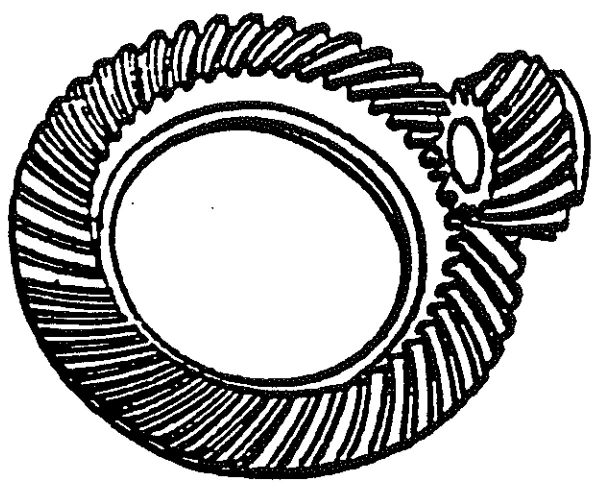
U.S. DEPARTMENT OF COMMERCE
BUREAU OF EXPORT ADMINISTRATION
OFFICE OF INDUSTRIAL RESOURCE ADMINISTRATION
STRATEGIC ANALYSIS DIVISION

NATIONAL SECURITY ASSESSMENT OF THE U.S. GEAR INDUSTRY



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NATIONAL SECURITY ASSESSMENT OF THE U.S. GEAR INDUSTRY

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EXECUTIVE SUMMARY

National Security Assessment of the U.S. Gear Industry

This study was conducted at the Department of the Navy's request by BXA's Office of Industrial Resource Administration to assess the gear industry's ability to meet national security needs. The report analyzes the industry's historical performance, and assesses production capabilities under both current conditions and in a national security emergency. Results of this report will be shared with appropriate officials within the Department of Defense and other national security agencies.

The continued viability of the domestic gear industry is critical to U.S. national security and economic competitiveness. Gears are basic components of most industrial machinery, construction and agricultural equipment, motor vehicles, ships and aircraft of all types. From a military perspective, gears are critical to the performance and construction of nearly all weapon systems, either as components of the weapons themselves or of the many different machines required to produce a particular system. A domestic gear industry provides a secure source of supply and maintains a U.S. presence in the continuing development of gear technology. As a highly specialized intermediate product, gear customers benefit strategically from a domestic source by having greater control over product quality and delivery schedules, and lower transaction, transportation and inventory costs.

The U.S. gear industry experienced significant decline during the 1980s. As producers of an intermediate product, gear manufacturers can perform no better than their end-markets. As a result, gear industry sales and profitability declined in the early 1980s as most gear end-markets experienced their worst contraction of the post-World War II period. Many of these gear-consuming industry sectors only partially recovered with the general economic expansion that followed. Since the late 1970s, for example, shipments of farm equipment have dropped 63 percent (in constant 1988 dollars) from $18 to $6.6 billion; shipments of construction equipment fell 50 percent from $24 to $12 billion, and shipments of oil field equipment collapsed from $11 to $3 billion, down 73 percent. The gear industry's decline was compounded as imports of products containing gears increased in nearly every sector, real interest rates remained high, and certain investment incentives were removed from the tax code.

The outlook for the 1990s is for continued decline in gear end-market industries. The combined passenger car production of General Motors, Ford, and Chrysler, for example, declined 38 percent over the past five years, and is expected to remain flat over the next several years. Similarly, in the marine gear sector, the last order for a merchant vessel placed with a U.S. shipyard was in 1984. Although the U.S. Navy placed a 20-year high 32 orders for new war vessels with private shipyards in 1988, a downturn in Navy business can now be expected. The outlook is for a comparable contraction in the overall aerospace gear market, as defense spending is reduced and gear-intensive helicopter orders decline.

The gear industry is commonly divided into four major market sectors based on end-use orientation. These include the motor vehicle, industrial, aerospace, and marine gear sectors. The motor vehicle gear sector, with 1988 revenues of $10.2 billion, represents about 76 percent of industry shipments. Industrial gear shipments of $2.1 billion represented a further 16 percent, with the aerospace ($725 million) and marine gear ($356 million) sectors representing five and three percent of industry shipments, respectively. The aerospace and marine gear sectors produce the highest precision gears; however, and devote a significantly higher share of their production (65 percent of aerospace gear shipments and 35 percent of marine gear shipments) to defense end-users.

By most measures (e.g., shipment volume, employment, investment), 'captive' producers dominate the gear industry. Captive producers (i.e., those dedicated to providing a single customer's needs) account for 78 percent of gear industry shipments - ranging from 23 percent of marine gear shipments to 90 percent of motor vehicle gear shipments. Given sufficient volume, it is cheaper to produce gears in-house than purchase them from outside sources. Further, end-users generally prefer to deal with captive producers as gear design and engineering most often require close technical coordination between supplier and user to produce a customized gear system for each model of final product.

Gear industry statistics are split between several unrelated SIC industry codes, making it difficult to measure industry-wide economic performance. Although the survey conducted for this study provides comprehensive data for the 1984-1988 period, earlier data is only available for the industrial and marine gear sectors. Industry trends noted below have been calculated based on available data.

- **<u>Industry shipments improved in 1987 and 1988 but remained below earlier peaks reached in 1979-1980</u>. Shipments fell 35 percent from 1980 to 1983, but have recovered about 10 percent since that time. Motor vehicle gear shipments, for example, rose 15 percent from 1984 to 1988 on the strength of increased gear-intensive truck and van production even as passenger car production declined.**

- **<u>In 1988, the gear industry experienced a trade deficit of about $318 million</u>. Most notably, the trade balance in the industrial gear sector continues to deteriorate at an alarming rate, with imports more than doubling between 1984 and 1988 - increasing from $266 million to $561 million. Trade in other sectors has improved slightly or remained stable over the same period.**

- **<u>Industry employment has declined since 1980</u>. By 1983, total employees had fallen by 31 percent, with production workers down nearly 35 percent. Total industry employment and number of production workers both continued to fall through the 1980s, down a cumulative 37 and 40 percent respectively by 1987. Moderate productivity increases led to further decreases in employment levels even as shipments stabilized in the late 1980s. Gear wage rates remain 64 percent higher than the average for all U.S. manufacturing.**

- **<u>Gear industry pre-tax profitability declined each year from 1984 to 1988, largely due to major new expenses incurred by the motor vehicle gear sector</u>. Profitability has been very unevenly distributed, reflecting the segmented and diversified nature of the business.**

- **<u>The largest U.S. gear producers (those with more than 500 employees) were disproportionately damaged by the industry's decline in the 1980s</u>. Large firms' share of industry shipments declined from 40 percent in 1977 to only 20 percent in 1987. Large gear firms typically operate in both nationwide and international markets, and therefore are more susceptible to international competitors. Decline of the largest firms will likely lead to further decline in the industry's competitiveness as large firms have historically devoted a relatively higher percentage of their sales to investment.**

Investment in plant and equipment has been inadequate for the gear industry to remain internationally competitive, and U.S. gear making equipment has steadily gotten older since the end of World War II. Investment has fluctuated in tandem with shipments from 1972 through 1987. This reflects the industry's preference for equity (as opposed to debt) financing. As in other industries with volatile business cycles, many firms avoid carrying high fixed costs, of which debt financing would be a major component. Among other of the numerous and complex reasons for the industry's lagging investment have been: (1) existing over-capacity with an outlook for continued flat growth; and (2) management's resistance to change and lack of knowledge about advanced technologies.

The increasingly global nature of the industry makes it imperative that gear firms invest in new machinery to remain competitive. Delays in acquiring state of the art equipment also delay the training of the workforce in its usage. At the same time, it is increasingly expensive to purchase and outfit new gear cutting and gear grinding machine tools. Relatively higher interest rates in the United States add further to this high cost. Many smaller gear companies have lacked the sales volume to afford or justify investment in new equipment, and have relied extensively on aging and/or used equipment.

Gear industry investment in research and development (about one-half of one percent of sales in 1988) has also been inadequate. In 1988, the average U.S. manufacturing firm spent almost three times as much as the average gear firm on R&D relative to sales, four times as much relative to profits, and 4.6 times as much per employee. Gear-related R&D undertaken in other countries, notably in Japan and West Germany, has long surpassed the U.S. effort, and firms in these countries now set the world quality standards in many gear product areas.

Alternative technologies have further eroded market opportunities for the U.S. gear industry. Heavy equipment (and some lighter equipment) manufacturers have been expanding their use of hydraulic or pneumatic "fluid power" systems, especially to transmit higher power ratios. Fluid power transmission systems demonstrate superior flexibility, but generally remain less efficient and more expensive than gear systems. Electronics, such as digital clocks and timers, have also displaced many smaller sized gears.

A prime example of the move away from gears has been the switch to servo-drives in the machine tool industry. Servo-drives can be controlled with greater precision, and deliver variable power as needed. In extreme cases as many as 100 gears (50 sets) have reportedly been displaced on a single machine.

Increases in machinery productivity have also served to decrease market opportunities for the gear industry. A single machining center, for example, can replace as many as 12 conventional machine tools, and in so doing displace many gears.

The decline in gear industry competitiveness has led, in part, to a situation where the industry would be unable to meet anticipated requirements for gears in a national security emergency. Specifically, the defense-intensive aerospace and marine gear sectors would not be able to reach emergency surge and mobilization production targets. Conversely, the less defense-intensive industrial and motor vehicle sectors should be able to meet surge and mobilization gear requirements on a selective basis. Some firms in these sectors will need assistance, however, especially if asked to convert a major portion of their production from civilian to defense production. Consistent with guidance from DOD's Joint Group on the Industrial Base, surge targets were defined as a doubling of defense production in six months, and mobilization targets as a four fold increase in defense production in two years.

Within existing manufacturing facilities, the constraints to increasing production cited most frequently were heat treatment and (post heat treatment) grinding operations. The availability of forgings and castings blanks from which to make gears from outside vendors was identified as the major material procurement problem. Excess capacity is expensive to maintain in such capital-intensive supplier industries, and has been eliminated by many manufacturers. We further anticipate that the gear industry would face a shortage of skilled labor during a surge or mobilization. To complicate the matter, other defense-critical industries expected to accelerate production during a national emergency would be seeking to hire the very same categories of machinists and machine operators expected to be needed in the gear industry.

<u>We recommend the following program of industry-specific actions targeted to the gear industry's unique needs</u>:

- o Introducing interested companies to industry support programs in Commerce's Technology Administration including: shared flexible centers for integrated manufacturing, R&D consortiums, vertically-oriented strategic partnerships, and development of a closer working relationship with the National Institute of Standards and Technology;

- o Maximum use of Defense's Industrial Modernization Incentive Program to assist in industry modernization;

- o Expanding the scope of the Defense Logistics Agency's Instrumented Factory program to include the entire gear sector and infrastructure;

- o A joint Defense/Commerce effort to ensure the industry's problems are being adequately addressed by existing government programs;

- o Encouraging gear industry consolidation into larger more technically efficient firms that can both afford and justify investment in the latest technologies; and

- o A joint industry/government effort to rectify current data shortcomings and to explore the need for better government monitoring.

INTRODUCTION

Background

The U.S. Department of Commerce, Bureau of Export Administration (BXA) is delegated authority under the Defense Production Act of 1950, as amended, (DPA) and related Executive Order 12656, to identify critical industries; assess their capabilities to meet national security needs; evaluate current and potential production bottlenecks; and propose remedial action when necessary. The Office of Industrial Resource Administration (OIRA), Strategic Analysis Division is responsible for conducting these national security industrial assessments.

In the course of an industry assessment, particular consideration is given to such factors as: industry structure, raw material availability, investment, foreign sourcing and dependency, labor and material cost, productivity, technological factors, trade patterns and market trends, and international competitiveness. Necessary data are collected by the Strategic Analysis Division from the private sector under authority of Title VII of the DPA. Independently, as well as in cooperation with the Armed Services, OIRA has completed a number of national security assessments including studies of the precision optics, gas turbine engines, anti-friction bearings, machine tools, industrial fasteners, plastic injection molding machines, investment castings, and the crude oil and petroleum products industries.

In the Summer of 1988, OIRA was requested by the Office of the Deputy Chief of Naval Operations to assist the Department of the Navy in a production base analysis of domestic naval gear manufacturers. The Department of Commerce accepted the request, but expanded the scope of the assessment to cover all defense related and commercial manufacturers of gears.

Concern about the availability of gears within the Department of Defense (DOD) had developed from increasing reports of excessively long lead times for the product, primarily in the aerospace gear sector. In addition, the continued erosion of the shipbuilding industry raised concerns about the economic survivability of main reduction gear manufacturers in the United States. Three separate DOD studies identified the deteriorating condition of portions of the domestic gear industry and potential logistics problems for defense. These studies are:

- <u>Assessment of Domestic Capabilities to Produce Large Hardened and Ground Reduction Gears</u>, March 1986, by the Naval Sea Systems Command (Sea 907)

  In late 1986, the Navy Department established an "informal" domestic content rule for the purchase of large reduction gears used on naval ships, based partly on the findings of this study. The last order for a merchant vessel placed with a U.S. shipyard was made in 1984, which left the U.S. Navy as the only remaining purchaser of large reduction gears in the U.S. market.

- <u>Production Base Analysis of the Domestic Gear Industry</u>, December 1986, by the Defense Construction Supply Center, Columbus, Ohio

  This study identified a general deterioration in the defense industrial base for gearing, and a significant increase in foreign penetration of the U.S. market. The study was based on survey responses from 61 domestic gear producers. Recommendations included establishing Industrial Modernization Incentives Programs (IMIPs) with the industry, encouraging more research and development, providing investment incentives and low interest loans. The study also called for an examination of import penetration of gears, possible dumping by foreign firms, and the impact of gearing imports on the domestic industry.

- <u>Manufacturing Technology Research Needs of the Gear Industry</u>, December 1987, by the Illinois Institute of Technology under contract from the Defense Logistics Agency, Alexandria, Virginia

  This study focused on the aerospace gear sector. Problems were identified with the production process, notably heat treating which for gears is technically very difficult and the cause of many rejected parts. The study also noted the widespread lack of modern production methods, long lead times, and a need for improved management. The Defense Logistics Agency responded by allocating $17 million over five years for the creation of an "Instrumented Factory" (INFAC) to improve manufacturing techniques and encourage modernization of the industry. INFAC is located at the Illinois Institute of Technology in Chicago and is expected to be operational in the Spring of 1991.

Simultaneous with the Commerce study the United States International Trade Commission (ITC) received a request from the Office of the U.S. Trade Representative to "conduct an investigation and prepare a report on the competitive position of the U.S. gear industry in U.S. and global markets." The ITC accepted the request and announced initiation of investigation number 332-275 in the Federal Register on April 27, 1989. With a one year deadline, the ITC published a final report in April, 1990, titled, "Competitive Position of the U.S. Gear Industry in U.S. and Global Markets" (USITC Publication 2278).

The Commerce Department national security assessment and the ITC competitive assessment would normally be conducted almost entirely independent of one another. However, because the firms to be surveyed and the information overlapped for the two studies, it was agreed after detailed negotiations between Commerce and ITC that only one survey instrument would be used, so as not to unnecessarily burden the industry. In August 1989, a jointly prepared survey questionnaire was sent to domestic gear producers by the ITC, informing the industry that certain data would be shared by the two agencies.

The ITC received the returned surveys and provided OIRA with the raw data. From this data, each agency created a separate data base. Supplementary information was obtained from visits to several gear production plants and interviews with industry officials and industry experts within and outside the government.

Scope

This national security assessment benefitted from the abundance of information that appeared in the ITC-332 study, and further by the many insights provided by the staff at the ITC. This assessment initially was to build on the three referenced Defense studies by looking at the broader picture, including both the commercial and international sectors. However, this assessment was abbreviated in certain areas so as not to duplicate and overlap with the ITC product.

This report includes a section describing the publicly available statistical information collected by the Commerce Department's Bureau of the Census under the Standard Industrial Classification

(SIC) system, which has been a major but incomplete source of gear statistics. Also, the structure of the industry is discussed at length to familiarize the reader with the unique features of the industry, and to lay the foundation for discussing structural impediments to investment in later sections.

A historical perspective is provided using mostly publicly available information to show where the industry has been, and to provide insight into the industry's decline during the past decade. This is followed by a section on the recent performance (1984-1988) of the gear industry by major gear sector based on industry survey responses. This section covers shipments, imports and exports, profitability, employment, investment, market volatility, research and development, and trends in foreign ownership of U.S. gear manufacturing facilities. Next, the production capabilities of the industry are discussed, including capacity, gear sizes and precision, and lead times. This leads into the section on surge and mobilization capabilities. The final section reviews the report's findings and makes recommendations to rectify identified problems.

INDUSTRY DESCRIPTION

Overview

As basic components of most industrial machinery and equipment, construction and agricultural equipment, motor vehicles, ships and aircraft of all types, gears are critical to the industrial base. From a military perspective, gears are critical to both the construction and performance of nearly all weapon systems, either as components of the many different machines required to produce a particular weapon system, or as components of the weapon systems themselves. Gears are produced in endless sizes and geometries, and can be found in virtually any factory or major weapon system in the world.[1]

It is critical to maintain a viable domestic gear production capability for both national security and economic competitiveness reasons. A domestic gear industry provides a secure source of supply for both military and civilian applications, and maintains a presence in the continuing development of gear technology. As a highly engineered intermediate product, gear customers benefit strategically by having greater control over product engineering and design, quality, and delivery schedules, and by having less exposure to exchange rate fluctuations. Gear customers also benefit directly by the close proximity of a domestic gear industry in terms of lower transaction, transportation and inventory costs. Finally, in the event of a national emergency, it would take several years to reestablish U.S. gear production capacity.

The gear industry is commonly divided into four sectors, primarily based on end-use orientation. The largest sector by far is the motor vehicle sector, which accounted for over 75 percent of the business in 1988 with sales of $10.2 billion. The industrial gear sector, with sales of $2.1 billion in 1988, is the second largest and most diverse in selling gear products to a wide range of machinery and equipment makers. The other two are the aerospace and the marine gear sectors.

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[1]For a detailed description of the various types of gears, please refer to Appendix A - Product Description.

The aerospace and marine sectors produce the highest precision gears in the industry, and are the most important to defense. Combined military-related shipments reached $601.8 million in 1988, a year in which the aerospace sector shipped $725.1 million and the marine sector shipped $356.3 million.

Classification

Analysts have noted the difficulty in statistically tracking the gear sector. Many have expressed the need for better statistical coverage of gear related imports and exports, and perhaps a consolidation of domestic related statistics which are currently contained in several different, and unrelated statistical categories.

The SIC system of the United States classifies the four gear sectors within three four-digit SIC industry codes. Establishments primarily engaged in manufacturing automotive power transmission equipment are classified in industry SIC 3714 - Motor Vehicle Parts and Accessories. However, SIC 3714 includes a great variety of diverse items in addition to auto transmissions, that conceals the gear data.

In 1982, the Bureau of the Census created a more narrowly defined five-digit product class 37146 - Drive Train Components, new, except Wheels and Brakes - that includes motor vehicle transmissions. This class was further divided into seven-digit product codes that include separate codes for transmissions, gear shifters, drive shafts, universal joints, axles and parts, and a few other items. Detail at the seven-digit product level is published only once every five years in the Commerce Department's Census of Manufactures. However, five-digit product class data is published in intervening years in Commerce's Annual Survey of Manufactures. For purposes of estimation, the transmission content within the five-digit class has been fairly consistent at about 60 percent of the total.

Since the seven-digit product data is so narrowly defined, some data items may be suppressed to protect proprietary information and therefore make the data less usable. However, in 1987, enough data was available so that transmissions of all types could be totalled, and these came to about $9.2 billion. This compares with $9.8 billion estimated from the ITC/DOC industry survey used for this assessment, which is less than a 7 percent difference. The difference may be partly explained by the composition of the numbers. The Census number is a "product" total, while the OIRA number is an "industry" total. This means for example, that if Caterpillar Corporation reports shipments of gearing for on-highway vehicle use, Census would count the shipment as motor vehicle gearing. However, OIRA classified all of Caterpillar's shipments in the industrial gear sector because a majority of the firm's gear production is for heavy equipment - an industrial market.

Establishments that manufacture aerospace gearing are classified in SIC 3728 - Aircraft and Engine Parts. At the four-digit level the aerospace gear information, as with auto transmissions, is overwhelmed by the many other parts that make up this category, and cannot be easily estimated. However, in the five-year Census of Manufactures, aircraft mechanical transmission equipment (AMTE) is captured in two seven-digit product codes. Product code 37281 13 is AMTE for military aircraft and all other aircraft built to military specifications. Product code 37281 15 is AMTE for civilian aircraft.

In 1987, Census reported shipments in 37281 13 totalled $690 million, and 37281 15 totalled $356.1 million. The combined total of $1,046.1 million is over 40 percent larger than the $746.6 million in aerospace gear shipments recorded from the ITC/DOC industry survey data. The explanation for the difference is probably related to differences in composition of the two numbers, but cannot be verified. The composition of the Census number is not publicly available, but likely includes many items not counted for purposes of this study.

The five-digit product class (37281) includes AMTE and several other items such as hydraulics and landing gear which over time do not change in a predictable or consistent manner relative to each other. It is, therefore, difficult to accurately estimate aerospace gearing from the SIC five-digit level as currently constructed.

Establishments primarily engaged in manufacturing industrial or marine gears are classified in SIC 3566 - Speed Changers, Industrial High-Speed Drives, and Gears. The Office of Management and Budget established SIC code 3566 in its present form in 1972. Prior to the 1972 change, the industrial and marine gear information was part of a more broadly defined SIC code called "Mechanical Power Transmission Equipment, Except Ball and Roller Bearings." From this information, it is possible to reconstruct gear shipments for these sectors from the 1950s forward that correspond to the current SIC 3566.

Since the establishment of SIC 3566, more comprehensive and detailed statistical information for these sectors has been collected on an annual basis. This information includes the number of establishments, production workers, production worker hours, wages, cost of materials, shipments, value added, new investment, and other data.

However, users of this information should be aware of several accounting problems which generally apply to all SIC codes. First, as intermediate products gears may be shipped several times before becoming part of a final product. Many gear producers classified within SIC 3566 ship product, such as open gears, to another firm, such as one that assembles gearboxes, also classified in SIC 3566. Since gear related shipments by both these firms will be counted, it results in some double counting.

Second, many plants produce open gears and assemble them into gearboxes at the same location. In addition, a few operations assemble gearboxes and mount them on final machinery or vehicles in the same plant. However, Census only captures shipments that leave the factory. Thus, if gear production and its mounting on a tractor takes place in the same factory, Census will count the tractor, but not the gearing. In this instance, the gearing portion is under-counted.

Third, SIC 3566 is an industry classification made up of establishments whose "primary" production is gears or gear units. Most establishments also produce "secondary" products, like couplings, bushings, or as may occur where SIC 3566 is concerned, aerospace or motor vehicle gearing. Secondary products are included in the industry totals and may distort shipment totals, as well as other numbers somewhat, such as employment totals and new investment.

In 1987, 91 percent of the industry's total value of shipments of $1,477 million (excluding miscellaneous receipts of $92.4 million) were gearing. The other nine percent, or $133.5 million, included various secondary products.

In the opposite direction, secondary products produced by other industries may include industrial or marine gearing. In 1987, a total of $198.4 million of gearing was identified as secondary product in other industries. Total product shipments of industrial and marine gearing in 1987, reported as primary and secondary products was $1,541.4 million.

Sector Descriptions

The motor vehicle gear industry is located for the most part in Michigan, Indiana, New York and Ohio. General Motors operates seven plants under the name Hydramatic which produce and assemble transmissions, and two axle facilities under its Saginaw Division. GM has the largest gear operation in the world with plants scattered around the Eastern Great Lakes states. Their gear facility in Ypsilanti, MI is a major gear cutting plant and feeds loose gears and other parts to the others. Ford also maintains an exceptionally large operation with ten gear and axle facilities in the Midwest. Ford's major gear cutting plant is in Livonia, MI. Chrysler's Acustar Division has major gear plants in Kokomo, IN; Syracuse, NY; and Detroit, MI. Mack Trucks has its own transmission operation in Hagerstown, MD. In addition, other companies which primarily manufacture truck transmissions, include Eaton, Dana, Rockwell, and Borg-Warner.

The industrial and marine gear sectors are more geographically dispersed. A large cluster of firms lie within a 150 mile radius of Chicago. In terms of employment, the leading states, accounting for about half the total, are Wisconsin, Illinois, Indiana and Pennsylvania. Some of the major companies include Falk and Milwaukee Gear in Milwaukee, WI; Caterpillar in East Peoria, IL, Fairfield in Lafayette, IN; and Philadelphia Gear in King of Prussia, PA.

The aerospace sector can be characterized as a small group of major operations that both cut gears and assemble gearboxes, and another group of smaller operations that builds loose gears to order, primarily for the majors but also on occasion as replacement parts for the DOD and others. The major players include Litton and Aircraft Gear in Chicago, Speco in Springfield, OH, and Lucas Aerospace in the City of Industry, CA. Captive operations, also major players, include Allison Gas Turbine in Indianapolis, IN; Garrett in Phoenix, AZ; Sikorsky and Textron Lycoming in Stratford, CT; and Textron Bell in Fort Worth, TX. Examples of smaller operations include Arrow Gear in Downer's Grove, IL; Riley Gear in Tonawanda, NY; and ACR in Mount Clemens, MI. Spar is a leading Canadian firm in Toronto, Ontario.

Industry Structure

The gear industry is basically composed of three types of business organizations - "captive" shops that provide a single customer's (usually a parent firm's) gear requirements and services; "integrated jobbers" that generally supply anywhere from a few to many customers, perhaps in a particular industrial category or categories with a range of specialized gear requirements and services; and "job shops" that build-to-order for many customers, but furnish little or no engineering services.

