwise) and strive to eliminate these. Where there is a close *working relationship* between the manufacturer and the user, more success and greater durability result. However, the manufacturer is limited in this regard since he seldom has information on the life of a product or a component based upon the service condition in which it operates. Thus, it can be concluded that the acquisition and distribution of such data would provide a necessary base to initiate the engineering development actions for achieving increased product durability.

The results of this workshop suggest that it is primarily the consumer who determines product durability. First of all, in a free-market system, products reflect consumer demands. Secondly, evidence presented at the workshop suggests that many failures are service-related and that product durability is often a function of the kind of usage and maintenance it receives rather than its design-related deficiencies. Market surveys have shown that product durability is very high on the list of customer wants. However, consumers are generally not willing to pay more for increased durability and often when given the choice, they select the lower cost, less durable items (e.g., power tools are often made in different quality lines; even professionals often select lower cost quality). It was further pointed out at the workshop that even sophisticated corporate "buy" decisions of capital equipment are based on maximizing the immediate cash flow (net present value computation) to the company. Thus, longer life at increased cost achieved by greater durability will not be sufficient justification for purchase. The incentive to buy must be lower operating or maintenance costs since these directly influence cash flow.

Thus it seems clear, based on the conclusions of this workshop, that one point of action for increased durability is the consumer, and two areas of appropriate investigation concern maintenance cost reductions and improved durability at equal cost. Programs which identify and correct service related malfunctions, for example, Navy's ARP, should be encouraged since they achieve the above mentioned goals as well as provide reciprocal information to the manufacturer.

Another incentive for the consumer would be the further acquisition of cost data. At this workshop, wear costs were shown to be surprisingly high in a variety of product areas. The same can undoubtedly be said for corrosion, fatigue, and other durability factors. If consumers realized these costs, they might be prompted to take remedial action. It was also pointed out at the workshop that there are acceptable techniques (e.g., cost modeling, economic system analysis) for both assessing durability (wear) costs and in determining how changes in durability would result in system cost savings for a number of products.

The Lifecycle

Product life is not a clear concept. As an individual product reaches the end of its useful life (as determined by its owner), it is not necessarily scrapped. A product may be reconditioned or rebuilt. Or, when a product is finally considered unusable, it may be used as a spare part for a similar model. Thus, it is possible to recycle parts as well as materials. It was also learned at the workshop that scrapped products and components could not be considered waste. For example, the majority of workshop participants felt that for those products considered, the recycling of materials reached 80 to 90 percent. Thus, while recycling can sometimes result in a combination of materials having different properties, it cannot be considered waste. Furthermore, scrapped products often find value as completely different products.

It should also be noted that the workshop participants expressed one area of concern regarding product life. It was reported that inventories for spare parts often reach a high of 20 to 1. Such an excess in inventory could cause severe economic loss. It was decided that this subject should receive careful consideration in the final assessment on materials conservation.

Materials Wastage

It was also found at the workshop that except for spare parts, wastage due to poor product durability seemed small for those products considered. Those products that do not enter the spare parts inventory are often recycled. And, as the supply of material decreases, one would expect more use of spares and more recycling. It was felt by the workshop participants that specific areas of possible wastage should be identified and corrections should be made when possible.

Significance for Research

Although this workshop was called to explore the questions of wear, product durability, and materials conservation, certain implications for research become obvious when that work is taken in its broadest context. A great proportion of the research undertaken in this country has been related to innovation, that is, finding new ways to accomplish a stated objective. Composite materials are a good example of this type of research. Much less attention has been devoted to disciplines such as wear, mechanical failures, corrosion, fatigue, etc., which affect our knowledge of such factors.

It is clear from the results of this workshop that the wearing of materials produces significant costs in the overall materials cycle. And even more particularly, wear degrades performance so that much of the original value of the product is lost. An emphasis on wear research, particularly those studies which emphasize predicitve capability, would be desirable. This emphasis need not be limited only to wear but to all life-limiting technologies. Product durability and life prediction are basically the same concept and increased durability will not be attainable without better concepts of component life.

Improved knowledge of component life and the factors which affect it would not only lead to improved durability but allow tradeoff decisions to be made relative to such factors as materials conservation, lifecycle costs, reimbursement for defective products, maintenance costs, net value, and depreciation. At the present time, these are largely guesses.

Life prediction need not be *a priori*. Diagnostic techniques such as those being used on naval aircraft should be further developed. Estimates of product life remaining allow "use" decisions to be made which result in longer life and improved utilization. Research emphasis on this subject could lead to considerable improvements in materials utilization.

A greater priority could be given to research that extends product life. That is,

1. Improved research and knowledge on what malfunctions actually limit product service life.
2. Increased research on those technologies responsible for life determination such as wear, fatigue, etc.
3. Increased support of research that allows estimates or predictions to be made of product and component life.
4. Expanded research on the subject of diagnostic instrumentation that will allow residual life estimates to be made.