By most measures - dollar volume, employment, investment - the captive organization dominates the gear industry. In 1988, almost 78 percent of total gearing production in the United States was done by captive firms. However, this large percentage is heavily weighted by the captive auto gear companies. While about 90 percent of the shipments by the motor vehicle sector in 1988 were captive, slightly less than 40 percent of the combined shipments by the industrial, aerospace and marine gear sectors were captive.

1988 Percent Captive Shipments
By Major Gear Sector
(in $thousands)

Sector	Total Shipments	Captive Shipments	Percent Captive
Motor Vehicle	$10,202,372	$9,185,450	90.0%
Industrial	2,101,791	887,801	42.2
Aerospace	725,097	258,418	35.6
Marine	356,295	83,013	23.3
Total	$13,385,555	$10,414,682	77.8

Source: Compiled from ITC/DOC Industry Survey Data

Captive firms typically produce a limited range of gears in very large volumes to meet the specific requirements of one customer - usually a parent or affiliate. Given sufficient volumes, it is cheaper to produce the devices in-house than purchase them from an outside source. Moreover, gears are integral subsystems of much larger final products. As such, the gear systems must be specially designed and engineered to optimize the transmission of power between the drive unit and the driven unit. Thus, each firm that makes final products - autos, tractors, helicopters, printing presses, power shovels, etc. - must essentially use a customized gear system for each model of final product. This requires close technical coordination between gear supplier and user.

Under these circumstances, it is not surprising to find captive gear firms affiliated with some of the largest and best known U.S. companies in the world. In addition to the auto companies, companies such as John Deere, Caterpillar, General Dynamics, Cummins Engine, Lufkin, Mack Trucks, Sikorsky, and Textron Lycoming maintain captive gear shops that provide most or some of their gear requirements. While the captives generally do most of their own work, to varying degrees, they also buy and sell gears to round out their business. And recently, two major captives, General Motors and Chrysler, formed a joint venture (October 1989) to produce manual transmissions in Muncie, Indiana.

The integrated jobbers, though not as large as many of the captives, are generally mid-sized or larger gear companies, with annual sales often exceeding $50 million. These firms supply intermediate sized final-product companies not large enough to economically maintain their own gear works. They will also supply the large captives when the opportunity presents itself, and other customers, including the military, and state and local governments. The integrated jobbers offer design and engineering services, and usually manufacture both open gears and complete gear systems. However, they also frequently build to customer drawings and specifications, which incidentally reduces their product liability risk. They can be thought of as large job shops, but with expanded capabilities.

Many of the integrated jobbers are specialized in certain market categories. This specialization is usually based on a narrower range of gear sizes and precision, and the special engineering and know-how problems encountered in a particular family of end-market applications. For example, Eaton, Borg-Warner, and Dana provide gear systems to truck manufacturers. Cincinnati Gear, Westech, General Electric, Westinghouse, Falk and Philadelphia Gear supply marine gears. Speco, Litton, International Gear (Argo-Tech), and Lucas Aerospace furnish gear systems to aircraft and helicopter companies. Others, like Fairfield and Regal-Beloit, have a broader focus and may sell to a variety of industrial customers.

Job shops are the most numerous form of business organization within the gear industry, but in terms of dollar volume, employment, and investment, they represent less than 5 percent of the gear industry. Few job shops do any automotive business. Their share of the non-automotive gear sector is closer to 20 percent. They are distinguished from integrated jobbers by their comparatively smaller size, lack of an engineering staff, and the exclusive production of open gears.

Job shops exist because of the numerous and diverse gear part numbers demanded in small quantities by the marketplace. Typically, job shops bid on drawings supplied by customers for small volumes. They are mostly privately owned by a few engineers, or often by a family. Many were founded by people formerly employed by a captive or larger jobber. Sales are frequently performed through distributors or sales representatives. Many sales are also made to the integrated jobbers and captives.

Although most gear houses fit into one of the three categories, others are borderline, and may exhibit features of more than one. For example, some job shops can offer design and engineering services if pressed to do so. Also, some integrated jobbers have the bulk of their sales to only one or two customers, resembling captive shops. Still others are in transition, with ambitions of moving from job shop to integrated jobber.

Factors Influencing Industry Structure

The structure of the gear industry is influenced by four fundamental criteria. First, gears are predominantly "customized" products. Gear design and engineering are application (i.e., end-user) determined. Once made, a gear system is essentially "frozen" to its application, and cannot be used elsewhere. This makes the end-user very important from a technical standpoint.

Second, end-users with larger production quantities are in a position to cover overhead costs, and bring gear production in-house. The large volume producer can essentially "hardwire" (i.e. dedicate) his production line to produce a single system at the least possible cost. On the other hand, it would be very risky for an independent gear producer to lock into a hardwired production line, without major assurances from his customer of future sales. Thus, independent gear manufacturers tend to have more flexibility built into their production lines which expands their market scope. However, for production of a single product, flexible lines cannot possibly compete on a cost basis against the dedicated lines of the large captives.

Third, gear applications are extremely "numerous and diverse." This means tens of thousands of gear part numbers are in circulation. They are produced in sizes ranging from a fraction of an inch to over 30 feet across. They have varying numbers of gear teeth relative to their diameters, and are made from a variety of materials. The entire gear market is the sum of hundreds of more or less specialized "niches," that revolve around production quantities, gear size, precision, and materials. The large number of job shops, not just in the United States, but in all major gear markets, is a direct consequence of the numerous lower volume niches.

And fourth, gears are close to the top of the spectrum in terms of geometric complexity and difficulty of manufacture among metal working industries, especially for higher precision gears. Numerous dimensions on a gear must be controlled to thousandths of an inch, or better. Machining time is very high relative to workpiece weight, particularly for ground high precision gears. Moreover, gear cutting and grinding machine tools are among the most expensive in the machine tool family. The accessories and cutting tools used on the machines are also among the most complex and expensive, both to buy and maintain. It is very important for design and process engineers to work closely together to achieve optimum quality, manufacturability, and efficient production at reasonable cost.

HISTORICAL PERSPECTIVE

This section relies heavily on statistical information collected and published by the Department of Commerce's Bureau of the Census in accordance with the SIC system. The data are drawn from various statistical time series published under SIC 3566 - Speed Changers, Industrial High-Speed Drives, and Gears, which the reader is reminded only covers industrial and marine gears. While the data may be incomplete in certain respects, they are collected and tabulated on a consistent basis, and are very useful for showing historical trends.

Long-Term Shipment and Employment Trends

From the recession year of 1958 to 1967, shipments of industrial and marine gears measured in constant 1988 dollars almost doubled from $1.1 billion to over $2 billion. A rise in inflation and higher interest rates were followed by a recession in the early 1970s, that ultimately pushed gear shipments down a total of 22 percent by 1971, to $1.58 billion. Shipments rose 8 percent in 1972, to $1.7 billion. This was followed by nine consecutive years of shipments over $2 billion.

Shipments of industrial and marine gears reached a peak in 1979 and 1980, at just under $2.3 billion. Following shipment trends closely, total employment in the industry also attained its highest level in 1980, at 28.3 thousand, as did production workers at 19.6 thousand. However, after 1980, shipments and employment fell sharply. By 1983, shipments were down over 35 percent, to $1.47 billion. In the same time span, all employees dropped to 19.6 thousand, off 30.7 percent, and production workers fell to 12.8 thousand, down nearly 35 percent.

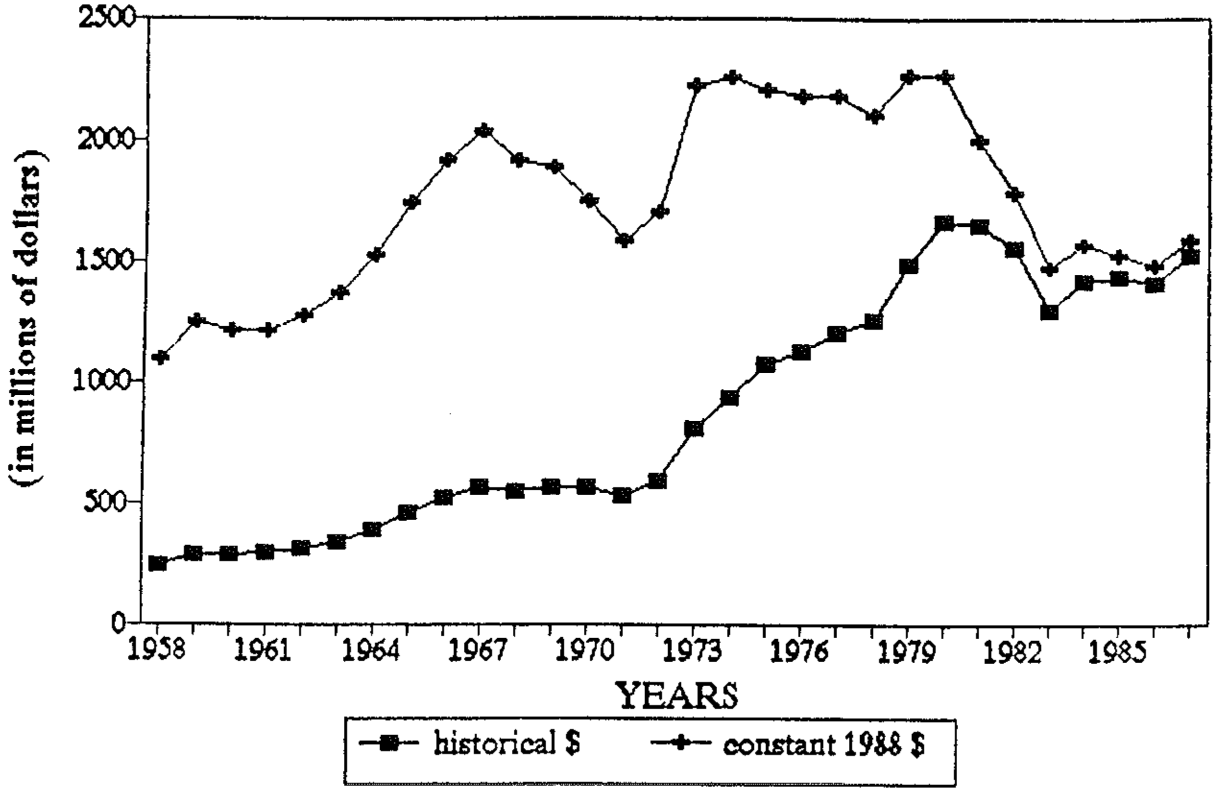
In recent years shipments improved a little, but even by 1987, still remained less than 70 percent of earlier high levels. Employment fell further. By 1987, all employees had fallen by another 1.7 thousand from 1983 levels, to a lower total of 17.9 thousand, down almost 37 percent from 1980. Production workers fell by another 900, to 11.9 thousand, down almost 40 percent.

Employment, Shipments, and Investment
Industrial and Marine Gears, 1972-1987
(in millions of 1988 dollars)

Year	All Employees	Production Workers	Value of Shipments	New Cap. Spending	New Cap. Spending Shipmts
	(in thousands)		-(in $88 millions)-		
1972	22.5	15.6	1,704.1	58.8	3.72%
1973	25.4	17.7	2,224.1	78.1	4.58
1974	27.0	19.3	2,259.0	95.1	4.28
1975	26.9	19.2	2,208.2	80.8	3.58
1976	25.2	17.8	2,175.6	106.2	4.81
5-Year Average:	25.4	17.9	2,114.2	83.8	4.20
1977	25.3	17.6	2,182.2	86.6	3.98
1978	25.9	17.8	2,105.1	117.0	5.36
1979	27.7	19.4	2,265.0	117.1	5.56
1980	28.3	19.6	2,264.3	100.8	4.45
1981	25.7	17.6	2,003.0	106.6	4.71
5-Year Average:	26.6	18.4	2,163.9	105.6	4.80
1982	24.1	15.8	1,781.0	101.7	5.08
1983	19.6	12.8	1,470.0	85.8	4.82
1984	20.6	13.8	1,564.2	71.5	4.86
1985	18.6	12.7	1,523.4	69.8	4.46
1986	17.4	11.7	1,476.1	63.3	4.53
5-Year Average:	20.1	13.4	1,562.9	78.4	4.70
1987	17.9	11.9	1,595.8	66.9	4.53

Source: USDOC, Bureau of the Census

FIGURE 1: SHIPMENTS OF GEARS, 1958-1987
IN HISTORICAL AND CONSTANT DOLLARS



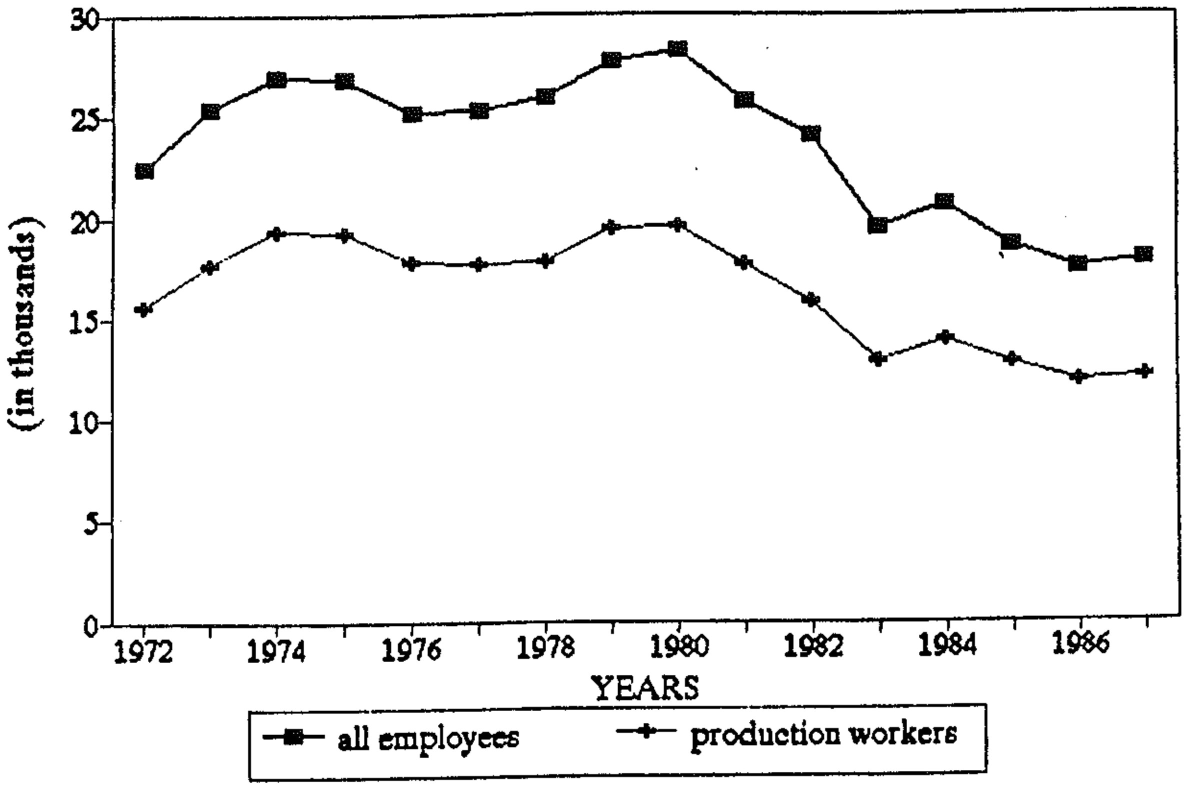
Source: DOC, Bureau of the Census

Investment Trends

New investment by most firms in the U.S. gear industry has been inadequate to remain internationally competitive. The amount of old equipment found in many gear plants is a major competitive problem, especially in light of the major technical advances embodied in the gear making machinery now offered on the market. More total investment is made in each of the gear industries of Germany, Japan, Korea, and perhaps Italy, than in the United States, despite the American market being much larger.

Investment in new plant and equipment by the U.S. gear industry generally rose and fell with shipments during the period 1972 to 1987. In constant 1988 dollar terms, investment ranged from a low of $58.8 million in 1972, to a high of $117.1 million in

FIGURE 2: EMPLOYMENT IN THE GEAR INDUSTRY
ALL EMPLOYEES AND PRODUCTION WORKERS



Source: DOC, Bureau of the Census

1979. From 1978 to 1982, investment exceeded $100 million each year, averaging almost $109 million per year. In the most recent five years (1983-1987), investment has averaged only $71.5 million per year, down over 34 percent from the previous five year average. Over the entire 16 year period, yearly investment averaged $87.9 million.

Increased investment in new machinery and equipment typically may lag an increase in shipments by up to a year. Thus, to measure investment against shipments more accurately, investment was lagged a year and compared to the previous year's shipments. Under this provision, investment by the gear industry averaged 4.57 percent of shipments from 1972-1987.

The percent invested to the previous year's shipments was lowest in 1975 at 3.58 percent (a recession year), and highest in 1979 at 5.56 percent (also the industry's highest shipments year). When shipments were above their 16 year average of $1,924 million, investments tended to exceed the average 4.57 percent, and fell below the average when shipments were down. For the nine years when shipments were above average, investments averaged 4.63 percent, or 6 basis points above average. In the seven years shipments were below average, investments averaged 4.45 percent, or 12 basis points below the average.

This is an indication that investment by the gear industry has been contingent on cash flow, in which the industry has a preference for self- or equity financing, as opposed to financing investment with debt. This is characteristic of many other U.S. manufacturing industries that face volatile and somewhat unpredictable business cycles. Under these circumstances, as a prudent business practice, many firms avoid carrying high fixed costs, of which debt-financing would be a major component.[2]

Historically high interest rates in the United States relative to our major international competitors may have contributed to this philosophy. However, the U.S. gear sector matured in the mid-1960s, long before that of other nations, after which time little, if any, need for capacity expansions has arisen. In fact, the industry's market has declined, primarily since 1980, further inhibiting the carrying of long-term debt for new investment. Debt financing is more common in fast growing markets. In countries such as Korea where the gear market is expanding rapidly, today's market is not generating sufficient funds for next year's expanded needs, so Korean gear firms wanting to invest must enter the capital markets to make up the deficit.

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[2]An examination of the year to year change in shipments by the industrial and marine gear sector from 1972-1987 showed an average up or down movement of 7.2 percent. This is not particularly volatile. However, the average volatility of individual firms is much higher at almost 20 percent, and is more relevant to the preference for equity financing. For a detailed discussion of the volatility issue, see the section on <u>Market Volatility</u> on page 73.

There may also be some legal justification underpinning a preference for equity financing. European and Japanese manufacturers have close ties with banks, sometimes based on interlocking ownership, where the bank can share some of the investment risk, as well as profits. This has resulted not only in higher levels of investment, but encourages longer term strategies. In the United States, laws enforce an arms length relationship between banks and other businesses.

While seemingly less risky, major problems with equity financing are that it deters a long range investment strategy and depends on strong markets. If the markets should soften, as they have in the gear sector, then investments are reduced. Reduced investment delays both the acquisition of the most advanced equipment, and coming down the learning curve in its usage. Another concern is that for some firms, equity financing may put the more expensive equipment beyond their reach.

Equity financing may be a successful strategy basically under two conditions. First, if advances in production technology progress slowly, which is not the case in the gear industry, the need to stay current would be less urgent. Second, if competition is limited for structural, geographic, cost-of-entry, or any other reasons, profitability would not be linked to new investment. While strong competition exists in some areas of the gear industry, it is for the most part rather limited.

The gear market is dominated by subordinated "captives" that supply a single customer. The captives compete indirectly through the final product their gear systems enter. But they are otherwise insulated from competition. Further, the market also has many "niches" that individually lack the breadth and scope to attract many suppliers. Additionally, once the engineering familiarity is established between buyer and seller, many end-users prefer not to switch "horses."

The future of the gear industry belongs to those who invest, especially given the increasing presence of well capitalized foreign competitors. The production technology has so improved in recent years that the industry should be redefined as capital-intensive. While some firms are investing heavily in recognition of this fact, many others are falling behind. It appears a new structure, with fewer and larger firms may emerge, as many firms are for sale or would sell if given the opportunity. This may already be happening. For instance, in the last few years, Regal-Beloit has purchased five or six smaller gear producers which collectively cover a wide cross section of the industrial gear market. With expanded market share and much higher sales volumes, the firm has become a major player in the gear industry. It is uncertain what Regal-Beloit's next move will be, but the industry's movement toward consolidation appears inevitable.

Age of Equipment

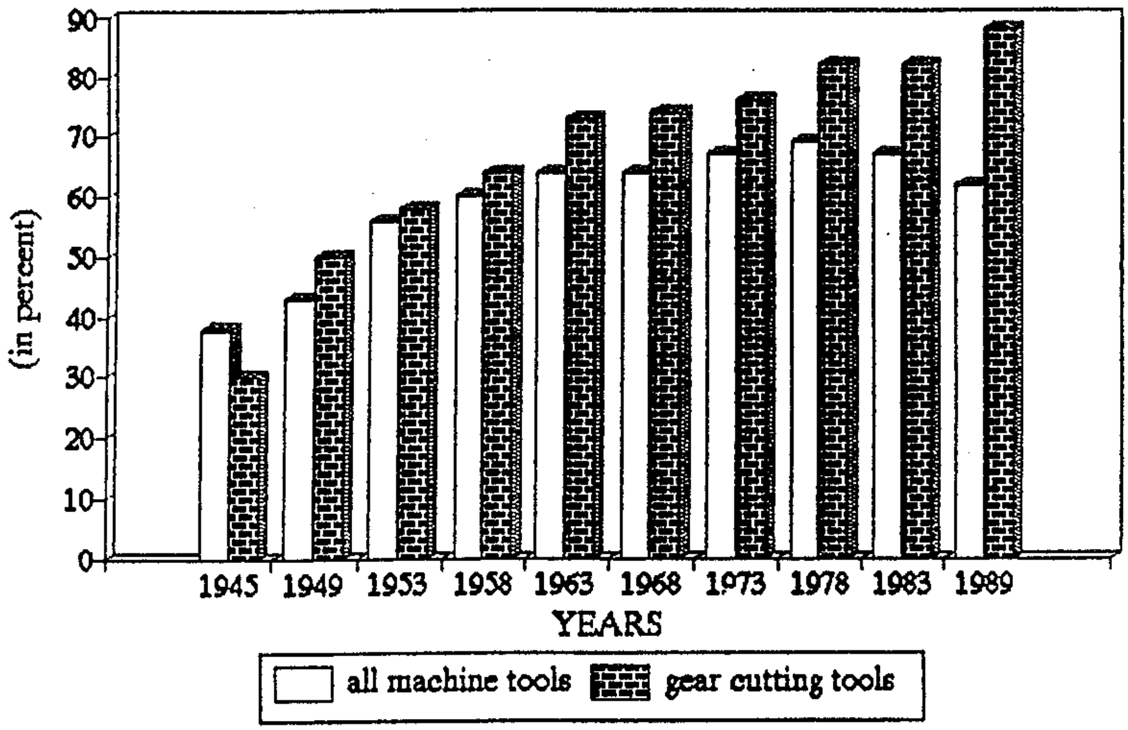
Roughly every five years since 1925, American Machinist magazine has published an inventory by age range of the various kinds of machine tools located in American manufacturing plants, including gear cutting types. A review of the last ten of these inventories shows a steady increase in the percent of gear cutting machines over 10 years old, from only 30 percent in 1945, immediately after the war, to 88 percent in 1989. This 88 percent figure is up from 82 percent in 1983. In contrast, for all machine types, the percent over 10 years old rose from 38 in 1945, to a high of 69 percent in 1978, and then came down to 62 percent in 1989.

Percent Machine Tools Over 10 Years Old

Year	All Machines	Gear Cutting Machines
1945	38	30
1949	43	50
1953	56	58
1958	60	64
1963	64	73
1968	64	74
1973	67	76
1978	69	82
1983	67	82
1989	62	88

Source: American Machinist Magazine (years shown)

FIGURE 3: PERCENT MACHINE TOOLS OVER 10 YEARS OLD
IN THE UNITED STATES, 1945 TO PRESENT



Source: American Machinist Magazine, (years shown)

Information gathered by the ITC/DOC Industry Survey showed similar results. Of 9,648 gear cutting and grinding machines[3] (shapers, hobbers, bevel generators, shavers, and grinders) reported in U.S. gear shops, more than half were over 20 years old, and more than 80 percent were over 10 years old.

A rough estimate of the average age of gear machinery can be developed by multiplying the midpoint of various age intervals - 0-5 years (2.5), 5-10 years (7.5), 10-20 years (15.0), and over 20 years (25.0) - by the number of machines reported within each interval, adding these together, and then dividing by the total number of machines.

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[3]For descriptions of gear cutting and grinding machines, refer to Appendix B - Manufacturing Process.

While this yields an average age of 18.3 years for the entire gear industry, it may understate the reality because of the very large number of machines over 20 years old (50.4 percent). Some of these pre-date World War II, and in exceptional cases even pre-date World War I. The midpoint for machines over 20 years was conservatively set at 25 years. If this were changed to 30 years, the average age would rise from 18.3 to 20.8 years.

On the other side of the issue, younger machines are generally more productive than older machines, and perhaps should receive more weight in determining average age. Further, younger machines are used more intensively than older machines. If age could be accurately related to machine hours-used, a younger picture would undoubtedly emerge. If a weight of '1' is assigned machines over 20 years, '1.5' to machines 10-20, '2' to machines 5-10, and '2.5' to machines 0-5 years old, the average age would fall from 18.3 to 15.7 years (or from 20.8 to 17.6 years if "over 20" midpoint set at 30).

With these concerns aside, among the different gear sectors, the motor vehicle sector reported the youngest overall gear machinery, at an estimated average age of 17.3 years, while the aerospace sector reported the oldest at 19.5 years. In between these, the industrial gear sector's average was estimated at 18.8 years, and the marine sector's at 18.1 years. An industry official who has visited gear plants in Europe and the Far East noted that each gear sector in the United States has older machinery than its counterparts in other countries.

The motor vehicle sector reported 78 percent of its machines over 10 years of age. The oldest category are bevel generators, with 94 percent over 10 years of age. One reason for this may be that the need for bevel generating machines in the auto sector declined with the switch away from rear wheel drives to front wheel drives. Front wheel drive vehicles eliminate the rear axle differential and require fewer bevel gears. However, more importantly there were few productivity enhancing innovations in bevel generating machines that might otherwise have induced more investments.

Gear Cutting Machine Age Profile
By Major Sector

GEAR SECTOR	SHAPERS	SHAVERS	HOBBERS	BEVELS	GRINDERS	ALL TYPES
	GEAR CUTTING MACHINES					
Motor Vehicle						
a. Average Age	14.9	17.2	14.9	21.1	20.2	17.3
b. % Over 10 yrs.	68.1	76.9	68.9	93.8	89.7	78.3
c. # Machines	723	666	1,294	926	546	4,155
d. % Foreign	7.6	8.4	31.9	2.5	2.6	13.5
e. % For. <5 yrs.	19.4	12.3	51.4	20.8	56.0	37.3
Industrial						
a. Average Age	18.9	19.3	18.9	20.8	15.3	18.8
b. % Over 10 yrs.	80.8	90.4	87.0	90.3	66.0	84.2
c. # Machines	832	302	1,696	526	397	3,753
d. % Foreign	13.8	2.6	32.6	1.3	43.1	22.8
e. % For. <5 yrs.	26.5	9.1	90.0	7.1	57.4	53.5
Aerospace						
a. Average Age	19.4	21.0	20.6	20.6	17.9	19.5
b. % Over 10 yrs.	79.2	91.4	86.6	87.5	69.5	79.8
c. # Machines	279	81	403	120	436	1,319
d. % Foreign	9.6	0.0	12.2	1.7	17.4	11.7
e. % For. <5 yrs.	51.7	0.0	55.2	0.0	36.2	41.6
Marine						
a. Average Age	20.2	24.0	19.0	16.1	12.7	18.1
b. % Over 10 yrs.	91.7	96.5	86.1	77.6	58.9	81.8
c. # Machines	36	57	129	107	56	385
d. % Foreign	41.7	1.8	44.2	3.7	80.4	31.7
e. % For. <5 yrs.	0.0	100.0	100.0	0.0	63.6	62.5
All Sectors						
a. Average Age	17.5	18.5	17.6	20.6	17.9	18.3
b. % Over 10 yrs.	76.0	82.7	80.3	91.3	75.9	81.0
c. # Machines	1,880	1,110	3,535	1,685	1,438	9,648
d. % Foreign	11.3	5.9	30.4	2.1	21.5	17.6
e. % For. <5 yrs.	28.6	12.3	61.0	10.2	50.0	42.7
Captive						
a. Average Age	15.2	17.9	14.7	21.0	18.7	17.2
b. % Over 10 yrs.	65.2	80.2	68.5	91.2	80.1	76.1
c. # Machines	909	686	1,380	945	769	4,689
d. % Foreign	11.4	2.2	32.7	1.8	7.8	13.8
e. % For. <5 yrs.	18.4	14.0	55.8	11.4	44.4	38.0
Non-Captive						
a. Average Age	19.7	19.3	19.5	20.1	16.9	19.3
b. % Over 10 yrs.	86.0	86.8	87.9	91.4	71.0	85.7
c. # Machines	971	424	2,155	740	669	4,959
d. % Foreign	11.1	11.8	29.0	2.6	37.2	21.2
e. % For. <5 yrs.	45.3	8.7	74.0	8.3	54.4	50.2

Source: Compiled from ITC/DOC Industry Survey Data

The same cannot be said of the other machine types. Not surprisingly, the motor vehicle gear sector reported the youngest group of shapers, shavers, and hobbers. It can be said that the motor vehicle gear sector plays a crucial role by not only providing the largest market for gear cutting machines, but also in stimulating productivity enhancing innovations in the machines that it needs by working closely with the machine tool companies.

The industrial gear sector has more hobbers than any other sector. However, 87 percent are more than 10 years of age, and only 3.5 percent are in the 0-5 age interval. Of these, 90 percent are foreign-origin. In contrast, while the auto industry has fewer hobbers overall than the industrial sector, in the 0-5 age interval they have roughly three times as many.

The marine gear sector has the oldest shavers, with almost 97 percent over 10 years old. However the marine sector also has the youngest bevel generators with 78 percent over 10 years old, and the youngest grinders with only 59 percent over 10 years old. One-third of the aerospace gear machines are grinders, which are critical for high precision. About 70 percent of the grinders are over 10 years old.

In general, captive firms have younger machines than non-captive firms. This is partly because the auto companies dominate these statistics and carry an inordinate amount of weight. However, it is also evident firms like Caterpillar and John Deere have been stimulated by the international competition in their final products to improve efficiency and cut costs in all areas. The average overall age of captives' machines was over two years younger than non-captives' machines.

The number and percentage of foreign machines held by U.S. gear companies are both increasing. Overall, about 18 percent of the machines are identified as foreign-origin. However, in the youngest age interval, the number foreign is 43 percent. These are dominated by hobbers and grinding machines. In the youngest category, about 61 percent of the hobbers, and 50 percent of the grinders are foreign.

Several possible reasons may explain why so much old equipment is in use. The high cost of capital coupled with the hefty price tags on new equipment, especially the high precision and computer numerically controlled (CNC) equipment, combine to make new machinery too expensive for many gear producers. Also, a contracting gear market has left many firms cash poor and unwilling to risk investment in new equipment. In addition, the industry has a chronic overcapacity problem, in large part aggravated by less efficient older equipment which has not yet been retired. Further, exchange rate swings have increased the price of new machinery produced overseas, and allowed domestic machine tool producers to increase prices as well.

In contrast, used equipment is much cheaper, available now, and able to do most things a new machine can, or may be rebuilt or retrofitted to do so. Also, fully depreciated equipment reduces overhead enabling a firm to better withstand business downturns. Moreover, many plant closings in recent years may have flooded the market with used equipment at distress prices.

By most accounts, the advanced age of gear cutting equipment is a major competitive disadvantage to the U.S. gear industry. Older machines increase the need for skilled labor, a commodity in short supply, and often cause delivery delays. Newer CNC machines greatly reduce set-up times, cut fewer defective parts, and consistently achieve better tolerances in shorter time frames. Additionally, new CNC gear cutting machines can do things older machines cannot, such as cut very complex or unusual geometries.

It is important for both industry and the government to recognize that the use of advanced technologies is a prerequisite for continued competitiveness. As one company reported, a single new machining center and three people now do all the machining on gearbox casings that formerly required 12 conventional machines, and 24 people to operate. However, this machining center cost over $5 million to purchase and install in its own air conditioned room with a stabilized floor.

In a report prepared for Commerce by the Technology Management Center of Philadelphia, PA[4], it was proposed a human "element" may be blocking the use of new technology. The major finding of

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[4]"The Use of Advanced Manufacturing Technology in Industries Impacted by Import Competition: An Analysis of Three Pennsylvania Industries," September, 1985

the project was that a majority of U.S. manufacturers have ignored the argument that new technologies produce higher quality products faster and cheaper and have hesitated to adopt modern manufacturing techniques. In addition, the report indicated that managements are often confused by and generally not knowledgeable about the advantages and capabilities of advanced manufacturing technologies. Many managers are ill-prepared to implement them effectively even when these technologies are acquired. Compounding the problem is the traditional organizational resistance to change[5].

While U.S. gear firms have been slow to invest in the newest gear equipment and technology, their counterparts in Germany, Italy, Japan, and other countries are investing heavily in plant modernization. The Gleason Machine Tool Company in Rochester, NY developed the "Phoenix" CNC bevel cutting or grinding machine, which many consider the best available in the world. As of this writing, the company has sold 80 of these machines, but only five were sold in the United States. Similarly, National Broach in Mount Clemens, MI developed a highly advanced CNC grinding machine several years ago for aerospace applications. Again, nearly all sales have been to foreign companies, despite the fact that the U.S. aerospace gear market is the largest in the world.

Trends in Establishment Size

With the rapid decline in gear business in the early 1980s, the industrial gear sector became less concentrated as a disproportionate share of the decline was absorbed by the sector's largest establishments. The large gear companies typically sell to large end-users. Many large gear system end-users, such as Dresser, Lufkin, Navistar, American Motors, and JI Case, were losing ground both domestically, because of shrinking markets, and internationally because of the pre-1986 strength of the U.S. dollar. Many of the larger gear firms, including

[5]In defense of management, long-term investment incentives in the U.S. tax code are almost non-existent. Tax incentives favor short-term gains (e.g., treating capital gains as ordinary income). Under investment may in fact be management optimizing behavior in the given economic environment.

several captive producers, were forced to retrench, and some left the business. An examination of the data on the table shows that establishments with over 500 employees suffered a very serious decline between 1977 and 1987. During this period, shipments by

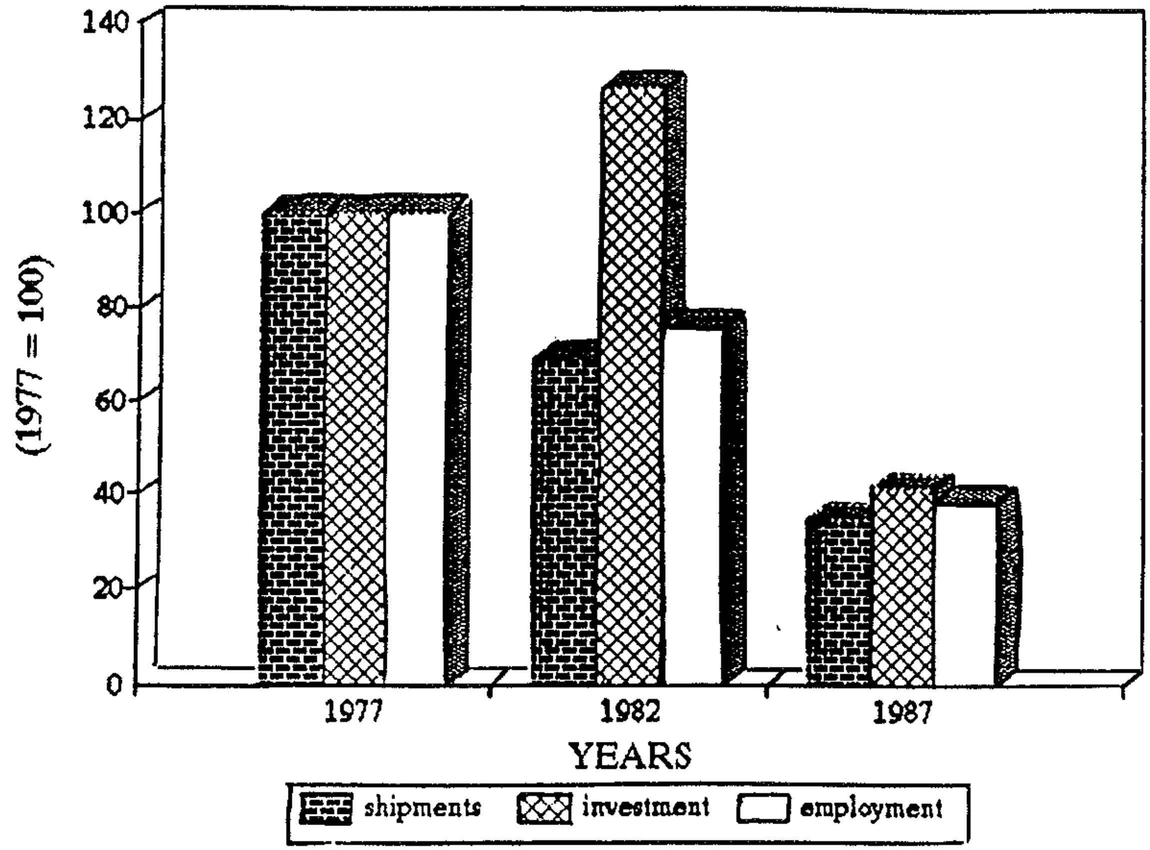
Decline of Large Establishments

Employee Range/Yr.	Number of Establishments	Production Workers (000s)	Value of Shipments --(in $87	New Capital Expenditures millions)--
20-99				
1977	112	4.0	407.8	13.7
1982	120	3.9	379.5	15.0
1987	117	3.7	428.4	17.6
100-249				
1977	29	3.4	384.8	13.2
1982	37	3.7	422.6	24.4
1987	23	2.3	336.9	12.6
250-499				
1977	13	3.2	434.2	17.0
1982	14	2.6	351.2	12.3
1987	13	2.7	427.3	15.8
Over 500				
1977	8	6.2	828.8	35.8
1982	7	4.7	570.6	45.1
1987	4	2.4	291.0	14.8
Total				
1977	162	16.8	2,055.6	79.7
1982	178	14.9	1,723.9	96.8
1987	157	11.1	1,483.6	60.8

Source: USDOC, Bureau of the Census, Census of Manufactures, 1977, 1982, 1987

the largest group fell 65 percent; production workers fell 61 percent; and, the number of establishments fell from 8 to 4, down by half. Of a $572 million decline in shipments for the entire industry between 1977 and 1987, the over 500 employee group accounted for more than 94 percent.

FIGURE 4: TRENDS IN PLANTS WITH OVER 500 EMPLOYEES



Source: DOC, Bureau of the Census

Larger gear firms typically operate nationwide or in global markets. In many respects, they form the first line of defense against international competitors. They also tend to be leading exporters. A consequence of their decline has been a drop in the competitiveness of the overall U.S. gear industry and its supporting infrastructure. This is evidenced by a loss of market share to rising levels of imported gears, and declining shipments of gear making machinery and gear-related forgings and castings. Imports of industrial gears, for example, rose over 100 percent between 1984 and 1988, from $266 million to $561 million.

Further, indications are that larger gear firms invest somewhat more per sales dollar than smaller firms. Over the last three

Census of Manufactures (1977, 1982 and 1987); establishments with over 500 employees accounted for only 32 percent of the shipments, but made 40 percent of the investment. [6]

Productivity Trends

Productivity in the industrial and marine gear industry declined 2.4 percent between 1979 and 1987. Over the same period, all manufacturing productivity was up 19.7 percent, and in SIC 35 - Producer Durables, productivity was up 20.1 percent.

Trends in Productivity*
Industrial and Marine Gear Sectors

	All Manufactures	SIC-35 Machinery	SIC-3566 Gears
1975	94.0	90.7	92.9
1979	100.0	100.0	100.0
1980	100.8	101.4	96.9
1981	101.8	105.4	99.2
1982	103.8	107.1	96.1
1983	107.1	105.5	97.5
1984	109.5	110.3	94.5
1985	109.5	109.3	93.7
1986	112.9	112.0	97.8
1987	119.7	120.1	97.6

Source: USDOC, Bureau of the Census

* Productivity in the gear industry was measured as the portion of value added constituted by total wages. This measure assumes that as capital is substituted for labor, the relative share of wages in value added will decline. It is, therefore, a measure of labor productivity. Other productivity measures were judged to be inappropriate due to inadequate data.

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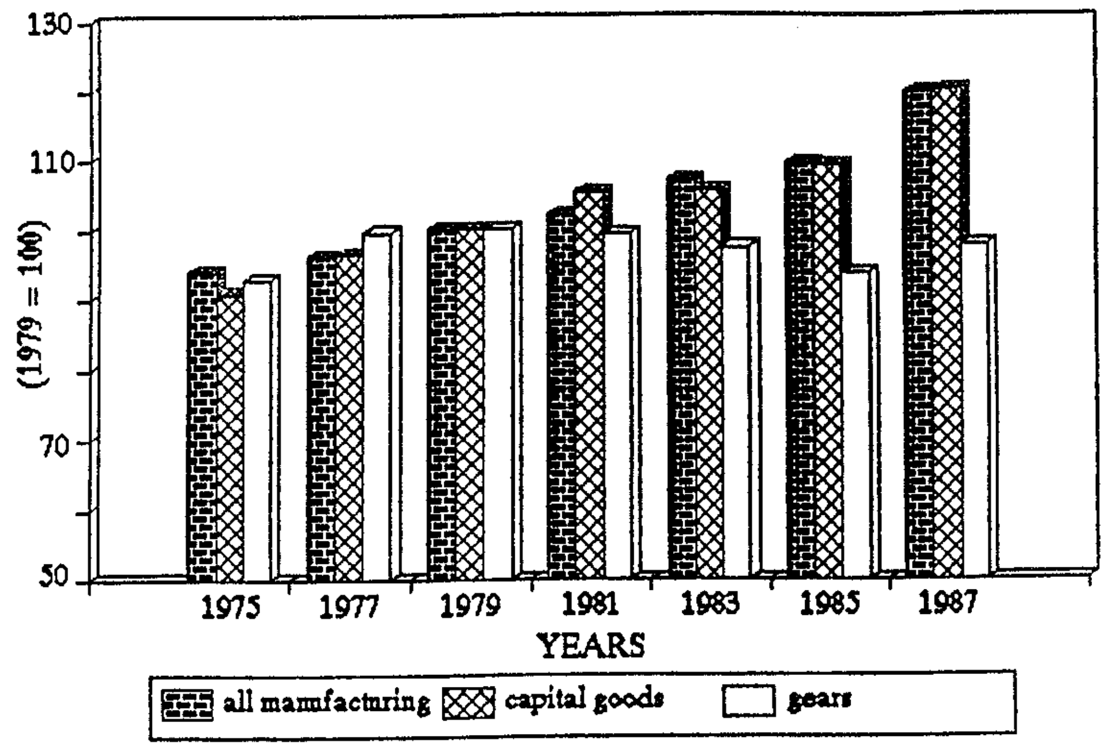
[6] In addition to major cost cutting measures being taken during this period, several larger firms reacted to the contracting market by making productivity enhancing investments. The extremely large investment outlay in 1982 reflects these efforts. While most of the employment loss during this time was caused by the dramatic shrinkage of end-markets, a portion was also due to increases in productivity by the firms involved.

FIGURE 5: TRENDS IN COMPARATIVE PRODUCTIVITY
ALL MANUFACTURES, CAPITAL GOODS & GEARS



Source: DOC, Bureau of the Census

Part of the reason for the poor showing is that the industry faced a declining market, and used capacity less than optimally. Additionally, the poor productivity performance was perpetuated by a history of inadequate investment in newer, more productive equipment. In fact, as previously cited during the last decade, the average age of gear cutting machinery installed in American factories increased, where today almost 90 percent of U.S. gear machinery is over 10 years old.

Declining Relative Usage of Gears

In a 1984 report prepared by the Institute for Trend Research in Contoocook, NH, it was stated that the gear industry peaked in

1966, and has been declining ever since. Another report compiled for the American Gear Manufacturers Association by the accounting firm of Deloitte, Haskins, and Sells showed a greater than 20 percent decline in orders (on trend) during the period 1972 to 1985.

Evidence from statistical data collected by the Bureau of the Census also shows a decline in the use of gears in the overall economy. As measured in historical dollars, U.S. consumption of industrial and marine gears relative to the total shipments of all manufacturing industries declined steadily by a total of 34.1 percent between 1975 and 1987.[7]

Three major reasons for this decline are apparent. First, less gear-intensive industrial products, such as computers, chemicals and electronics, have increased their shares of the manufacturing dollar, while many of the traditional and more gear-intensive products - autos, construction equipment, ships and mining equipment - have held steady or declined. Second, the productivity level of a broad range of capital machinery and equipment, such as machine tools, printing presses and textile machines, has increased with the application of new technology so that more output can be achieved using fewer machines, reducing the overall gear requirement. And third, certain alternative technologies have encroached on gear markets. These include servo-mechanisms, fluid power, and electronics.

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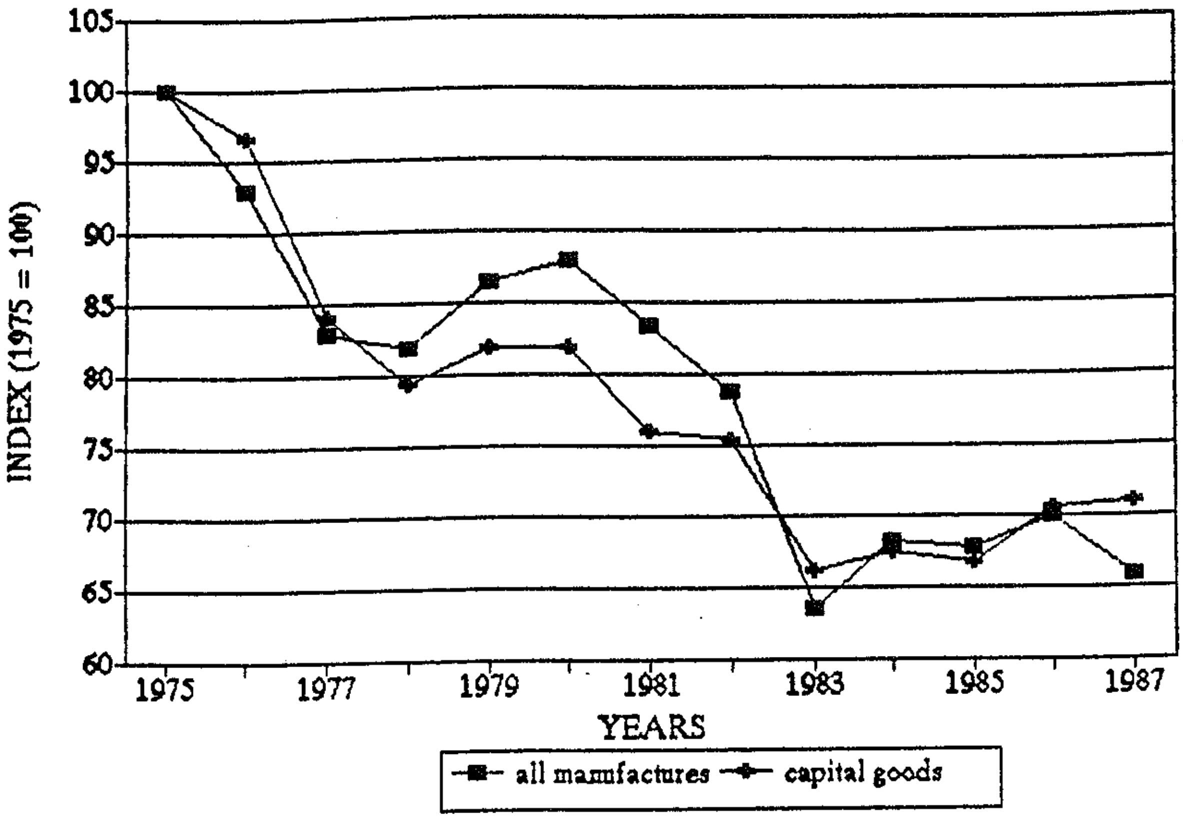
[7] During the same time period, it was also found that gear shipments declined relative to their major end-markets, as classified within SIC 35 - Producer Durables. A decline of 28.9 percent in the shipment of gears relative to shipments of SIC 35 was observed. If one subsector, SIC 357 -Computers and Office Equipment, was removed from the calculation because of its comparatively low use of gears, and large relative size, a decline of 14.6 percent would be recorded.

FIGURE 6: DECLINING CONTENT OF GEARS RELATIVE TO ALL MANUFACTURES & PRODUCER DURABLES



Source: DOC, Bureau of the Census

Most of the 34.1 percent decline is related to shifts to lower-intensity gear-using products and significant declines in gear-intensive markets many of which are in SIC 35 (Producer Durables). SIC 35 includes almost every conceivable type of machine, from shoe making machines, sewing machines, and conveyors to tobacco equipment, ice making machines, and ore crushing machines. Generally, the heaviest equipment industries, such as construction and mining machinery, have a greater impact on gears than lighter equipment since these industries use gears with greater intensity than the others. The statistical evidence shows a larger reduction in shipments of heavy equipment within SIC 35. Thus, the 28.9 percent fall in the gear index attributable to SIC 35 (see Footnote 7) can be partly explained by the fall in heavy equipment shipments, and a rise in heavy equipment imports. The slight rise in the index following its low in 1983, was fueled by a slow recovery in these end-markets.

When the dollar lost value on global exchange markets in 1986, it may have further helped heavy industry recover some ground lost previously, by making imports more expensive and giving exports a boost, and thereby increasing relative gear demand.

We estimate that about one-fourth of the decline in relative gear shipments is related to technological innovation. Encroaching technologies, for example, have significantly penetrated some markets formerly dominated by gears. A prime example is machine tools, which have largely switched to servo-drives, which can be controlled with greater precision, and deliver variable power as needed. In extreme cases, as many as 100 gears (50 sets) have reportedly been displaced in a single machine. To date, these work most effectively with machines using low power ratios. Heavier equipment (and some lighter equipment) is increasingly using "fluid power," or hydraulic systems to transmit higher power ratios. Fluid power transmission is flexible where mechanical transmission is not, but fluid power generally remains more expensive and lacks the efficiency of gear systems. It remains to be seen how much gear business will be displaced[8]. Electronics, such as digital clocks and timers, have also displaced many smaller sized (horological) gears.

Another trend, related to the increase in machinery productivity, is that fewer gears are needed. End-users are looking for machines that perform more and more functions. For example, the machining center mentioned previously replaced many conventional machine tools, and in so doing displaced many gears. Another consideration is that as a machine's capabilities increase the relative value of the gears in the machine declines.

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[8]In the last 20 years, fluid power has made inroads into certain gear markets, such as farm combines and other heavy equipment. While mechanical gears have been reduced, they were not eliminated in most of these applications. Most of the applications for fluid power have now been exploited. Future encroachment will require further advances in the technology. Mechanical gear systems still remain the most efficient means of power transmission as far as getting power out of a system comparable to the input power (roughly 98 percent). Mechanical gear systems will continue to dominate applications transmitting high horse powers.

The automobile illustrates this point. The options available on cars today, such as automatic seat positioners, anti-lock brakes, power windows, and electronic diagnostics, lower the value of the transmission relative to the price of the car. At the same time, the transmissions have improved because of advances in manufacturing technology (near net shaping, induction hardening, and CBN grinding), which allow more power transfer with smaller and actually cheaper parts. As a result, transmissions almost never fail, and fewer replacements are required.

Gear Markets

The decade of the 1980s was a disaster not only for the gear industry, but for major portions of industrial America as well. As an intermediate product, it is axiomatic that gears can do no better than the markets into which they are sold. During the early 1980s, the gear sector followed helplessly as its major markets spiraled into their worse contraction of the post World War II period. Further, many of these markets did not return to

1986 Shipments, Exports and Imports of
Major Subgroups of SIC 35
(billions of current dollars)

Major Group	Shipments	Exports	Imports	Consumption
351: Engines and Turbines	13.70	2.71	0.77	11.77
352: Farm and Garden Mach.	9.59	1.20	1.76	10.15
353: Construction, Mining, and Matl. Hand. Mach.	23.58	6.28	4.05	21.35
354: Metalworking Mach.	20.22	1.93	4.33	22.62
355: Special Ind. Mach.	13.93	1.91	4.00	16.02
356: General Ind. Mach.	23.22	4.51	6.23	24.94
357: Office and Comp. Mach.	53.69	15.15	13.44	51.98
358: Refrigeration and Service Machinery	19.48	1.42	1.16	19.22
359: Machinery, Except Electrical	16.50	1.25	0	15.25
TOTAL	193.90	36.36	35.74	193.29

* Due to 1987 changes in the SIC system, 1986 data is the most recent and reliable available at this time.

Source: USDOC, Bureau of the Census

prior levels of activity in the general recovery that followed in 1984 and beyond. Real interest rates remained high, certain investment incentives were removed from the tax code, and imports of a broad range of industrial items, including gears, increased. Many important end-markets for gears are classified within SIC major group 35 - Producer Durables or Capital Goods. As an indication of this group's poor performance, employment in SIC 35 fell by 511 thousand production workers during the recession of the early 1980s, from an all-time peak level of 1.673 million in January 1980, to 1.162 million in April 1983, a 31 percent decline.

In evaluating the strength of the industries within this group as end-markets for gears, products in industry group 357, Computer and Office Equipment were excluded, since these products use

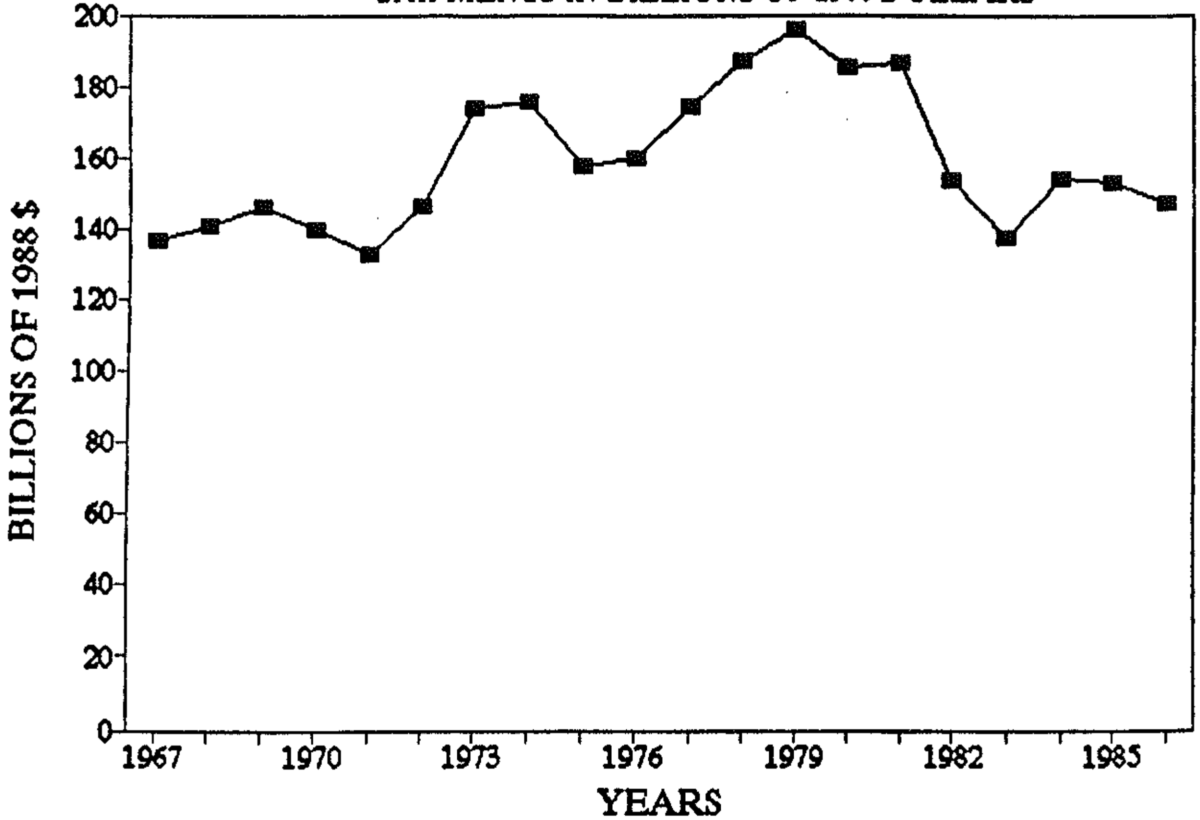
SIC 35 - Industrial and Commercial Machinery and Equipment
(except Office and Computing Machines under SIC 357)
(billions of 1988 dollars)

Year	Shipments	Exports	Imports	Apparent Consumption
1967	137.1	16.7	4.5	124.9
1968	141.3	16.9	4.9	129.3
1969	146.4	17.9	5.2	133.7
1970	140.0	19.1	5.6	126.5
1971	133.1	18.4	5.7	120.4
1972	146.4	20.0	7.3	133.7
1973	174.2	25.0	8.8	158.0
1974	175.5	30.2	9.4	154.7
1975	157.5	34.0	8.9	132.4
1976	160.2	33.3	8.6	135.5
1977	174.4	30.8	9.8	153.4
1978	187.7	32.1	12.8	168.4
1979	196.5	35.1	14.6	176.0
1980	185.7	38.9	14.1	160.9
1981	186.9	40.0	14.6	161.5
1982	154.2	32.8	12.7	134.1
1983	137.3	24.2	12.3	125.4
1984	154.1	25.1	17.5	146.5
1985	152.9	24.3	19.8	148.4
1986	147.1	22.3	23.4	148.2

Source: USDOC, Bureau of the Census

FIGURE 7: SIC 35:PRODUCER DURABLES (EXCPT SIC357)

SHIPMENTS IN BILLIONS OF 1988 DOLLARS



Source: DOC, Bureau of the Census

relatively few gears. Shipments, exports, and imports for SIC 35, excluding SIC 357, are shown in the table below.[9] Shipments for SIC 35, excluding computer and office equipment, grew by 43.3 percent between 1967 and 1979, from $137.1 billion to $196.5 billion. Shipments fell 25 percent from their peak in 1979 to $147.1 billion in 1986, going as low as $137.3 billion in 1983. Between 1967 and 1986, imports grew by 416 percent, while exports rose only 33 percent. Exports peaked in 1981, and then declined 44 percent between 1981 and 1986. In 1986, for the first time in the 1967-1986 period, imports surpassed exports.

[9] All data are in 1988 dollars, unless otherwise noted.

SIC 3523 Farm Machinery and Equipment
Industry Peak Year* and 1988 Imports and Exports
(billions of 1988 dollars)

	Peak Year: 1979	1988	% Change
Shipments	17.97	6.63	(63)
Imports	1.86	2.21	18
Exports	3.54	1.91	(46)

* Peak year = highest shipments, in 1988 dollars, since 1967.

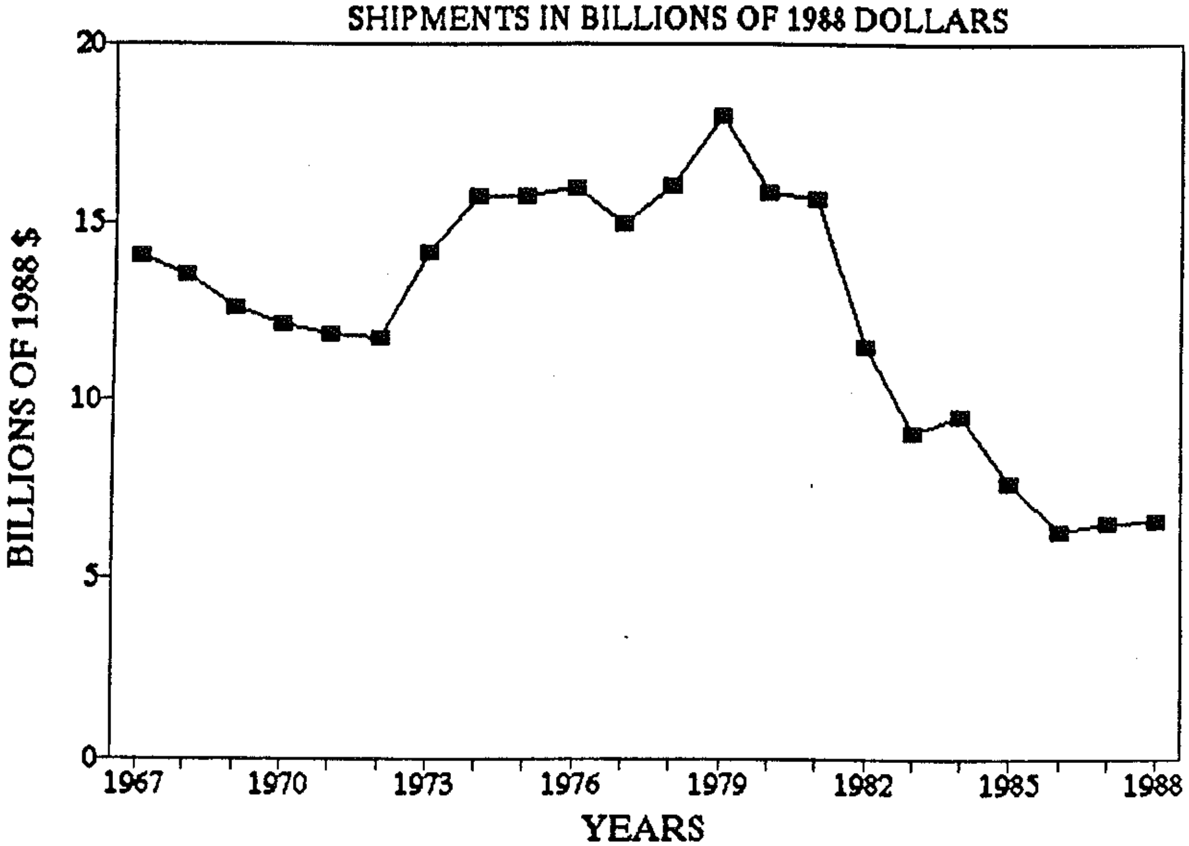
Source: USDOC, Bureau of the Census

Product shipments of farm machinery and equipment fell by nearly 65 percent from a high of nearly $18 billion in 1979 to a low of $6.3 billion in 1986. Worldwide crop failures in the 1970s created a strong export market for American farm products and, therefore, boosted demand for farm machinery. While this climaxed in 1979, the Russian grain embargo following the Soviets invasion of Afghanistan; the Iraq-Iran war, which precipitated a second round of oil price rises (1979-1980); the collapse of farm land values following a period of excessive speculation; and the U.S. Federal Reserve's battle against inflation combined to greatly reduce the demand for farm equipment, from which the farm equipment industry has never really recovered.

The industry did show some signs of improvement, with product shipments rising slightly through 1987, 1988 and 1989. However, demographic and industry structure factors do not bode well for the sale of domestically-produced farm machinery and equipment in the United States. There has been a tremendous decline in the number of active farms over the last three decades. The proportion of sales accounted for by domestically-produced equipment also fell dramatically. Between 1979 and 1988, as shown above, exports of farm machinery fell by almost 46 percent, while imports rose by 18 percent (due, in part, to equipment imported into the United States from foreign facilities of U.S. firms), signalling a weakness in domestic production.

John Deere & Company, which had 45 percent of the U.S. farm equipment market in 1988, survived hard times in the early 1980s

FIGURE 8: SIC 3523: FARM MACHINERY & EQUIPMENT



Source: DOC, Bureau of the Census

by reducing its work force and investing in more modern machinery. In 1979, the company's net earnings[10] were more than $310 million; in 1987, the company lost $99 million. In 1988, profits topped $200 million. Deere cut its work force by 44 percent between 1980 and 1988, and increased manufacturing efficiency by replacing old machine tools with newer, more productive systems.

John Deere's captive gear production suffered along with declines in demand for the firm's end-products. However, had Deere's captive shop been an independent firm, it probably would have shut down. Deere's gear operations were cutback in terms of

[10]All data for John Deere are in current dollars.

output and employment. In large part because of smaller volumes, John Deere is now considering outsourcing more of its gearing requirements. The major hesitation is finding a supplier capable of meeting Deere's high quality standards and strict delivery schedules at a reasonable and competitive price. Other gear companies with sales in the agricultural equipment business, such as Hub City in Aberdeen, SD and Adams Company in Dubuque, IA, though smaller than Deere, also experienced declines in the agricultural gear business.

SIC 3531 Construction Machinery and Equipment
(billions of 1988 dollars)

	Peak Year: 1978	1988	% Change
Shipments	24.04	12.24	(49)
Imports	1.33	2.70	103
Exports	6.81	3.37	(50)

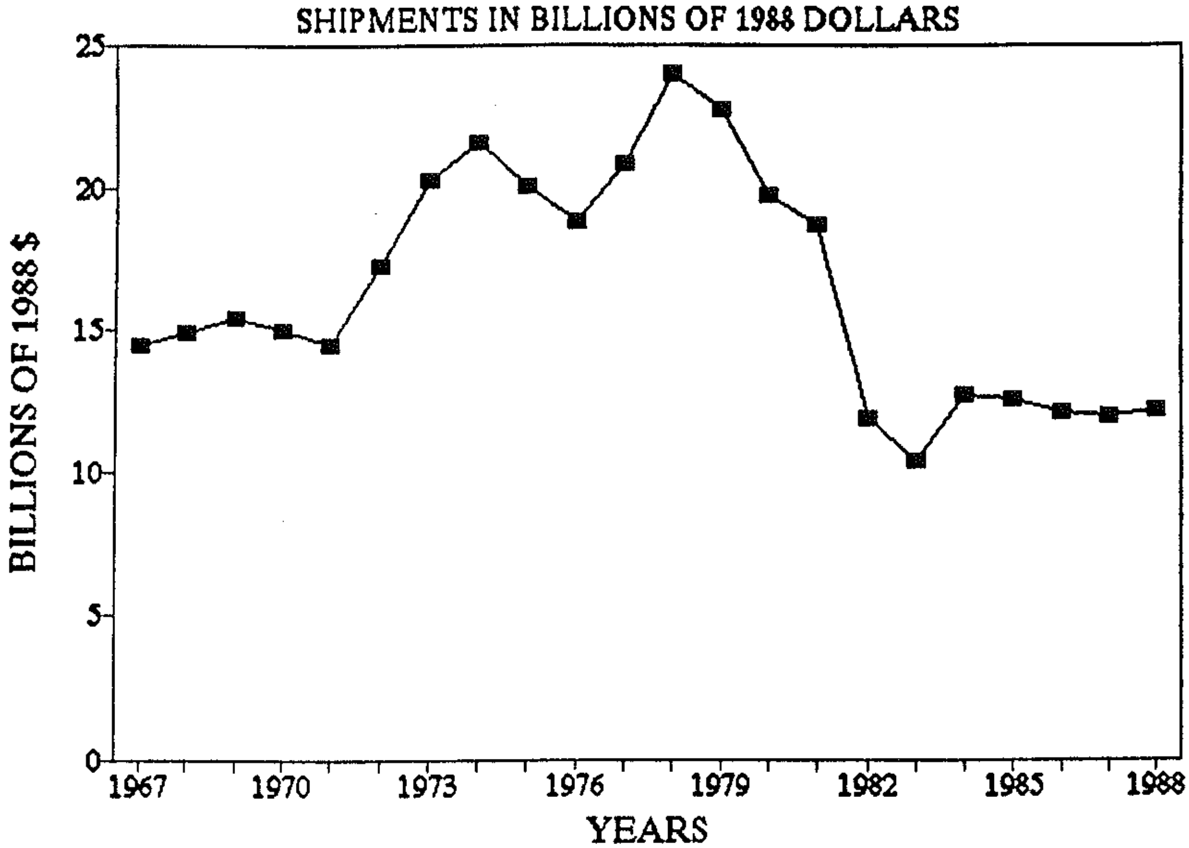
* Peak year = highest shipments, in 1988 dollars, since 1967.

Source: USDOC, Bureau of the Census

Like farm equipment, shipments of construction machinery also fell, from a high in 1978 of $24 billion to a low of almost $12.0 billion in 1987, a drop of 50 percent. Shipments have started to climb, with 1988 shipments of $12.2 billion. Between 1978 and 1988, imports grew by 103 percent, while exports fell by 50 percent. Activity in building construction, public works, and surface mining are the main determinants of demand for construction machinery. Like the farm machinery industry, the construction equipment industry is international; many U.S. firms have recently established manufacturing facilities abroad and now import some equipment from their foreign facilities.

Caterpillar, Inc. has long been a leader in the U.S. construction equipment market. However, it suffered deep losses when demand for its products fell, and along with other firms such as Dresser Industries, it lost sales opportunities after the U.S. embargoed export of construction equipment for use in building the Soviet gas pipeline into Western Europe in the early 1980s. Japan's Komatsu Ltd., gained much of this business as a result, and

FIGURE 9: SIC 3531: CONSTRUCTION MACHINERY



Source: DOC, Bureau of the Census

has since entered the U.S. market and become a major factor. To survive, Caterpillar cut its work force between 1982 and 1988 and closed several plants. The resulting lower costs helped the company keep its prices low: its prices[11] rose only 9.5 percent between 1981 and 1988, while Komatsu's prices rose by as much as 20 percent. Also, Caterpillar added new products to its line and implemented product improvements. As a result, its profits recovered, and it regained some of the market share that it had lost to Komatsu. Komatsu is not out of the picture. It formed a joint venture with Dresser Industries, in which the two companies combined their construction equipment businesses in North America.

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[11]Data in current dollars.

Caterpillar's captive gear shops in Illinois decreased in concert with the construction business. In the early 1980s, Caterpillar's management ordered an in-depth study to determine whether to outsource gears or continue producing them in-house. The decision was made to retain gear production in-house. Since then, the firm has committed the resources to make high quality gears efficiently under the rubric 'Factory with a Future.' Many other gear companies lost business during this period. Some of these were Twin Disc, Regal Beloit and Clark Equipment. Additional business was lost as imports of construction equipment (containing gear systems) more than doubled, and exports fell by half.

SIC 3532 Mining Machinery and Equipment
(billions of 1988 dollars)

Peak Year:	1976	1988	% Change
Shipments	3.55	1.42	(60)
Imports	0.11	0.25	139
Exports	0.67	0.42	(38)

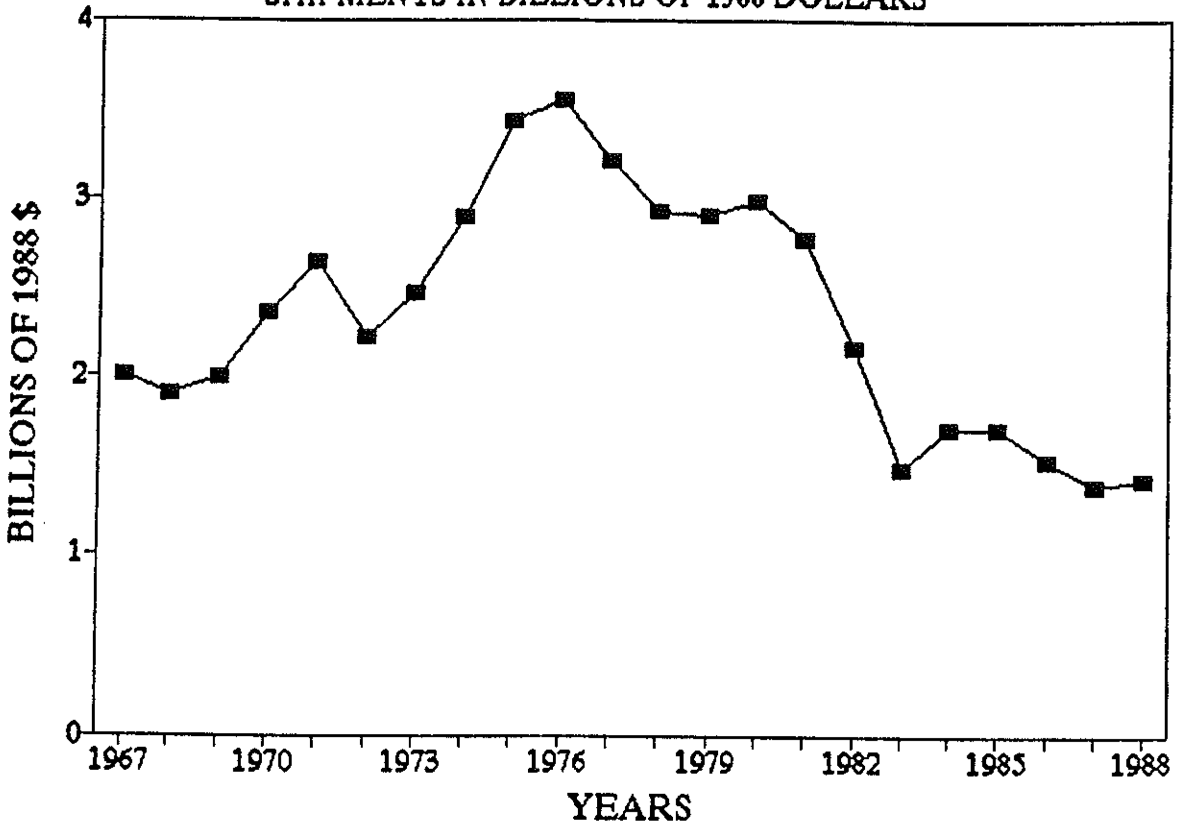
* Peak year = highest shipments, in 1988 dollars, since 1967.

Source: USDOC, Bureau of the Census

The mining equipment industry has suffered recently, as well. In 1988, shipments totaled just over $1.4 billion, down about 60 percent from a high in 1976 of almost $3.55 billion but up slightly from 1987 levels. Imports rose by 139 percent between 1976 and 1988, while exports fell nearly 38 percent. The market for mining equipment is largely a function of the demand for mine products; the industry profits when industrial production levels and construction activity are high, creating demand for basic metals and quarry products. Harnischfeger saw its captive gear business decrease with declines in sales of mining equipment. Other affected gear firms included Renold, Fairfield, and Regal Beloit.

FIGURE 10: SIC 3532: COAL MINING MACHINERY

SHIPMENTS IN BILLIONS OF 1988 DOLLARS



Source: DOC, Bureau of the Census

SIC 3533 Oil and Gas Field Machinery and Equipment
(billions of 1988 dollars)

	Peak Year: 1981	1988	% Change
Shipments	10.78	2.75	(73)
Imports	0.29	0.05	(83)
Exports	4.55	2.30	(50)

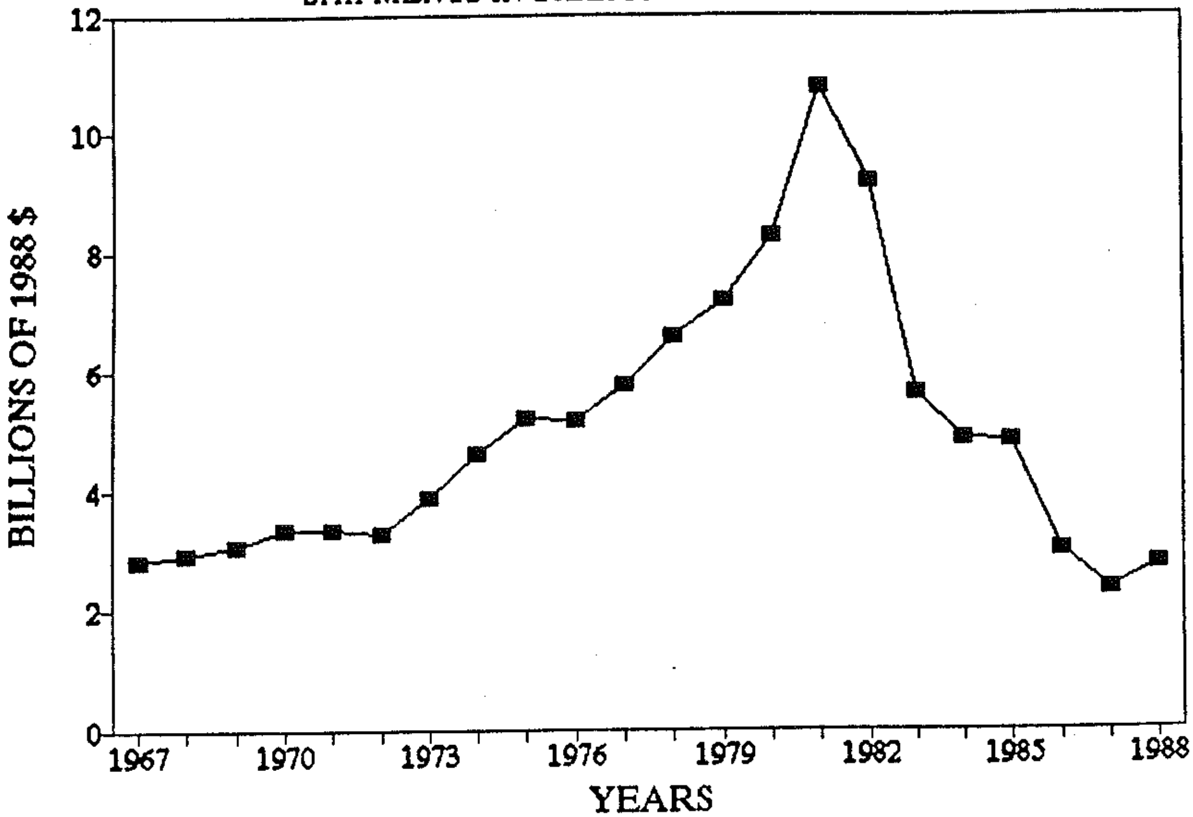
* Peak year = highest shipments, in 1988 dollars, since 1967.

Source: USDOC, Bureau of the Census

Shipments of oil and gas field machinery grew steadily from $2.8 billion in 1967 to almost $10.8 billion in 1981, a rise of 282 percent. Since then, shipments have declined, and 1988

FIGURE 11: SIC 3533: OIL & GAS FIELD MACHINERY

SHIPMENTS IN BILLIONS OF 1988 DOLLARS



Source: DOC, Bureau of the Census

shipments, totaling $2.75 billion, fell below those of 1967. Not surprisingly, shipments peaked with the oil boom and then declined throughout most of the 1980s. Imports declined 83 percent between 1981 and 1988, and exports dropped 48 percent. In recent years, export markets have been the mainstay of the industry, as foreign drilling activity has increased.

At one time, oil field equipment accounted for 47 percent of Dresser Industries' profits. However, after the onset of the oil bust in 1982, the company turned five of its seven oil services divisions into joint ventures and cut its work force in half. Dresser diversified into related areas, such as refinery construction and energy processing equipment, and also sold its gear production division. These moves helped to save the company from greater revenue losses than it might have suffered, had it stayed in the oil services business. Lufkin's captive gear shop collapsed with the oil field equipment market. Lufkin, although captive, also sold gears to others in other gear markets for a substantial part of its business. This helped the firm survive. Many other gear shops lost business, particularly in the pump-jack market during this period.

SIC 3541 Machine Tools, Metal Cutting Types, and
SIC 3542 Metal Forming Types*
(billions of 1988 dollars)

	SIC 3541			SIC 3542		
Peak Year	1967	1988	%change	1973	1988	% change
Shpmts.	8.29	2.35	(72)	3.02	1.84	(39)
Imports	0.67	1.91	187	0.14	0.57	302
Exports	0.70	0.69	(1)	0.45	0.53	19

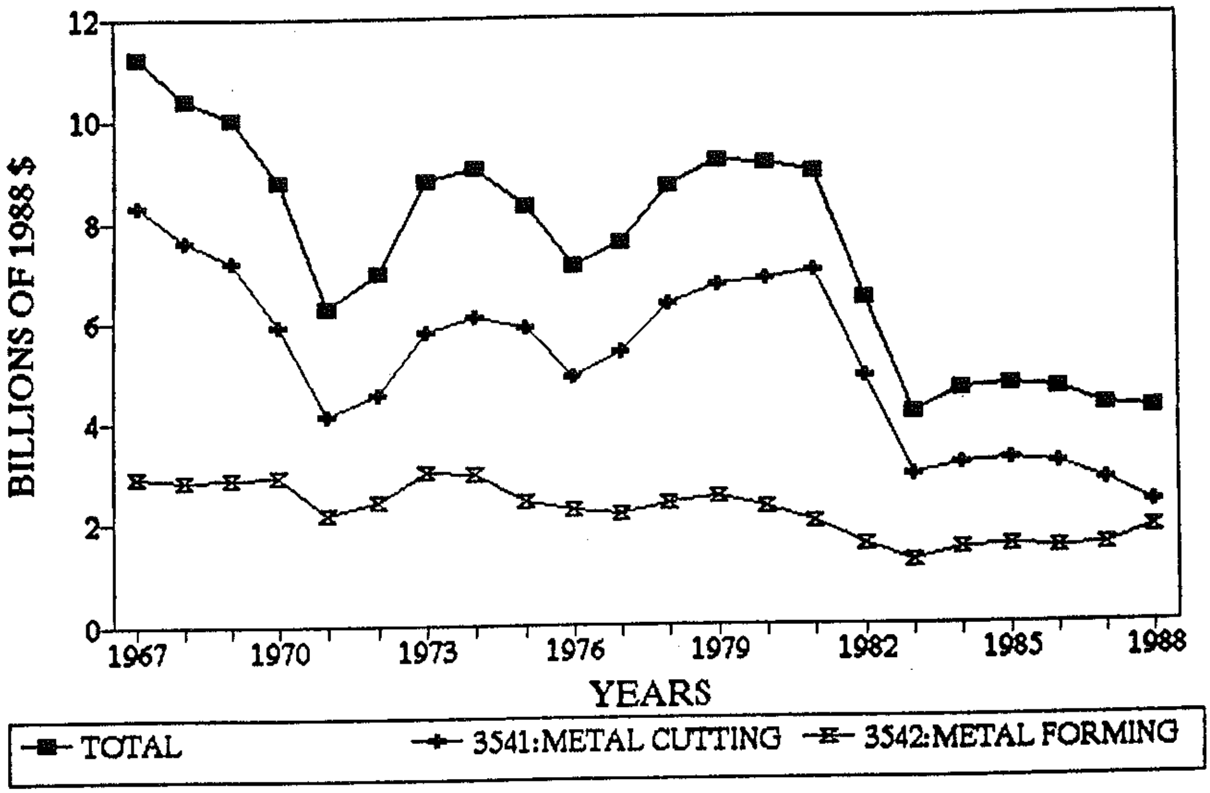
* Peak year = highest shipments, in 1988 dollars, since 1967.

Source: USDOC, Bureau of the Census

The machine tool industry, as a rule, suffers disproportionately in periods of economic decline. As suppliers to other manufacturing industries, machine tool manufacturers are the first to feel the effects of economic downturns and the last to recover, as their customers accelerate capital spending. Shipments of metal cutting machine tools fell 60 percent between 1967 and 1986. Shipments of metal forming machine tools fell 59 percent between 1973 and 1983, then began a slow recovery. However, shipments of these tools for 1988 were below 1970 shipments. Unit shipment losses were also dramatic. In 1967, 117,651 metal cutting and metal forming machine tools were shipped; in 1988, that number was 48,668, down nearly 59 percent.

Most of the major machine tool companies - Cincinnati Milacron, Brown and Sharpe, and J. Lamb, etc. - have lost stature from their once dominant positions. This is exemplified by Cross & Trecker. Cross & Trecker, once considered one of America's strongest machine tool manufacturers, has been slow in recovering from the economic downturn of the early 1980s. The company lost share in auto transfer lines, the machines that shape parts for motor vehicles, dropping from 25 percent market share to under 11 percent during the mid-1980s.

FIGURE 12: SIC 3541 & 3542: MACHINE TOOLS
SHIPMENTS IN BILLIONS OF 1988 DOLLARS



Source: DOC, Bureau of the Census

During the last decade, the company acquired a number of machine tool companies including Kearney & Trecker (machining centers) and Warner & Swasey (lathes). Recent increased domestic orders across several of these lines and cost-cutting efforts have helped, but recovery has been slow. The company continues to face stiff competition from the Japanese.

As previously discussed, many machine tools have reduced gear content because of advances in servo drives and hydraulic technologies. The impact on gear companies, therefore, has been greater than just the decline in machine tool shipments. Many gear companies were affected, but most survived by diversifying or expanding gear sales into other areas. Affected gear firms included Grant Gear, Niagara Gear, Moore Gear, Patterson Gear and many others. A much smaller machine tool market remains.

SIC 3519 Internal Combustion Engines, Except Aircraft and Nondiesel Automotive

Shipments of internal combustion engines grew 88 percent between 1967 and 1978, from $8.16 billion to $15.35 billion. Between 1978 and 1983, shipments fell more than 39 percent, to $9.28 billion, below 1969 levels. The industry has recovered somewhat in recent years, with 1987 shipments of $11.1 billion. Cummins Engine is a major player in this market and has a captive gear shop. Other gear companies that supply this market include Skidmore Gear and LM Gear.

In summary, many of the most important industrial gear markets as defined in SIC 35 - Producer Durables (except SIC 357-Computer and Office Equipment) contracted dramatically and are not expected to return to prior high levels in the foreseeable future. After many years as a leading exporter, the Producer Durables sector is now a net importer. Thus, while exports fell 44 percent between 1981 and 1986 to $22.3 billion, imports grew by over 60 percent to $23.4 billion. In fact, the industry went from a trade surplus of $25.4 billion in 1981 to a deficit of $1.1 billion. This is a total net change of $26.5 billion, or an estimated trade related net loss of business to industrial gear firms of $265 million (assuming conservatively a one percent gear content within all products in SIC 35).

SIC 37 TRANSPORTATION EQUIPMENT

Another major SIC group containing many end-markets for gears is SIC 37, Transportation Equipment. This group includes, among others, the motor vehicle, aerospace, and shipbuilding and repair industries.

In dollar amounts, shipments of motor vehicles and car bodies rose 85 percent between 1967 and 1978; between 1978 and 1982, however, shipments decreased by nearly 39 percent, falling below 1968 levels. Shipments have been rising since 1982, reaching $127.7 billion in 1988, up nearly 67 percent from 1982 shipments of $76.6 billion.

Unit shipment data indicate an interesting trend. In 1967, the number of passenger cars shipped outstripped the number of trucks and buses shipped by a ratio of 4.8 to 1. In 1988, that ratio was 1.7 to 1. Unit shipments of both categories peaked in the late 1970s and declined in the recession of the early 1980s, each dropping by about 45 percent between 1977 and 1982. However, between 1982 and 1988, unit shipments of trucks and buses rose by 115 percent, while the number of passenger cars shipped rose by only 41 percent.

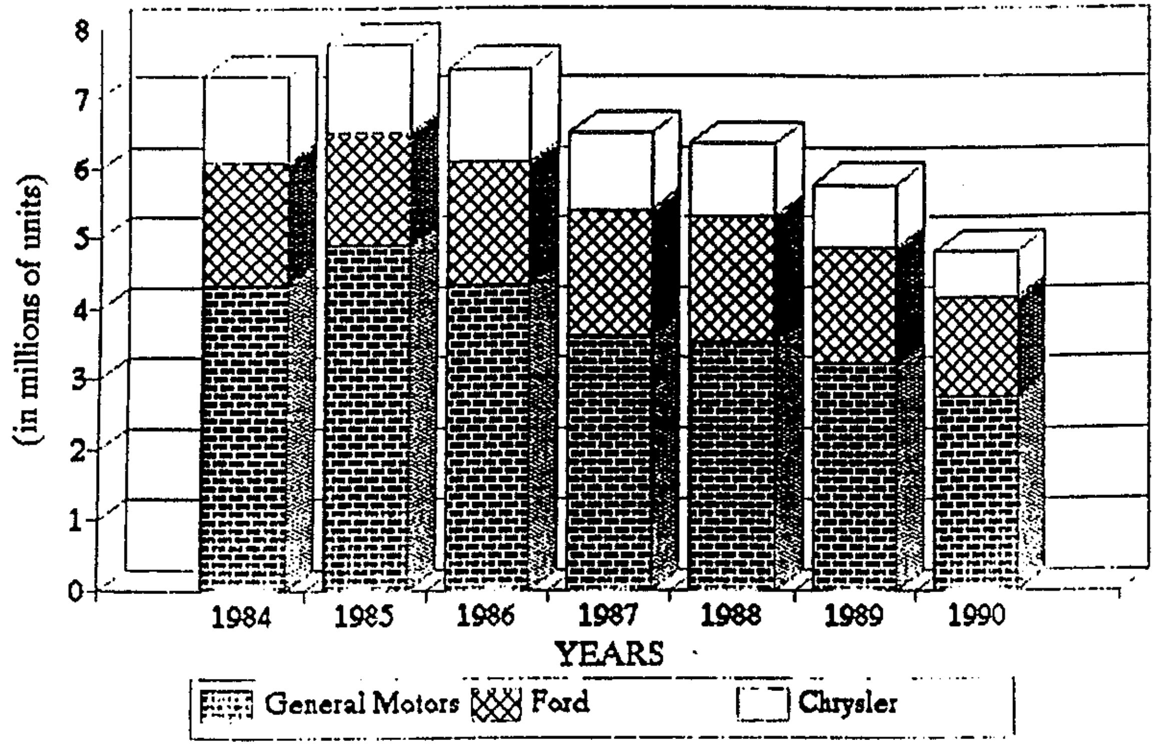
Motor Vehicle Production, 1985-1990
by General Motors, Ford and Chrysler
(in 000s of units)

	Passenger Cars					
	1985	1986	1987	1988	1989	1990
General Motors	4,887	4,316	3,603	3,501	3,214	2,747
Ford	1,636	1,764	1,830	1,806	1,677	1,381
Chrysler	1,266	1,347	1,109	1,073	916	681
Total:	7,789	7,427	6,542	6,380	5,807	4,809
	Trucks					
	1985	1986	1987	1988	1989	1990
General Motors	1,537	1,519	1,521	1,661	1,592	1,496
Ford	1,218	1,382	1,479	1,519	1,497	1,366
Chrysler	449	344	555	655	660	536
Total:	3,204	3,245	3,555	3,835	3,749	3,398
Combined Total:	10,993	10,672	10,097	10,215	9,556	8,207

Source: Motor Vehicle Manufacturer's Association

General Motors, Ford, and Chrysler each have captive gear production, and have made substantial investments to improve gear quality, and extend the life of their transmissions to cover the life of their vehicles. However, the large domestic auto companies continue losing market share to imports (despite the

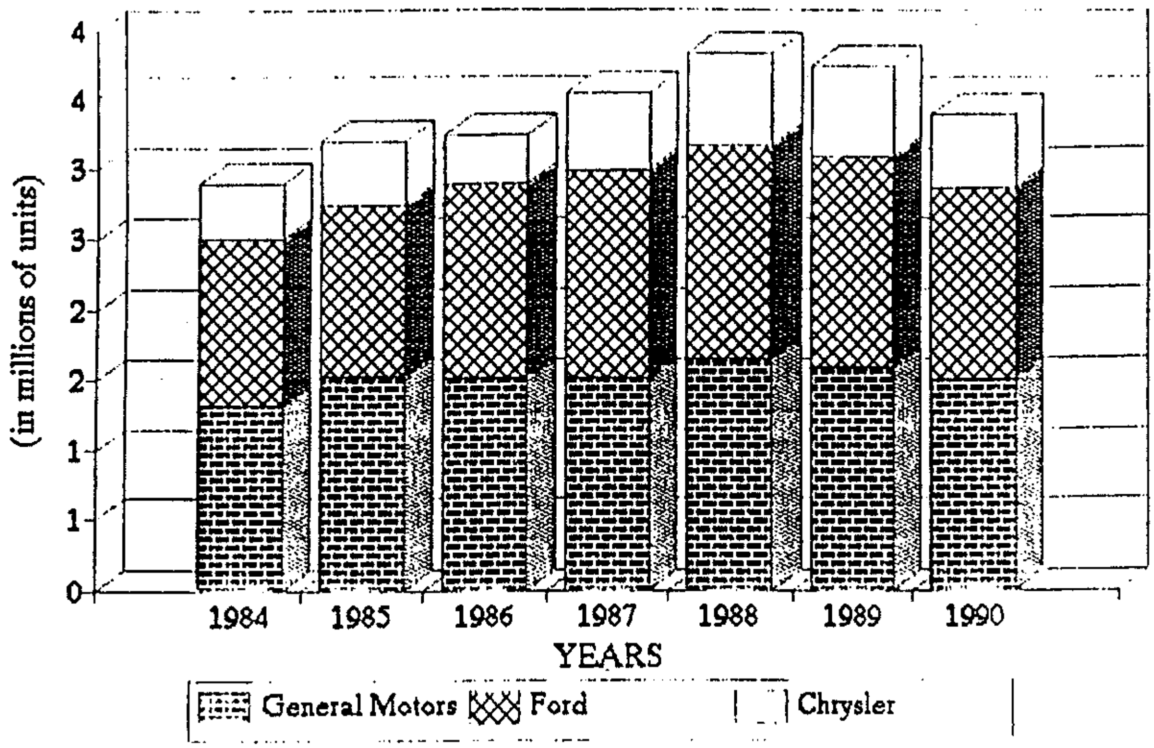
FIGURE 13 : PASSENGER CAR SHIPMENTS, 1984-1990
GENERAL MOTORS, FORD & CHRYSLER



Source : Motor Vehicle Manufacturers Association

Voluntary Restraint Agreements self-administered by the Japanese) and transplanted foreign producers. In 1990, the three are only expected to produce 4.8 million cars in the United States, compared with 7.8 million just five years ago. This is a drop of three million units, or slightly more than 38 percent. The increased production of trucks, which includes mini-vans, jeeps and pick-up trucks, rose from 3.2 million to 3.8 million between 1985 and 1988. However, since 1988, truck production has dropped 11 percent to an estimated 3.4 million units in 1990. The captive gear production operations of the auto companies require volume throughput to operate efficiently. As previously mentioned, GM and Chrysler formed a joint venture in Muncie, IN to build manual transmissions. This was a cost cutting action to take advantage of economies of scale, and could set the stage for additional ventures in the future. In fact, if present downward

FIGURE 14 : TRUCK SHIPMENTS, 1984-1990
GENERAL MOTORS, FORD & CHRYSLER

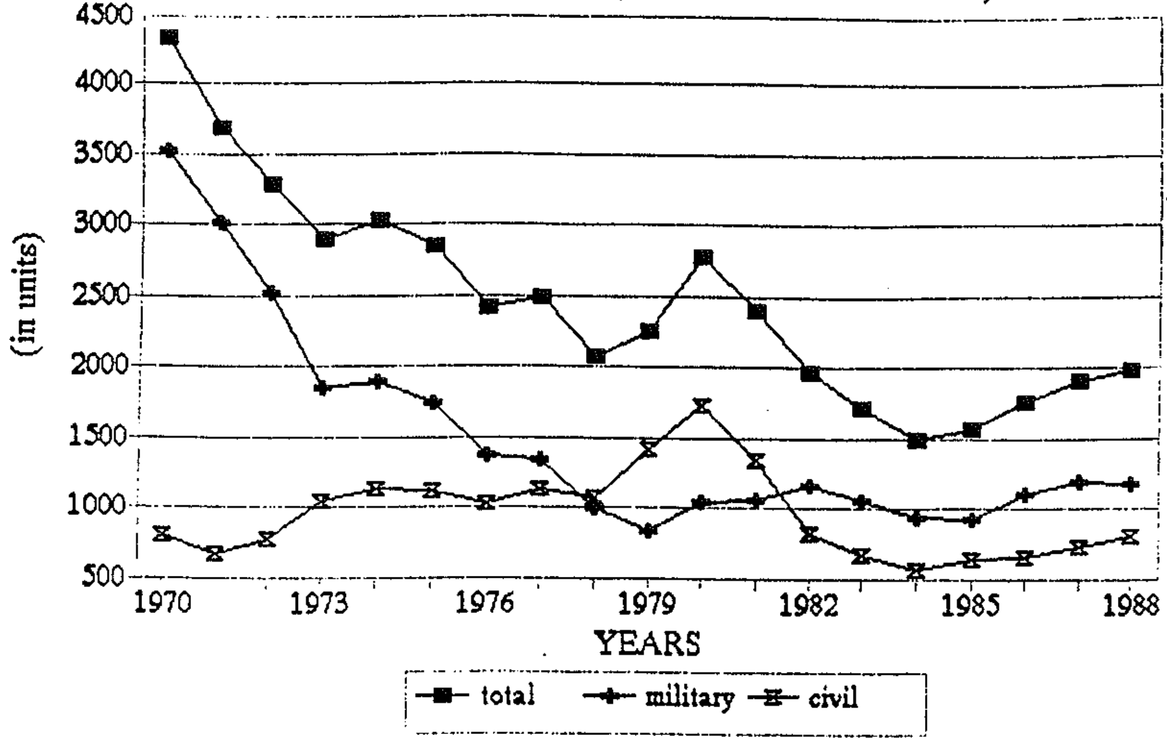


Source : Motor Vehicle Manufacturers Association

trends continue, it is likely some of these captive operations will be realigned as parts of joint ventures, while others may be spun-off, or liquidated.

Total unit shipments of U.S. aircraft declined by 73 percent between 1977 and 1988, dropping from 11,632 units to 3,133. Data for individual sectors showed mixed performances. Shipments of large transports rose, irregularly by 36 percent between 1970 and 1988. Growth in air passenger traffic fueled demand for new large commercial aircraft, as did increased air freight activity. Unit shipments of general aviation aircraft peaked in 1978 at 17,811 units, up 144 percent from 1970's shipments of 7,292. However, because of numerous product liability suits brought against U.S. producers, shipments of general aviation aircraft nosedived between 1978 and 1988, dropping by 94 percent.

FIGURE 15 : AIRCRAFT PRODUCT SHIPMENTS, 1970-1988
CIVIL & MILITARY (EXCPT GEN. AVIATION)



Source : Aerospace Facts and Figures, 1990

Shipments of rotorcraft or helicopters grew by 173 percent between 1970 and 1980, the peak year. Between 1980 and 1988, the number shipped dropped by 72 percent. Shipments of military aircraft fell irregularly, largely at the mercy of defense budgets, from 3,534 units in 1970 to 1,185 in 1988; military aircraft shipments hit a low of 837 units in 1979.

The aerospace industry consumes a variety of gears for use in engines, differential transmissions, auxiliary power units, flap actuators, and gear-type fuel and hydraulic pumps. Aerospace gears are generally lightweight high precision gears, used as part components and subassemblies in helicopters, fixed-wing aircraft, spacecraft, missiles, and satellites. Aerospace gears can be grouped into three different sized categories. The largest and strongest gears, which convey very high torque (turning) forces, are usually found in turbo-shaft, drive line gear boxes used for helicopters or tilt-wing aircraft. Medium sized gears are used in landing gear retraction mechanisms, flap or control surface actuators, and aircraft accessory gear boxes. Small gears are required to run at varying speeds for use in fuel, lubrication, and scavenge pumps, in different types of actuators, and in various control functions and instrumentation.

Over the last 20 years unit production of aircraft has fallen while unit value has increased enormously, mostly because of increased aircraft sophistication, lower order quantities, and the growth of avionics. While the gearing has also improved, its relative value to the value of the helicopter or fixed wing aircraft continues to decline.

The U.S. shipbuilding industry has been on the decline since the early 1970s. Losses in merchant vessel construction are especially striking. In 1972, 47 new contracts for merchant vessels were placed with U.S. private shipyards; between 1985 and 1989, no new orders were placed, and after 1987, no new merchant type vessels were delivered by U.S. private shipyards. Japan leads the world in merchant vessel production, followed by South Korea. Foreign shipbuilders enjoy a significant cost advantage over domestic producers, due, in part, to direct subsidies provided by foreign governments. Orders for military vessels provide business for some private shipyards and have been on the rise in recent years. In 1988, 32 orders for new naval combatant and auxiliary vessels were placed, the high point of the period between 1968 and 1988.

The transportation equipment sector is far and away the largest consumer of gear products. The sector is also a major consumer of parts and components, and capital machinery produced in SIC 35 - the producer durables sector. The problems this sector is experiencing are enormous, and for the most part beyond the purview of this report. However, each industry within this sector - motor vehicles, railroads, aerospace, shipbuilding, etc. - has long been global in scope, and each continues to lose market share in almost every market where they compete, including in our own vast domestic market. If this trend continues, the gear sector is doomed to follow.

RECENT INDUSTRY PERFORMANCE

The information presented in this section is based on U.S. gear producer data collected by the ITC in the joint ITC/DOC survey of the industry conducted in the fall of 1989. The Commerce Department compiled a separate data base from this data, that does not in all instances agree with the compilations of the ITC. Noticeable discrepancies appear in the size of the industrial gear sector and the motor vehicle gear sector. These are due to differences in the way the industries were constituted, as well as differences in estimation procedures.

Motor Vehicle Gear Sector

In 1988, the top four motor vehicle gear producers accounted for 78 percent of the business, and the top eight, for 90 percent. This level of concentration remained about the same during the 1984-1988 period. In 1988, firms with over $100 million in sales accounted for almost 97 percent of the total.

Motor vehicle gear shipments rose from $8.9 billion in 1984, to $10.2 billion in 1988, a 15 percent increase. However, during the same period, the production of passenger cars in the United States by General Motors, Ford, and Chrysler, who each produce gear systems in captive shops, fell from 7.4 to 6.3 million. The increase in the dollar value of shipments was caused by a shift toward light trucks and vans, and renewed popularity with four wheel drives, all of which use more elaborate and expensive gear systems, and not by a unit increase. Production of trucks and buses by all producers in the United States increased from 3.1 to 4.1 million over the same period. Most of these were light trucks (pick-ups) and vans, including the very popular mini-vans.

Imports of motor vehicle gearing increased from $1.44 billion in 1984, to $2.12 billion in 1988. As a percent of apparent consumption, imports rose from 16.9 to 20.7 percent. Much of the increase came from foreign owned motor vehicle manufacturers, who established and expanded production in the United States during this period and imported motor vehicle gearing from their home countries. In 1984, Honda and Volkswagen together produced 214 thousand vehicles in the United States. By 1988, production by these companies along with new production by Toyota, Nissan, and

Mazda totalled about 750 thousand vehicles. In addition, Ford and Chrysler began importing some standard transmissions, and GM began importing six speed transmissions for Corvettes.

Exports also rose slightly during the 1984-1988 period from $1.74 to $2.10 billion, mostly to the Canadian operations of the American auto companies. The trade balance was in surplus at the beginning of the period, but fell into deficit in 1986, at $40 million. The deficit increased to $260 million in 1987, but then fell back to $17 million in 1988.

Motor Vehicle Gear Sector
Total Shipments, Imports, Exports
and Defense Shipments, 1984-1988
(in $000,000s)

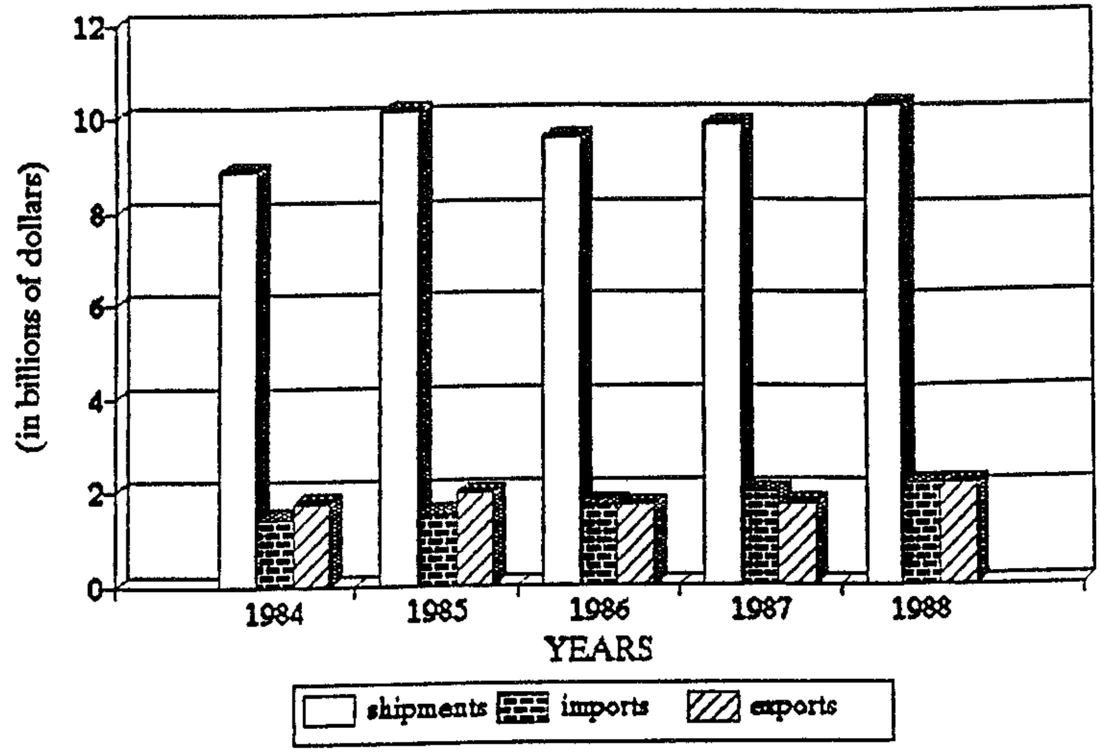
	1984	1985	1986	1987	1988
Total Shipments	8,856.7	10,120.3	9,546.4	9,811.2	10,202.4
Imports	1,443.8	1,520.7	1,701.9	1,944.1	2,118.2
Exports	1,737.0	1,946.2	1,661.5	1,683.8	2,101.4
App. Consumption	8,563.5	9,694.8	9,586.8	10,071.5	10,219.2
% Imports	16.9	15.9	17.8	19.3	20.7
Trade Balance	293.2	425.5	(40.1)	(260.3)	(16.8)
Defense Shipments*	150.9	129.2	98.5	72.6	60.4
% Defense*	1.7	1.3	1.0	0.7	0.6

* Likely understated due to incomplete data

Defense shipments by the motor vehicle gear sector are understated, as several major companies failed to supply the information. From the data available, defense shipments ranged from 1.7 percent of total shipments in 1984, to less than .6 percent in 1988.

Motor Vehicle Gear Sector Outlook - Despite major improvements in motor vehicle quality in recent years, the major three domestic auto companies are expected to lose additional market share in the next five years. The motor vehicle gear sector will follow

FIGURE 16 : MOTOR VEHICLE GEAR SECTOR
SHIPMENTS, IMPORTS, AND EXPORTS



Source : Compiled from ITC/DOC Industry Survey Data

the same downward path. In 1990, combined passenger car and truck production by the major three domestics is expected to total only 8.2 million, down almost 2.8 million from 1985. This is a decline of over 25 percent. Trucking firms, such as Mack Trucks, Navistar, and Freightliner (recently bought by Daimler-Benz) are not doing well either as sales continue to slip.

Industrial Gear Sector

The industrial gear sector contains more firms and establishments than the other three sectors combined. A total of 108 firms operating 155 establishments in the industrial gear sector responded to the ITC/DOC survey. The top four firms in the industrial gear sector made about 38 percent of the industrial type gear shipments in 1988, and the top eight, 53 percent.

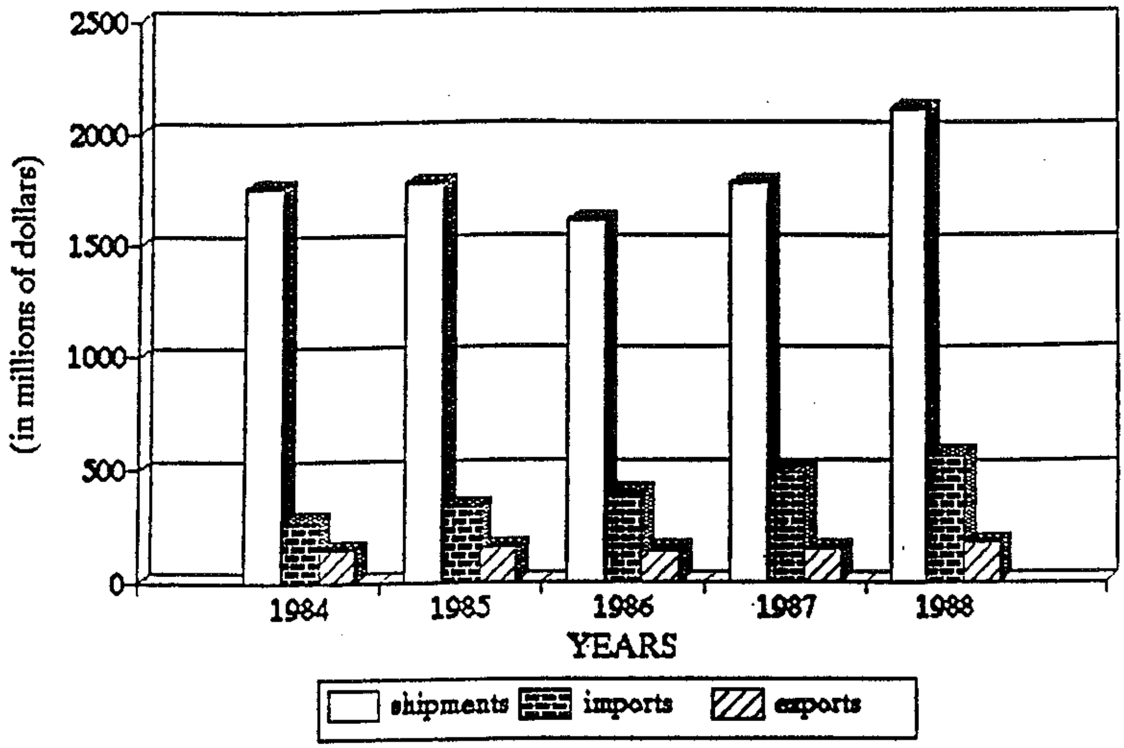
Shipments of industrial gears fell from $1.8 billion in 1984 and 1985, to a five year low of $1.6 billion in 1986. In 1986, about one third of the firms reported losses, and according to the Bureau of the Census "County Business Patterns," ten establishments with over 100 employees either shut down, or substantially reduced employment. During the next two years, as demand in many markets improved, shipments rose almost 31 percent to $2.1 billion in 1988. However, not all firms participated in the increase as 26 reported a drop in sales between 1987 to 1988.

Total Shipments, Imports, Exports
and Defense Shipments, 1984-1988
(in $millions)

	1984	1985	1986	1987	1988
Total Shipments	1,752.3	1,767.8	1,606.4	1,773.0	2,101.8
Imports	266.3	329.0	391.5	479.6	561.1
Exports	144.6	148.3	136.4	145.8	166.7
App. Consumption	1,874.0	1,948.5	1,861.5	2,106.8	2,496.2
% Imports	14.2	16.9	21.0	22.8	22.5
Trade Balance	(119.7)	(180.7)	(255.1)	(333.8)	(394.4)
Defense Shipments*	61.3	64.1	54.4	70.4	70.8
% Defense*	3.5	3.6	3.4	4.0	3.4

* Likely understated due to incomplete data

FIGURE 17: INDUSTRIAL GEAR SECTOR
SHIPMENTS, IMPORTS, AND EXPORTS



Source: Compiled from ITC/DOC Industry Survey Data

Several key firms failed to report defense shipments. The reported amount at less than four percent of shipments, is likely understated. In fact, we estimate that direct and indirect defense shipments account for between 5-10 percent of shipments.

In addition, their importance as components in machinery and equipment used throughout the defense industrial base, while difficult to quantify, should not be overlooked or minimized. Reported defense shipments reached a low point in 1986, at only $54 million (3.4 percent of sales). In 1988, reported defense shipments rose to $71 million, but since overall shipments increased proportionately, still accounted for only 3.4 percent of sales.

Imports during the period rose dramatically from $266 million in 1984, to over $561 million in 1988. This is a 111 percent increase, which occurred despite the drop in the value of the dollar against major currencies after 1985. Also, imports rose each year, even in 1986, when overall demand was declining. Import penetration levels increased from 14.2 percent in 1984, to 22.8 percent of apparent consumption in 1988.

It is evident that imports are capturing the more lucrative and larger orders first[12]. These were previously supplied by larger domestic establishments (over 500 employees) that, as already mentioned, experienced a 65 percent decline in shipments between 1977 and 1987. Orders of a smaller magnitude will be tougher to supply from overseas. However, the major foreign firms have rapidly expanded their capabilities in the United States by building new facilities, or buying existing ones. In 1988, an estimated $118 million of industrial gearing was produced in the United States in foreign owned facilities, up from about $46 million in 1984.

Exports changed little during the period, although they rose about 23 percent by 1988 to $167 million, from a 1986 low of $136 million. Exports remained around 8 percent of shipments over the period. The trade deficit in industrial gearing grew from $119.7 million in 1984, to $394.4 million in 1988.

Industrial Gear Sector Outlook - The U.S. industrial gear sector has serious competitive problems and is burdened with excess capacity. It is likely the industry will experience further consolidations, especially if the economy moves into a recession. Overall, U.S. demand for industrial gears will probably be static for the next five years, with selected sectors, such as food processing equipment, expected to improve. Foreign presence in the American market can be expected to increase, both in imports and in ownership of domestic manufacturing capacity.

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[12] Allegations of gearing being dumped in the American market in violation of unfair trade laws have been made by several gear firms and the American Gear Manufacturers Association. In addition, industry survey responses strongly favored some kind of government assurance of fair global competition, and strict policing of suspected dumping activities.

Aerospace Gear Sector

The aerospace gear sector reported production of a larger dollar amount for the military than the other three sectors combined. More than half of these shipments were accounted for by helicopters, a particularly intensive application of gear systems. By some estimates, as much as 20 percent of the cost of a helicopter can be the gearing, although the increased use of avionics in helicopters probably makes this estimate high. In contrast, gearing on commercial jetliners or fighter aircraft represent only about 2 percent of the value.

Several aerospace gear firms dedicate nearly 100 percent of their business to defense. These are primarily companies with a major part of their business focused on helicopters - Speco, Litton, Sikorsky, Bell, International Gear Works (formerly Indiana Gear), RAF and Fenn. It would appear the overhead, such as special testing equipment, rigorous design and engineering specifications, material usage and other special problems, might make it difficult for these firms to compete effectively in the non-defense aerospace market.

The top four firms in the aerospace gear sector account for about 50 percent of the business, and the top eight for 75 percent. Aerospace gear shipments peaked in 1986 at $750.8 million. Defense shipments also reached a peak that year at $515.8 million. By 1988, total shipments were down 3.4 percent to $725.1 million, while defense shipments were down 7.7 percent to $476 million. As a percent of total shipments, defense rose from 65.2 percent in 1984 to 68.7 in 1986, and then contracted back to 65.7 percent by 1988. Non-defense shipments rose from $227.9 million in 1984 to $249.1 million in 1988, a 9.3 percent increase.

In 1988, the aerospace gear sector had a positive trade balance of $94 million, equal to about 15 percent of apparent consumption. Both imports and exports expanded over the period from 1984-1988. Imports doubled from a small base of $25 million in 1984, to $49.5 million in 1988. Expressed as a percent of apparent consumption, imports rose from 4.3 percent to 7.8 percent. Exports increased 47 percent between 1984 and 1988,

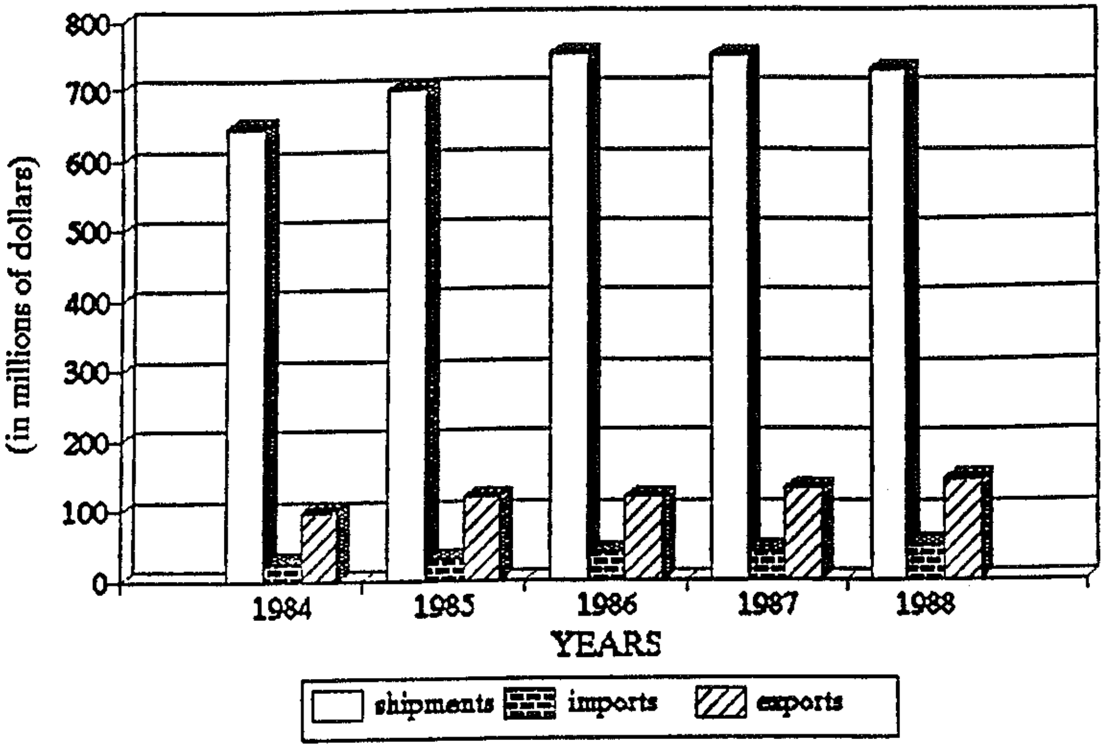
Aerospace Gear Sector
Total Shipments, Imports, Exports
and Defense Shipments, 1984-1988
(in $000,000s)

	1984	1985	1986	1987	1988
Total Shipments	654.6	698.2	750.8	746.6	725.1
Imports	25.0	30.6	38.5	40.6	49.5
Exports	98.0	118.5	118.7	129.3	143.7
App. Consumption	581.6	610.3	670.6	657.9	630.9
% Imports	4.3	5.0	5.7	6.2	7.8
Trade Balance	73.0	87.9	80.2	88.7	94.2
Defense Shipments	426.7	461.1	515.8	506.9	476.0
% Defense	65.2	66.0	68.7	67.9	65.7

expanding from $98 million to $143 million. As a percent of shipments, exports rose from 15 percent in 1984, to 20 percent in 1988.

Aerospace Gear Sector Outlook - The five year outlook for the aerospace gear sector is for declines in defense shipments, and further increases in commercial shipments. Overall, the market is expected to contract somewhat because of declines in military helicopter production. Also, expect pressures from international competitors to increase. Several firms in the sector are having serious financial problems, and one or more of these are likely to exit the business.

FIGURE 18 : AEROSPACE GEAR SECTOR
SHIPMENTS, IMPORTS, AND EXPORTS



Source : Compiled from ITC/DOC Industry Survey Data

Marine Gear Sector

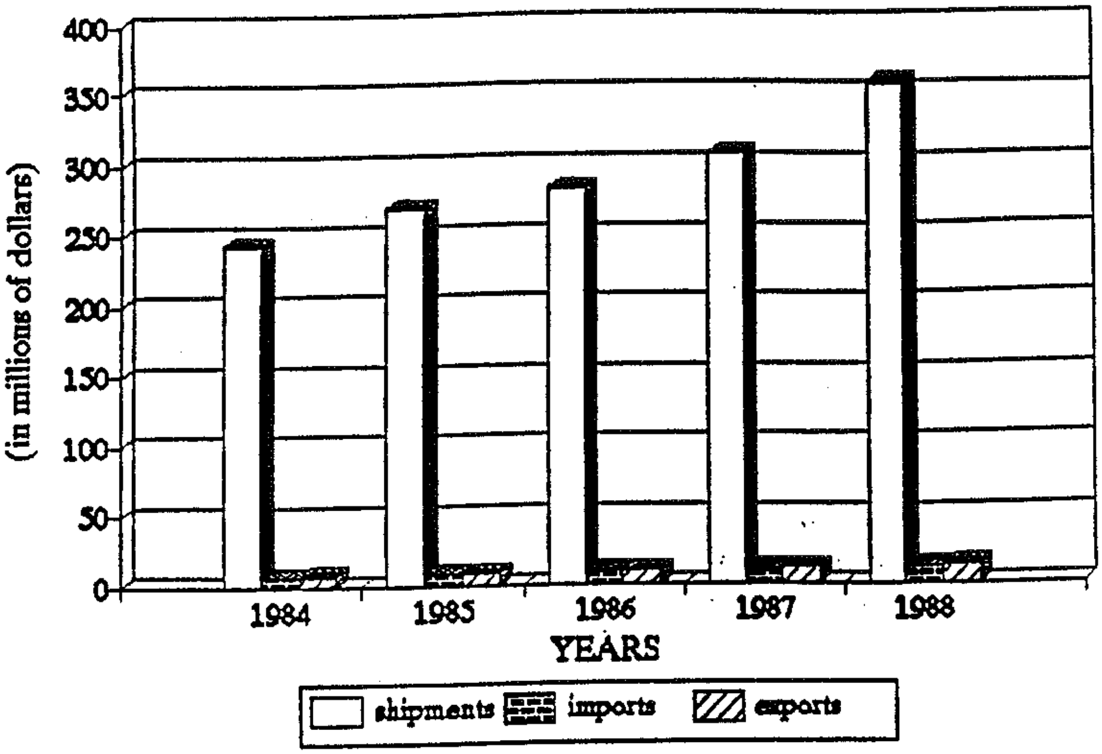
The marine gear sector makes some of the largest and highest precision gears in existence, which can cost many millions of dollars for a single set. In addition to large ocean vessels, the sector produces gears for fishing vessels, harbor boats, barges, and recreation craft. Between 1984 and 1988, shipments of marine gearing grew steadily from $243 to $356 million. A very high percentage of these shipments are destined for defense applications. In 1985, defense accounted for 49 percent of total shipments. However, as the recreation craft business picked up in 1987 and 1988, defense shipments, while holding steady, fell to 35 percent of the business in 1988.

Imports are of little consequence in the marine sector, amounting to only about 3 percent of apparent consumption. However, the U.S. Navy adopted a U.S. content rule in late 1986, and has since given all marine gear work to U.S. firms. In addition, the Navy has always purchased its nuclear propulsion gear systems domestically. General Electric in Lynn, MA is the only supplier of gearing systems for nuclear submarines. Exports are also of minor consequence, and amount to only about 3 percent of shipments.

Marine Gear Sector
Total Shipments, Imports, Exports
and Defense Shipments, 1984-1988
(in $000,000s)

	1984	1985	1986	1987	1988
Total Shipments	242.9	268.5	282.6	306.0	356.3
Imports	6.0	8.0	9.0	10.0	12.0
Exports	7.0	8.0	9.0	11.0	13.0
App. Consumption	241.9	268.5	282.6	305.0	355.3
% Imports	2.5	3.0	3.2	3.3	3.4
Trade Balance	1.0	0.0	0.0	1.0	1.0
Defense Shipments	106.6	132.6	123.7	131.3	125.8
% Defense	43.9	49.4	43.8	42.9	35.3

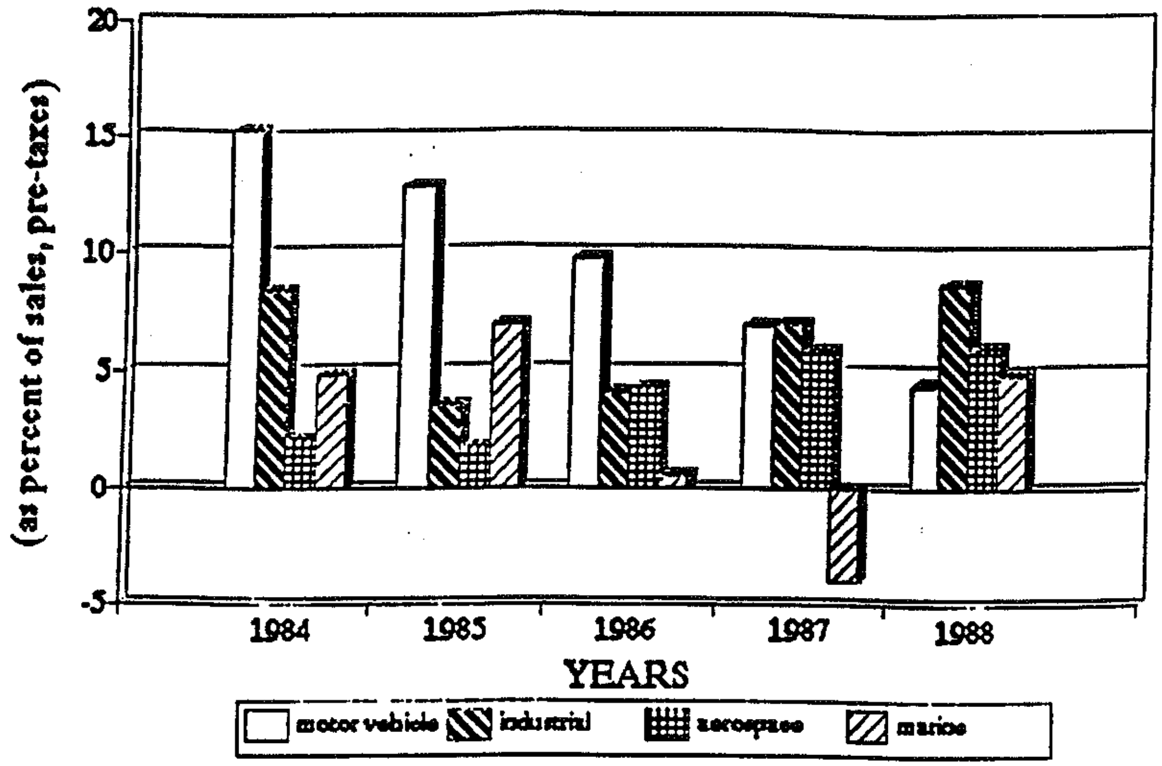
FIGURE 19: MARINE GEAR SECTOR
SHIPMENTS, IMPORTS, AND EXPORTS



Source: Compiled from ITC/DOC Industry Survey Data

Marine Gear Sector Outlook - A downturn in U.S. Navy business can be expected, and in one respected observer's view, only one main reduction gear firm of six may remain in this line over the next few years. The recreation craft business is also down, causing firms to reduce employment and shut down plants. The last merchant vessel built in a U.S. shipyard was delivered in 1987. Little prospect exists for a revival of the merchant market.

FIGURE 20: PROFITABILITY BY GEAR SECTOR
1984 TO 1988



Source: Compiled from ITC/DOC Industry Survey Data

Profitability

The pre-tax return of the gear industry declined each year from 1984 to 1988, from 12.22 percent to 6.05 percent. The motor vehicle gear sector, which incurred some major new expenses, is primarily responsible for the decline. The independent truck transmission suppliers also showed a downward trend, as the large truck business soured.

During the period 1984-1988, profits of the industrial gear sector closely followed its shipment trends, which were high in both the early and later part of the period, but low in the middle. The industrial sector finished with the highest profits in the gear industry in 1988, at 8.57 percent. The aerospace sector showed low profitability as some firms reported large losses. The marine sector was the least profitable, and in fact reported a net loss of 4 percent in 1987.

Several captive firms from all gear sectors failed to report. Some operate on a cost basis. However, the captives that did report (although maybe not representative of the total) showed a steady decline in profits from 12.4 percent in 1984 to only 1.44 percent in 1988. Some captives spent large sums on new investments, which would have deflated profits toward the end of the period by increasing depreciation levels and interest expenses. Others operated at less than optimal rates.

In 1986, nearly 31 percent of the reporting firms in the gear industry showed losses. All but one of these were in the non-automotive gear sectors. Of 36 firms reporting losses in 1986, 26 were industrial. The marine sector had four of six firms report losses in 1986. Little improvement in these numbers was shown in 1987, as 34 of 120 firms (28 percent) reported losses. In 1988 the profit picture improved; however, 22 of 122 firms (18 percent) still reported losses.

While some firms were doing poorly, others did very well. Profitability has been very unevenly distributed, which again reflects the segmented and diversified nature of the business. In 1986, when 26 of 79 industrial gear firms reported losses, 14 others reported profits exceeding 10 percent. The following year, when 24 reported losses, 18 came in over 10 percent. And in 1988, 23 firms, or nearly 28 percent of the total, reported more than 10 percent profits.

Percent Net Profit to Sales (before taxes)
Reported by Gear Industry, 1984-1988
(in percent)

Sector	1984	1985	1986	1987	1988
Motor Vehicle	15.27	12.83	9.68	6.91	4.41
Industrial	8.36	3.56	4.09	6.97	8.57
Aerospace	2.09	1.68	4.24	5.89	5.93
Marine	4.82	6.89	0.53	(4.04)	4.84
Total:	12.22	9.37	6.78	6.22	6.05
Captive	12.36	8.10	4.74	2.61	1.44
Non-Captive	12.11	10.45	7.95	8.20	8.68

Number of Firms Reporting Losses
Compared with Total Reporting,1984-1988
(#losses/#reporting)

Sector	1984	1985	1986	1987	1988
Motor Vehicle	1/12	1/12	1/12	2/12	1/12
Industrial	7/39	10/40	26/79	24/82	14/83
Aerospace	1/9	1/9	4/18	3/18	4/19
Marine	0/6	0/6	4/6	4/6	2/6
Total:	9/66	13/67	36/117	34/120	22/122
Captive	1/8	1/8	1/8	3/8	1/8
Non-Captive	8/58	12/59	35/109	31/112	21/114

Source: Compiled from ITC/DOC Industry Survey Data

Employment

Employment of production workers in the gear industry declined by just over 6 percent between 1984 and 1988. Most of this drop was recorded by the motor vehicle sector, where employment fell by almost 9 percent. By 1988, the industrial sector added almost two thousand workers, from its five year low of 12.3 thousand in 1986. This was almost a 16 percent increase brought on by expanding markets. The aerospace sector and marine sector each reached a low point in terms of employment in 1988. The captive shops, mainly because of the automotive presence, reduced employment by 5.5 thousand. Overall, non-captives expanded employment by a modest 356.

Production Workers in the Gear Industry, 1984-1988

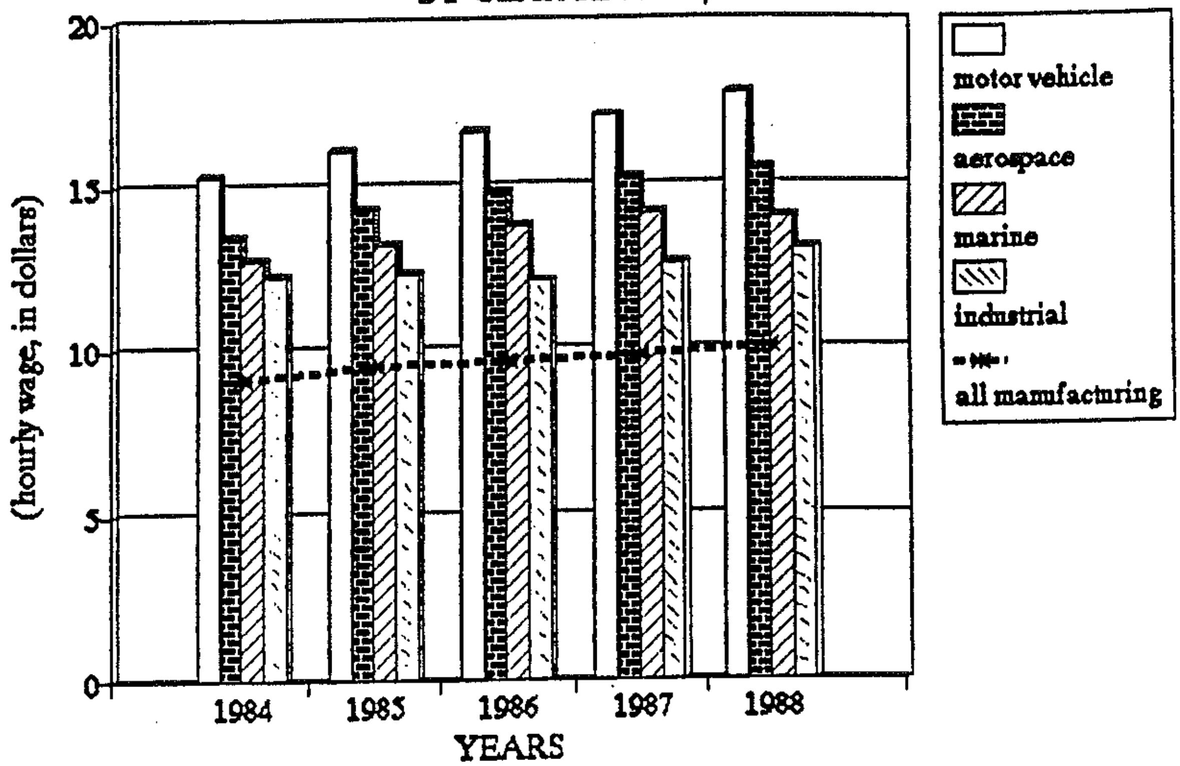
Sector	1984	1985	1986	1987	1988
Motor Vehicle	59,264	59,049	57,796	54,209	54,045
Industrial	13,466	13,362	12,307	12,897	14,255
Aerospace	6,091	6,242	6,017	5,846	5,820
Marine	2,893	2,740	2,735	2,508	2,455
Total:	81,714	81,393	78,855	75,460	76,575
Captive	61,317	61,556	59,642	55,879	55,822
Non-Captive	20,397	19,837	19,213	19,581	20,753

Source: Compiled from ITC/DOC Industry Survey Data

Some motor vehicle gear plants are operating under work or pay agreements. Under these agreements, the auto company must continue paying the work force if the plant shuts down. It is generally cheaper to keep the plants operating under these circumstances, and gradually move people, and/or let attrition take its course.

Production worker wages kept pace with inflation over the period, growing from an average of $14.63 to $16.67, about 14 percent in current dollars. As might be expected, wage rates were heavily influenced by the motor vehicle gear sector, which pays the highest wages and employs the most people. Motor vehicle gear wages rose from an average of $15.30 in 1984, to $17.79 in 1988, up over 16 percent. Industrial gear sector wages grew only 7 percent, from $12.25 to $13.11. In 1988, industrial gear wages were slightly less than 74 percent of the motor vehicle gear wages, down from over 80 percent in 1984. Aerospace gear wages grew over 15 percent during the period from $13.46 to $15.52, and were about 87 percent of motor vehicle wages. The marine sector saw its wages increase just over 10 percent from $12.72 to $14.02, falling from 83 percent of auto wages in 1984, to about 79 percent in 1988.

FIGURE 21: PRODUCTION WORKER WAGE RATES BY GEAR SECTOR, 1984-1988



Source: Compiled from ITC/DOC Industry Survey Data, and DOL, Bureau of Labor Statistics

Gear wage rates are significantly higher than the average for all manufacturers. In 1984, gear wages were 59.2 percent higher than all manufacturing. This ratio rose slightly through 1988, when gear wages were 63.8 percent higher. This disparity was greatly influenced by motor vehicle gear wage rates, which are among the highest in all of industry. The industrial gear sector wage scale was 33.3 percent higher than all manufactures in 1984, but fell to 28.8 percent in 1988. The relative drop may be related to the decline in larger industrial gear establishments, which typically paid higher wages to production workers[13]. However, it may also be in response to competitive pressures from imports and aggressive domestic firms. This suggests the industrial gear wage is not competitive, and is one of the reasons shortages of skilled labor are now a major concern in the sector.

Production Worker Hourly Wage, 1984-1988

Sector	1984	1985	1986	1987	1988
Motor Vehicle	15.30	16.06	16.62	17.11	17.79
Industrial	12.25	12.30	12.08	12.62	13.11
Aerospace	13.46	14.25	14.77	15.25	15.52
Marine	12.72	13.20	13.79	14.17	14.02
Total:	14.63	15.27	15.71	16.16	16.67
Captive	15.64	16.34	16.80	17.37	18.08
Non-Captive	11.66	12.04	12.39	12.75	13.03
All Manufactures	9.19	9.54	9.73	9.91	10.18

Source: Compiled from ITC/DOC Industry Survey Data, and the Department of Labor, Bureau of Labor Statistics

Investment

The gear industry relies extensively on used equipment, which in some cases, has been retrofitted with computer controls. Also, some firms have refurbishing capabilities and rebuild older equipment to satisfy their needs. In 1988, the gear industry reported spending $20.3 million on used gear equipment, about half of which came from the motor vehicle gear sector. The rate of investment in used gear machinery fluctuated in a narrow band between $17 and $25 million during the 1984-1988 period.

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[13]Larger establishments tend to be more capital intensive because of the nature of their business (high volume). Their capital-labor ratio is higher, which enables each worker to be more productive, and thereby be paid a higher wage. Note the difference shown on the table above between captive (very large establishments) and non-captive firms.

Investment in Used Gear Machinery, 1984-1988

(in $000s)

Sector	1984	1985	1986	1987	1988
Motor Vehicle	15,935	14,076	6,380	9,425	10,114
Industrial	5,099	6,334	8,509	7,289	8,482
Aerospace	915	400	1,589	1,792	900
Marine	3,077	778	1,020	540	818
Total:	25,026	21,588	17,498	19,046	20,314
Captive	12,422	9,988	4,726	7,080	3,874
Non-Captive	12,604	11,600	12,772	11,966	16,440

Source: Compiled from ITC/DOC Industry Survey Data

Captive firms invested much less in used gear machinery both in absolute dollar terms and relative to sales. This is not unexpected: the captives are much larger firms that can afford new machines and have access to capital at lower interest rates than their non-captive counterparts. Further, by virtue of assured sales, they work closely with the end-user and can strategize investment over a longer planning horizon. Also, the captives typically produce smaller size gears in higher volumes. Smaller gears require smaller machines, which to an extent correlate to a lower price tag. And further, because high volume machines tend to be more dedicated and may lack the flexibility to be reset for new designs, a design change can also induce new investment.

In contrast, non-captives are more likely to be played off against one another by end-users (many of whom are under intense global competitive pressures) interested in obtaining the lowest possible up front gear cost. End-users appear to be in a better bargaining position because of increasing international gear competition and overcapacity in the gear market. This has not only reenforced the fragmentation in the gear industry, but also reduced investment incentives that would result from longer term contracts. This adversarial relationship between buyers and sellers all along the supply chain has not helped the industry's long-term competitive prospects, especially in the face of more cooperative structures in other countries.

Reported investment in new gear machinery rose dramatically over the 1984-1989 period. However, the motor vehicle sector began several major modernizations. Chrysler bought large numbers of machines for its Kokomo, IN plant, and began modernizing its Syracuse plant. Ford is currently modernizing its Livonia, MI plant. In fact, the motor vehicle share of new investment rose from 60 percent of the total in 1984 to over 72 percent in 1988. Over the five years, the motor vehicle gear sector averaged only 1.02 percent of sales in investment in new gear machinery.

The industrial sector also saw an upward trend in the purchase of new gear machinery, which rose from $11.7 million in 1984, to $38.7 million in 1988. The trend was also up as a percent of sales, rising from a low of 0.96 percent in 1984 to a high of 2.11 percent in 1988. The five year average was 1.34 percent. For the five years taken together, only one firm invested more than a total of $10 million. Seven others each invested more than $4.0 million. These eight firms accounted for almost 60 percent of the industrial gear sector's total investment from 1984-1988, while representing less than 50 percent of total shipments.

Investment in New Gear Machinery, 1984-1988
(in $000s)

Sector	1984	1985	1986	1987	1988
Motor Vehicle	45,556	46,678	39,807	143,928	177,938
Industrial	11,714	14,452	16,809	19,709	38,733
Aerospace	9,155	7,386	8,239	14,009	17,902
Marine	9,037	12,903	10,619	11,074	11,256
Total:	75,462	81,419	75,474	188,720	245,829
Captive	43,267	42,352	33,547	131,278	168,491
Non-Captive	32,195	39,067	41,927	57,442	77,338

Source: Compiled from ITC/DOC Industry Survey Data

The aerospace gear sector also showed a rising trend in new gear machinery investment, from $9.2 million in 1984 to $17.9 million in 1988. For the five year period, the sector averaged

2.75 percent of sales in new gear machinery investment. This is inadequate to modernize facilities. The fact that a single new grinding machine may cost over $1 million, is one of the reasons.[14]

Investment by the marine gear sector was dominated by two firms, General Electric and Falk. The marine producers averaged 4.33 percent invested in new gear machinery to the sales dollar. This high percentage far outstripped investment reported by the other three sectors. The marine gear sector is the most capital intensive in the gear industry, and uses very large, high precision machinery often costing several million dollars.

Gear companies also invest in other new machinery such as lathes, milling machines, machining centers, and drilling machines, which are used for operations related to gear production. This area of new investment was also dominated by the motor vehicle gear sector which in some years accounted for more than 90 percent of the total. This is not surprising since over 90 percent of the value of a passenger car's transmission is parts and components other than gears that have different machining needs.

Investment in Other New Machinery, 1984-1988
(in $000s)

Sector	1984	1985	1986	1987	1988
Motor Vehicle	228,272	251,128	254,157	405,316	204,424
Industrial	14,913	20,522	31,871	27,372	39,084
Aerospace	4,007	4,357	4,828	3,820	12,300
Marine	747	3,857	9,274	2,851	3,177
Total:	247,939	279,864	300,130	439,359	258,985
Captive	233,304	255,225	268,078	388,067	228,265
Non-Captive	14,635	24,639	32,052	51,292	30,720

Source: Compiled from USITC/DOC Industry Survey Data

[14]Allison Gas Turbine in Indianapolis, IN recently began a modernization project, indicating investment in 1989-1990 may have continued on an increasing trend.

Comparatively, the motor vehicle sector averaged 3.04 percent in "other new machinery" investment relative to sales, while the industrial sector averaged 1.83 percent, the aerospace sector 1.42 percent, and the marine sector 1.56 percent.

Market Volatility

The gear industry has not experienced excessive year-to-year fluctuations in total shipments in recent years. In fact, during the 1984-1988 period, the composite industry average year-to-year change up or down in shipments was only 6.44 percent. However, this number conceals the much greater volatility encountered by individual gear firms. The average year-to-year change up or down in shipments for individual firms averaged 18.94 percent, three times the composite industry average. This amount of volatility at the firm level has discouraged debt financing and new investment. It also suggests that a number of strategic consolidations among smaller firms could counteract the severity of these fluctuations, and improve the sector's overall credit worthiness and competitive prospects. The consolidation of certain smaller gear operations followed by the acquisition of new equipment will allow many to achieve technical efficiencies not possible with existing older equipment, and thereby to actually cut production costs while improving product quality.

Volatility for firms within gear sectors showed a similar pattern. Motor vehicle gear firms recorded an average 21.34 percent shipment change, compared to an 6.46 percent for the motor vehicle gear sector as a whole. Industrial gear firms showed a volatility of 19.11 percent, which was almost twice the sector average of 9.94 percent. Individual aerospace gear concerns had the lowest average volatility at 12.27 percent, which may be lower because some companies have large order backlogs. The aerospace sector as a whole also recorded the lowest volatility at 4.62 percent. Marine firms recorded the highest volatility at 26.53 percent, but the second lowest sector rate at 5.88 percent.

Larger firms exhibited somewhat less year-to-year change than smaller firms. The lower volatility shown by larger firms could be for a number of reasons, including a greater number of customers in diversified markets, a broader geographic market not

Average Year-to-Year Percent Changes in Shipments Experienced by Individual Gear Firms, and by Gear Sector 1984-1988

(average volatility, in percent)

Sector	1984 to 85	1985 to 86	1986 to 87	1987 to 88	4-Yr. Ave.
Motor Vehicle					
by Firms	18.91	25.05	28.81	12.58	21.34
by Sector	14.27	-5.67	2.41	3.50	6.46
Industrial					
by Firms	16.97	20.33	17.92	21.21	19.11
by Sector	0.85	-9.59	10.36	18.94	9.94
Aerospace					
by Firms	12.62	13.08	12.81	10.55	12.27
by Sector	6.86	7.56	-0.89	-3.14	4.62
Marine					
by Firms	31.15	28.43	16.[illegible]9	29.86	26.53
by Sector	9.08	-4.92	3.33	6.19	5.88
All Sector Total:					
by Firms	17.50	20.52	18.79	18.94	18.94
All Sectors	11.75	-5.47	3.24	5.28	6.44
Captive					
by Firms	12.26	18.13	21.23	15.88	16.88
by Sector	14.52	-6.52	2.01	4.31	6.84
Non-Captive					
by Firms	18.95	21.19	18.11	19.79	19.51
by Sector	1.13	-0.92	8.29	9.01	4.84
Large firms (sales over $10 million)					
by Firms	14.77	18.34	17.75	16.55	16.85
by Sector	11.88	-5.58	3.15	5.08	6.42
Small firms (sales under $10 million)					
by Firms	20.46	22.89	19.90	21.53	21.20
by Sector	5.18	0.48	8.47	15.60	7.43

Source: Compiled from USITC/DOC Industry Survey Data particularly tied to regional or local economies, or longer term contracts. For firms with yearly sales in excess of $10 million, annual fluctuations averaged 16.85 percent, compared to 21.2 percent for firms with sales of less than $10 million. Captive firms, which are generally larger than non-captives, also recorded less volatility. Captives recorded 16.85 percent shipment volatility, while non-captives came in at 19.51 percent.

A total of 608 observations were made for individual firm year-to-year volatility over the period 1984-1988 for 152 firms. Of these, 375 were positive changes in which shipments increased from one year to the next, and 233 were negative changes. The average of all positive changes was 20.13 percent, while the average of all negative changes was 11.45 percent.[15] The greater number of positive changes reflects growth in the overall market, which rose 14.84 percent between 1984-1988, from $1.14 to $1.31 billion.

If adjustment is made for inflation, the effect would be to reduce the magnitude of the up changes and raise that of the down changes[16]. The average positive changes would fall to 19.24 percent, and the average negative changes rise to 11.76 percent. The overall average volatility drops from 18.94 to 17.75 percent. Also, the number of positive changes drops to 313, while the negatives increase to 295, and growth in the overall market falls from 14.8 to 5.2 percent.

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[15]A distortion arises because of low base/high base starting points. Assuming a starting point of 100, an increase in shipments of 20 percent would be an increase of 16.67 percent if measured against the end-base (i.e., 20/120=16.67). In reverse, if a decrease of 20 percent from 100 is measured from its end-base, the decline rises to about 25 percent (i.e., 20/80 = 25).

[16]For example, if shipments in year '1' are 100, and in year '2' rise to 120, the gain is 20 percent. However, if inflation ran at 3 percent, real shipments in year 2 would be 116.5 (i.e., 120/1.03) and the real rise would be 16.5 percent. On the down side, if shipments in year '1' are 100, and in year '2' fall to 88.5, the decline is 11.5 percent. Again, if inflation ran at 3 percent, real shipments in year '2' would be 85.9 (i.e., 88.5/1.03) and the real decline 14.1 percent.

Research and Development

Research and development (R&D) expenditures are an important indicator of future competitiveness in the manufacturing sector, where about 95 percent of total private R&D is undertaken. This is still very true for the gear sector as well, despite the fact the basic technology is roughly 4,000 years old. Recent advancements in gear materials, products, and processes continue to improve the durability and functionality of gear systems.

In the broader picture, gear products have also benefitted greatly from breakthroughs in other metal working industries, and for that matter, from advances in electronics, chemicals, and many other disciplines. The gear industry has gained directly from advances in induction heat treating, cubic boron nitride grinding, near net shaping, laser metrology, laser welding, computer control systems, better cutting oils, improved steels, powdered metals, lubricants, composites, and much more. The industry has also benefitted from participation in educational and training courses in the management and human relations sciences, and technical subjects.

The United States has the largest R&D establishment in the world by almost any measure - total spending, number of scientists and engineers, laboratory space, and technology development. This provides an enormous, though perhaps under-utilized, advantage to U.S. firms, including the gear industry. However, as a nation, we seem better at developing technology than using it.

The United States also has the world's finest university system. However, until the past few years, there has been little research money available for university professors to investigate manufacturing issues. The problem may be compounded by the fact that most professors have had little exposure to factory life. When manufacturing research is proposed, it often reflects the scientific and analytic orientation of professors, and is perceived by industrialists as impractical, and remote from industrial problems. Thus, much R&D is not even undertaken. Also, many funding agencies prefer to underwrite "cutting edge" research in fast growing fields, such as superconductivity and low temperature fusion, which are more glamorous and provide greater opportunities for recognition.

Recent private studies have reported that gear related research activities in U.S. universities were far below the levels in certain other leading gear-producing countries. According to one report[17], in 1988, the number of graduate students, researchers, faculty, and support staff involved in gear research totaled 73 in the United States, compared with 155 in West Germany and 222 in Japan. Further, during 1981-1985, a total of 60 masters and doctoral degrees in the gear field were conferred in the United States, compared with 102 degrees in Japan and 259 in Germany. Also, a total of 23 special purpose gear test facilities were located at American universities, compared with 72 in West Germany and 81 in Japan. Only one gear manufacturing facility was located on an American campus, while ten were on West German campuses and reportedly 43 at universities in Japan.

Internationally, the United States is falling further behind in nearly all aspects of gear technology, and rapidly losing ground in the aerospace gear sector. Gear related R&D undertaken in other countries, notably Japan and West Germany, has long exceeded the U.S. effort, and firms in these countries now set the world quality standards in many gear product areas.

In recent years, several privately and government funded R&D efforts related to gears have begun. In 1980, Ohio State University's Department of Mechanical Engineering established the "Gear Dynamics and Gear Noise Laboratory" under Dr. Donald R. Houser, which was funded by industry. Most funds received by the laboratory are used to provide financial aid for Master and PhD candidates working on thesis projects related to gearing.

In the mid-1980s, the National Science Foundation (NSF) provided about $10 million over a five-year period to Ohio State for an Engineering Research Center. The Center is a cooperative activity by NSF, the university, and industry to improve manufacturing processes (including those for gears) and make U.S. manufactured items more internationally competitive. Industry is providing guidance to ensure research is directed toward relevant manufacturing problems. Gear measurement, near net shape, investment castings, spiral bevel forging, and orbital forging are all under study.

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[17] "A Worldwide Survey of University Research in Gearing," Dr. Donald Houser, Ohio State University, 1988

The Gear Research Institute (GRI), affiliated with the American Society of Mechanical Engineers (ASME), was founded by gear industry interests in 1982, in Naperville, IL under the direction of Dale H. Breen and others. It was founded in recognition of increasing international competition and greater R&D efforts in other countries, notably Germany and Japan. Modeled somewhat after the German system, GRI believes in the concept of 'Cooperative Pre-competitive Research and Development.' This involves the pooling of resources and working cooperatively in the early stages of technology developments which supposedly will not jeopardize the competitive position of individual firms. GRI seeks to identify a need, initiate a project, and enlist support from industry and government, and other organizations.

A major project undertaken by GRI was in "austempered ductile iron" funded in part by the Department of Commerce's Trade Adjustment Assistance Office. Other projects have included work in boron alloyed steels, heat treatment distortion, lubricants, surface finishing, and fatigue analysis. GRI has the capabilities to undertake additional projects. However, total cumulative funding for GRI only reached $2 million in 1989, which officials at GRI indicated was inadequate to the needs of the industry.

Recently, the GRI board voted to provide a larger role for the American Gear Manufacturers Association (AGMA), and to relocate to Lisle, IL. The organization will now be GRI of ASME and AGMA. GRI continues to undertake R&D projects, and is now examining anti-corrosion and preservative coatings, high temperature materials, and developing a comprehensive stress/life computer evaluation system. Further, Mr. R. Bergmann of Cleveland Gear has raised over $500 thousand from the industry to study worm gears.

The American Pfauter Company, a subsidiary of Herman Pfauter in Germany, opened a $9 million gear technology center in Rockford, IL in January 1990. Pfauter, which is a major producer of gear hobbers and grinders, will offer customers and researchers the opportunity to solve problems related to machine speed, set-up time, reliability, and utilization. The center will also provide project engineering, computer simulation, training services, and software development.

Further, General Motors is now establishing a gear research facility in Romulus, MI in part to facilitate introducing new technologies into its gear making operations. The facility currently employs about 30 people, and contains over 21,000 square feet.

A major Federal research effort is underway at the National Aeronautics and Space Administration's Lewis Research Center in Cleveland, OH. This is a $13 million project sponsored by the Department of the Army relating to helicopter transmissions. The Army is the largest single user of helicopters. This funding covers the period 1989-1990.

The latest major R&D effort began in the fall of 1989, under the sponsorship of the Defense Logistics Agency (DLA). The DLA is spending $17 million over a five-year period to retrofit and equip an Instrumented Factory (INFAC) in Chicago at the Illinois Institute of Technology (IIT). "Factory" may be a misnomer, because the facility is actually going to be used like a research laboratory. The facility should be completed in the spring of 1991, and will initially focus on aerospace gear production processes. An important goal of INFAC is to demonstrate the value of the latest machinery technologies to the gear industry, and allow individuals hands-on experience in its usage. It is hoped this will encourage investment and modernization. It will also "prove" the technologies and provide an alternative to machine tool sales engineers, who many claim have a tendency to exaggerate the capabilities of their new machines.

The domestic gear industry has reacted slowly to INFAC, with most firms so far showing little interest. However, INFAC is gaining acceptance and continues expanding its membership. Eaton Corporation, a major motor vehicle gear manufacturer with a very substantial research program of its own, has approached INFAC for help with simulation work. Also, as of this writing, the Gleason Company has donated about $500 thousand, and is providing a "Phoenix" bevel generator and grinder to INFAC. IBM has contributed about $350 thousand in computer hardware and software, in an effort to further expand its activities in the factory automation field. Cincinnati Milacron has supplied a CNC Lathe, Machining Center and Grinding Machine.

DOD's Industrial Modernization Incentive Program (IMIP) has been very successful in improving production efficiencies of individual firms in various sectors of the defense base. The IMIP program is carried out in three phases[18].

- Phase I - Factory Analysis - is a top-down analysis of a contractor's facility to identify and prioritize needed factory modernization projects. This phase is performed by the contractor and culminates in a strategic plan and conceptual design to modernize the entire factory or a single product line. After completion, a business deal is negotiated between the government and the contractor to initiate Phase II.

- Phase II - Technology Demonstration - involves the detailed design, development, and demonstration of modernization opportunities and technologies noted in Phase I. These will be brought to the point where they can be confidently used in production. Detailed implementation plans and an analysis of the cost-benefit and lead time improvement that can be anticipated will result.

- Phase III - Implementation - the contractor implements the results of Phase II into production. Through a negotiated business agreement, both the contractor and the government share in the savings and investment costs.

Three IMIP programs are on-going with gear firms. Two of these, involving Summit Gear in Plymouth, MN and Sundstrand in Denver, CO, are being sponsored by Wright Patterson Air Force Base, and have been coordinating with the INFAC group. The third, with General Motors' Allison Gas Turbine Division in Indianapolis, IN is being funded by the U.S. Army.

Summit Gear recently completed Phase I. Summit is an important producer of precision gears supplying systems such as the F-15 and F-16. The company is a custom order manufacturer, supplying

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[18]The information on IMIP and the details that follow on the three gear companies currently involved in IMIP programs was largely extracted from, "Gear and Bearing News", published by the Illinois Institute of Technology Research Institute in the fall of 1989.

high precision, low volume, and traceable lot gears for aerospace applications. The firm's production capacity exceeds 50 thousand machine hours per month.

Sundstrand Corporation also recently completed Phase I of an IMIP. The program is working through the Sundstrand Advanced Technology Group which comprises four product-line divisions - Electric Power Systems, Aerospace Mechanical Systems, Aerospace Fluid Systems, and Power Systems. These support several key military programs such as the C-17, F-15, F-16, and F/A-18. The firm is also extensively involved in a variety of classified programs. Also, Sundstrand has previous IMIP experience under a program administered by General Dynamics.

Allison Gas Turbines proposed a study to develop advanced heat treatment methods for precision gear production. The program involves assessment and optimization of two technologies - dual pulse induction and plasma carburizing. The dual pulse technique is a GM patented process for hardening gears using medium carbon steel. The other technique is a plasma form of vacuum carburizing. All of the Services are interested in this program. Allison is an important captive producer of gears for engines such as the T-56 and soon to be developed T-800.

Company R&D Expenditures - Information on gear company-financed R&D expenditures and activities was collected from the gear industry in the ITC/DOC industry survey. Sixty-seven firms supplied R&D information. In 1988, total reported R&D expenditures by the gear industry were $74 million. This was up 38 percent from the 1984 level of $53.5 million. The increase in expenditures was led by the motor vehicle and aerospace gear sectors. Motor vehicle gear firms increased expenditures from $20.9 million in 1984 to about $32 million in 1988, up 58 percent, and aerospace gear companies increased from $4 to $11.2 million, an increase of 182 percent. The industrial gear sector increased expenditures moderately by 11 percent, while the marine sector reduced reported R&D spending by over 40 percent.

The gear industry spends much less on R&D relative to all manufacturers. In 1988, all manufacturing spent almost three times as much as the gear industry relative to sales, four times

Comparison With All Manufacturing:[19]

	all manufacturing	gear industry
% R&D to sales	3.4%	1.2%
% R&D to pretax profits	39.4%	9.9%
R&D per Employee	$6,000	$1,296

Source: "Business Week", June 1990, and Compiled from ITC/DOC Industry Survey Data

as much relative to profits, and 4.6 times as much per employee. This implies a great deal of R&D related to gears is not undertaken.

Over 70 percent of total R&D expenditures by the gear sector were dedicated to product related activities. This includes the building of prototypes, experimenting with new designs, and improving or establishing testing methods. Individual companies cited research into endurance, fatigue, tolerance/speed ratios, load-life testing, vibration and noise reduction, and lubricants. Being closer to the market, R&D in this area generally has a quicker payoff, and sometimes may be specific customer related, which may explain its higher relative level.

In 1988, reported total product related expenditures of $53.2 million probably included some R&D paid for by the customer, in which case the $53 million is overstated. It is also possible the number includes design engineering done in the normal course of business for a specific application and expensed as incurred.

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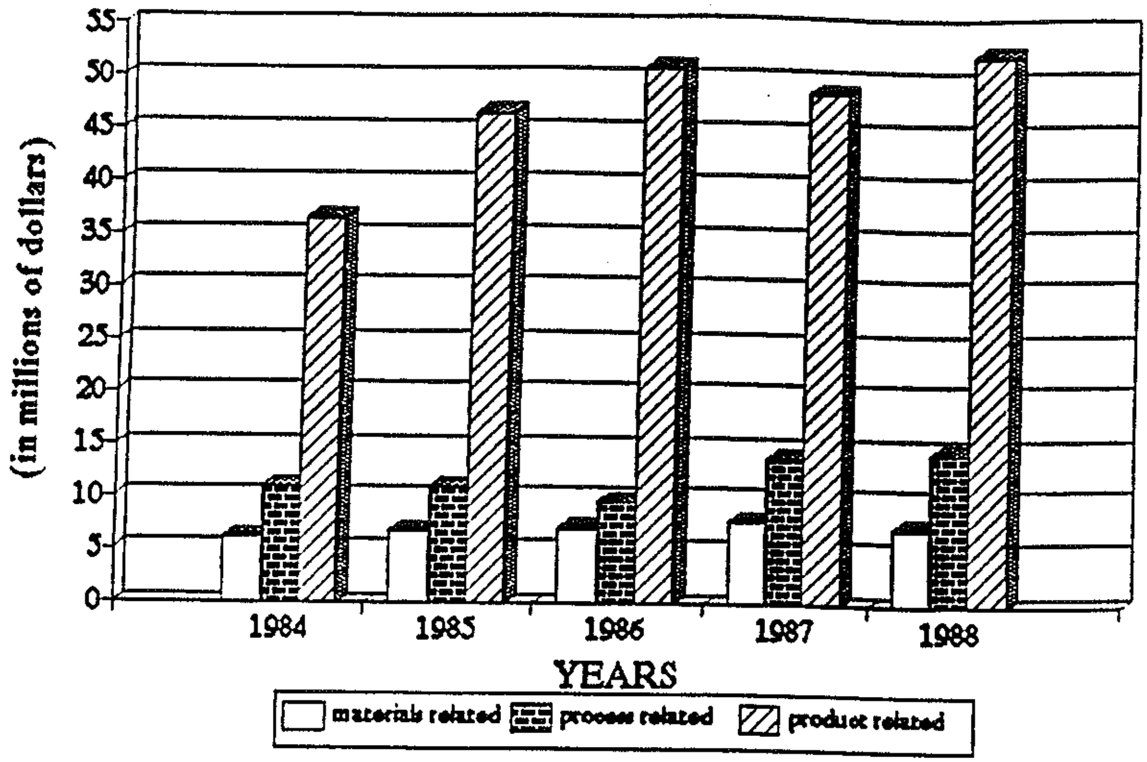
[19]The comparison is for firms that reported R&D expenditures, not for the entire sectors. Many gear firms and firms in the manufacturing sector do not engage in R&D. If the entire gear sector was represented, the ratios for the gear industry would be reduced by about 50 percent.

Gear Industry
Research and Development Expenditures
By Sector, 1984-1988
(in $000s)

	1984	1985	1986	1987	1988
Motor Vehicle					
On Materials	1,830	1,580	1,846	1,975	2,458
On Processes	2,537	3,190	3,524	3,706	3,919
On Products	16,536	21,560	22,345	25,517	26,608
Total	20,903	26,330	27,715	31,198	32,985
Industrial					
On Materials	2,823	4,017	3,492	4,617	3,846
On Processes	6,861	6,295	5,239	9,386	9,388
On Products	15,073	15,122	16,570	14,391	14,270
Total	24,757	25,434	25,301	28,394	27,504
Aerospace					
On Materials	267	339	496	250	261
On Processes	372	562	433	430	551
On Products	3,324	8,686	11,426	8,039	10,381
Total	3,963	9,587	12,355	8,719	11,193
Marine					
On Materials	1,218	789	1,132	880	670
On Processes	1,123	871	378	338	561
On Products	1,527	1,050	504	650	1,068
Total	3,868	2,710	2,014	1,868	2,299
All Sectors					
On Materials	6,138	6,725	6,966	7,722	7,235
On Processes	10,893	10,918	9,574	13,860	14,419
On Products	36,460	46,418	50,845	48,597	52,327
Total	53,491	64,061	67,385	70,179	73,981
Captives					
On Materials	2,859	3,195	3,658	3,825	4,198
On Processes	5,951	5,920	5,422	9,317	8,567
On Products	17,701	24,738	30,106	26,942	30,154
Total	26,511	33,853	39,186	40,084	42,919
Non-Captives					
On Materials	3,279	3,530	3,308	3,897	3,037
On Processes	4,942	4,998	4,152	4,543	5,852
On Products	18,759	21,680	20,739	21,655	22,173
Total	26,980	30,208	28,179	30,095	31,062

Source: Compiled from ITC/DOC Industry Survey Data

FIGURE 22: RESEARCH AND DEVELOPMENT SPENDING
MATERIALS, PROCESSES, AND PRODUCTS



Source: Compiled from ITC/DOC Industry Survey Data

While over 70 percent of gear industry R&D was product related, about 20 percent was reported as process related, and the other 10 percent for material related activities. These activities are usually more remote from any particular sale, and are intended to enhance the firm's efficiency and product quality.

In 1988, process related research totalled $14.4 million, up over 32 percent from 1984. Companies reported R&D activities in computer aided engineering, hard turning, improved fixtures and tooling, shot peening, cubic boron nitride grinding, induction heat treating, CNC machining, cell production, near net forging, co-rotating extrusion, and measures to improve production efficiency and productivity.

Material related research totalled $7.2 million in 1988, up about 18 percent from 1984. Activities included expenditures in powdered metals, composites, other non-metallic gears, austempered ductile iron, and new alloys. Some of the process and material related R&D appears to be duplicated from one firm to the next. However, it is very difficult to quantify.

Research and Development Expenditures in the
U.S. Gear Industry by Sector and Function, 1988
(in $000s)

	Motor Vehicle	Indust'l Sector	Aerospace Sector	Marine Sector	Total All
MATERIALS/METALLURGY					
All Types	$2,458	$3,846	$261	$670	$7,235
PROCESS RELATED					
Gear Cutting	1,466	2,719	170	0	4,356
Heat Treating	1,011	3,384	170	155	4,719
Grinding	1,442	3,285	210	407	5,343
Total:	$3,919	$9,388	$551	$561	$14,418
PRODUCT RELATED					
Product Dev.	18,443	1,400	870	105	20,818
Product Design	6,907	5,887	8,773	327	21,894
Product Testing	1,258	6,984	738	636	8,869
Total:	$26,608	$14,270	$10,381	$1,068	$52,327
TOTAL					
Sector Totals	$32,985	$27,504	$11,193	$2,299	$73,980
# of Reports	12	45	6	4	67
% R&D by Top 3 Firms:					
Total -	84%	72%	96%	99%	48%
Material -	81	82	68	100	61
Process -	69	79	93	99	51
Product -	95	83	100	97	62

Source: Compiled from ITC/DOC Industry Survey Data

A more detailed breakdown was attempted on R&D data for 1988 as shown on the above and following tables. In 1988, three firms accounted for 48 percent of total reported R&D expenditures. Within the separate gear sectors, total R&D is even more

Percent Research and Development Expenditures
to Sales and Dollar Equivalent by Sector, 1988
(in percent: one percent = 1.00)

	Reporting Companies Only		Entire Sector	
	Percent	Sales/$1 R&D	Percent	Sales/$1 R&D
Motor Vehicle				
On Materials	0.0571	$1,751	0.0241	$4,149
On Processes	0.0911	1,098	0.0384	2,604
On Products	0.6183	162	0.2608	383
Total:	0.7665	$130	0.3233	$309
Industrial				
On Materials	0.2396	$417	0.1830	$546
On Processes	0.5850	171	0.4467	224
On Products	0.8892	112	0.6789	147
Total:	1.7138	$58	1.3086	$76
Aerospace				
On Materials	0.0996	$1,004	0.0360	$2,778
On Processes	0.2102	476	0.0774	$1,292
On Products	3.9607	25	1.4317	70
Total:	4.2705	$23	1.5451	$65
Marine				
On Materials	0.3355	$298	0.1879	$532
On Processes	0.2809	356	0.1573	636
On Products	0.5348	187	0.2994	334
Total:	1.1512	$87	0.6446	$155
All Sectors Combined				
On Materials	0.1136	$880	0.0541	$1,848
On Processes	0.2263	442	0.1077	929
On Products	0.8214	122	0.3909	256
Total:	1.1613	$86	0.5527	$181

Source: Compiled from ITC/DOC Industry Survey Data

concentrated. In 1988, the top three motor vehicle gear firms accounted for 84 percent of the total, while in the industrial sector, the top three accounted for 72 percent. In the aerospace and marine sectors, the top three were responsible for almost 100 percent of the total.

The most reports (45) of R&D spending came from the industrial sector. However, 25 of these reported less than $100 thousand in R&D spending, and 40 reported less than $1 million. These 40 represented less than 18 percent of the sector's total R&D. The industrial gear sector led all others by a wide margin in both material and process related research, accounting for 53 percent of material R&D and 65 percent of process expenditures.

In 1988, total R&D expenditures for the entire gear sector represented only 0.55 percent of sales. Looked at in another way, it took $181 of sales to support a dollar of R&D. R&D expenditures on materials and processes represented 0.16 percent of sales, or one dollar of R&D for every $618 of sales. Within gear sectors, the motor vehicle sector had the lowest rate of R&D spending. The sector spent only 0.32 percent of sales on R&D, or one dollar for every $309 of sales. Of this amount, only 0.06 percent was spent for material and process related research, which amounts to only one dollar for each $1,600 in sales. The industrial sector, which reported the highest rate of R&D spending, returned 1.31 percent of sales to R&D, or one dollar for each $76 in sales. As for material and process related R&D, the industrial sector returned 0.63 percent of sales, which is approximately a dollar for each $159 in sales.

Foreign Ownership

Foreign-owned gear production capacity in the United States has increased rapidly in recent years. In 1984, reported shipments from eight part- or fully-owned U.S. facilities totalled $161.2 million. In 1988, 14 part- or fully-owned foreign firms reported total shipments of $437.2 million, for a 171 percent increase. In 1990, 15 foreign-owned firms are estimated to have shipments totaling between $500-600 million.

Three firms are partially foreign-owned. The French auto company Renault purchased a minor interest in Mack Trucks in the late 1970s, which was slowly increased to 44.6 percent by the mid-1980s. As recently announced, Renault will now purchase the remainder of the outstanding stock of Mack. Redex, SA, another French firm, has held a minor interest in Andantex since 1980 which was boosted to 37 percent in 1984. Redex provides engineering support, but does not control the activities of Andantex. New Angle Gear of Elkton, MD was established in 1987 as a joint venture between Philadelphia Gear and Klingelnburg of Germany. Each partner has a 50 percent stake in the company.

Shipments from foreign-owned facilities in the industrial gear sector rose from $46.1 million in 1984 to $118.2 million in 1988. Projected shipments in 1990 are estimated at over $200 million. Combined shipments from foreign-owned facilities of motor vehicle and aerospace gearing increased from $115.1 million in 1984 to $319.0 million in 1988. Shipments in 1990 may approach $400 million. No marine sector gear shipments originate from foreign-owned U.S. facilities.

Major foreign-owned facilities, with 1990 shipments estimated at over $100 million each include Lucas Western, SEW-Eurodrive and Zahnradfabrik Friedrichshafen (ZF). Lucas Aerospace of the United Kingdom purchased Western Gear in July 1987. The company has plants in City of Industry, CA and Park City, Utah, and is a major factor in the international aerospace market. SEW-Eurodrive constructed a new facility in Lyman, SC in the early 1980s, and has steadily expanded operations since then. The firm is a major player in the industrial gear markets of Europe and the United States. SEW has several satellite assembly plants near major end-users in various strategic locations around the United States. ZF is the world's largest independent gear producer, and is active across most gear markets. The firm had sales of about $3.5 billion in 1989, and about 35 thousand employees. ZF built a new plant in Gainsville, GA which began operations in 1986, and supplies motor vehicle transmissions.

Another potentially large foreign-owned producer is Sumitomo Machinery in Chesapeake, VA. Sumitomo's plant is newly built, and supplies the industrial gear market. The firm is the only Japanese-owned U.S. producer thus far. Like SEW, Sumitomo has satellite assembly plants in various locations, including Canada.

PRODUCTION CAPABILITIES

Capacity and Capacity Utilization

Gear production capacity is extremely difficult to measure. The difficulty arises because gear production involves so many steps and contains numerous variations in terms of production volumes, part complexity, heat treatments, testing requirements, age of equipment, and plant layout and capabilities. In consultations with persons knowledgeable about the subject, an effort was made to define capacity in terms of total machine hours. While this seemed reasonable, in actuality, many machines in a gear shop are used only occasionally, while other types are used more intensively. Also, older machines are generally used less than newer machines, but under this system are given an equal weight. Thus, this method of measuring capacity yielded poor results.

In addition, because of industry confusion regarding the survey question about capacity, the responses received were inconsistent. For example, only on rare occasions could a correlation be made between the number of machines a company reported and the number of "machine hours" reported as practical capacity. Also, there were extremely wide variations in the comparison of value of shipments to total machine hours. As a result, a great deal of estimation went into the aggregate totals, and a number of responses had to be discarded. Finally, the Commerce Department estimates of capacity and capacity utilization were done independently of the ITC estimates. The results, therefore, will not necessarily agree.

Within these limitations, capacity and capacity utilization rates were determined for the four sectors - motor vehicle, industrial, aerospace, and marine. If the utilization rates are considered representative for all firms within a given sector, capacity expressed in terms of shipments could be estimated as follows:

Estimated 1988 Capacity, Dollar Value

Sector	Estimated 1988 Capacity Utilization (A) (percent)	1988 Shipments (B)	Estimated 1988 Capacity (B/A)
		(----in $billions----)	
Motor Vehicle	72.0%	$10.20	$14.16
Industrial	58.2	2.10	3.61
Aerospace	31.7	.73	2.30
Marine	63.3	.36	.57
Total:	64.9%	$13.39	$20.64

Source: Compiled from ITC/DOC Industry Survey Data

Capacity utilization rates are based on actual machine hours used (running time plus set-up time) divided by hours available, which companies generally set at 120 hours a week (5 days, 24 hours each). However, many firms, particularly smaller ones, operate only one shift, in which case, available hours would be set at 40 hours a week. Also, some firms operate on Saturdays, and base their figures on 144 hours a week.

Capacity and capacity utilization rates were requested by major operation, beginning with the initial "turning" of the gear blank and working through the production process to the grinding. For a more detailed discussion of the production process please refer to Appendix B.

Capacity Utilization Rates (1988)
(in percent)

	Motor Vehicle	Industrial	Aerospace	Marine
All Operations	72.0	58.2	31.7	63.3
Turning	70.1	64.6	37.9	61.0
Tooth Cutting				
Hobbing	71.8	61.3	32.0	64.8
Shaping	76.5	58.2	30.7	61.6
Spiral Bevel	63.9	50.6	23.2	66.2
Str. Bevel	55.2	43.3	47.4	64.5
Heat Treating				
Carburizing	88.9	65.6	53.8	82.1
Nitriding	92.8	54.5	48.3	75.6
Tooth Grinding				
Spur/Helical	85.9	56.0	37.8	71.1
Spiral Bevel	66.1	28.9	33.1	67.2
Str. Bevel	67.0	46.0	25.0	66.3
All Other	87.0	49.7	46.5	62.6

Source: Compiled from ITC/DOC Industry Survey Data

An alternative method for determining capacity would be to measure it against the most intensively used process operation, the operation which "paces" all the others. This operation will, of course, differ from one firm to the next, but in general, the gear industry uses the heat treating operation the most intensively.

Many firms do not have heat treating capabilities in-house. Many smaller firms must subcontract the operation to an outside vendor, and in limited instances no heat treat is required. However, a majority of aerospace and marine firms, and most larger firms that make gears, have their own heat treating operations, so that on a total shipment basis, most of the industry is represented. The ITC 332 report noted in its Appendix G that 81 establishments had carburizing heat treating capabilities, and 41 had their own nitriding heat treating facilities.

Estimated 1988 Capacity, Dollar Value
(Based on utilization of heat treating operations)

Sector	Estimated 1988 Capacity Utilization (A) (percent)	1988 Shipments (B) (----in	1988 Capacity (B/A) $billions----)
Motor Vehicle	89.4%	$10.20	$11.41
Industrial	63.1	2.10	3.33
Aerospace	51.4	.73	1.42
Marine	79.8	.36	.45
Total:	80.6%	$13.39	$16.61

Source: Compiled from ITC/DOC Industry Survey Data

If gear industry capacity is based on the heat treating operation, potential capacity is reduced from the total machine hours method by almost 20 percent from a capacity of $20.64 to $16.61 billion. Heat treating related capacity was estimated as shown above.

If heat treating is in fact the pacing operation, it would reduce the need and the urgency to modernize other operations in the process that do not otherwise pace production, and may be another reason for the lack of investment in modern gear cutting equipment. It is interesting also that sector utilization rates correlate rather closely with sector age of machinery. The motor vehicle gear sector has the highest utilization rate and the youngest machinery, while the aerospace sector has the lowest utilization rate and the oldest machinery, and so on.

Another measure of intensity of use is average annual machine hours. These were estimated for the four sectors from the information available. An effort was made to screen out inconsistent data to obtain the most accurate estimates. However, the results should be viewed as rough indicators.

For the entire gear industry, all the shapers, hobbers, bevel generators, and grinders averaged 2,253 hours in use, including set-up and actual running time. This estimate is based on an accounting of 60 percent of the machines. Hobbers were most used at 2,579 average hours, followed closely by shapers at 2,350 hours. The motor vehicle gear sector was poorly represented in the totals, as few reports were acceptable. The motor vehicle use of shapers and hobbers, at 4,659 hours and 3,560 hours, would have pulled the overall average higher were they given proper weight.

The individual sectors' average machine hours coincided with capacity utilization and machine age, which add to their credibility. The motor vehicle sector reported the highest average hours along with the youngest machines, and the highest rate of capacity utilization. The aerospace sector reported the fewest average hours, the lowest capacity utilization, and the oldest machines. The marine sector possesses very large and expensive machinery with presumably a longer useful life. The high average annual hours reflect this, and are illustrative of a more capital intensive industry. Information on the marine gear sector's shapers and grinders was based on too small a sample, and was not reliable.

Average Annual Machine Hours
By Sector

Machine Type	Motor Vehicle	Industrial	Aerospace	Marine
Shapers	4,659	2,078	1,398	na
Hobbers	3,560	2,355	1,511	5,004
Bevels	1,804	1,216	1,316	4,013
Grinders	1,974	1,346	1,834	na
Total	2,587	2,011	1,573	na

Source: Compiled from ITC/DOC Industry Survey Data

Gear Sizes and Precision

The capabilities of each gear sector vary in terms of gear sizes and precision, and also in volumes produced. Gear precision is measured by AGMA Precision Class ratings; gearing classes 11 and above are generally considered precision gears. In dollar value, over 90 percent of the motor vehicle gears are less than 12 inches in diameter, and nearly all have an AGMA Precision Class rating of 8-10, which is average. Bevel gears comprise about 20 percent of shipments. Roughly 25 percent of the bevel gears are over 12 inches in diameter, reflecting their greater use on trucks which require larger sizes.

In contrast to motor vehicle gearing, more than 50 percent of the dollar value of industrial gears are over 12 inches in diameter. And about 15 percent are over 36 inches. Roughly 30 percent of the shipments were bevel gears. About 25-30 percent of the shipments are AGMA Precision Class 11 or higher.

Class 11 and higher gears normally must be precision ground to tolerances of less than a thousandth of an inch (tooth to tooth) after surface hardening by heat treatment. This is done on very expensive grinding machines, and must be quality tested on sophisticated measuring equipment. Because of the number of teeth on the gears, the heat treating process is also extremely difficult and frequently causes distortions. This was identified as a major problem in the aerospace sector by the Manufacturing Technology Information Analysis Center's 1987 report on the gear sector prepared for the Defense Logistics Agency.

The marine gear sector, which produces main propulsion reduction gears for merchant and naval vessels, has a significant amount of gear production over 100 inches, and above the AGMA Precision Class 10. The higher precision reduces noise, vibration, and wear, which is of particular importance to naval vessels. Smaller marine gear sizes are produced for fishing vessels, barges and recreation craft.

Nearly all aerospace gearing is AGMA Precision Class 11 or higher, and very few gears exceed 24 inches in diameter as size and weight are critical considerations. In dollar terms, bevel gears represent about 30 percent of the aerospace business, due in part to their extensive use in helicopters.

Lead Times

Lead times are a major concern for both military and commercial users of gear systems. Generally, the higher the precision, the longer the lead time, which in part explains the longer defense lead times. Also, the special steels the military uses generally take longer to acquire, are usually more difficult to process, and must be certified and tested to military specifications.

Recent reports have cited complaints from many end-users, including the military, of excessively long lead times. The gear industry, however, has little control over the many suppliers it relies on for steel, casings, bearings, shafts, and other parts, any of which could delay final deliveries. Moreover, the gear industry also has a large stock of old equipment that breaks down quite frequently, and produces more defective parts than is necessary. While the flow of materials at some facilities could also be better managed, a reduction in lead times will require an effort by all parties involved. Efforts to bring lead times down that have to do with the manufacturing process are being addressed as part of the Defense Logistics Agency's Instrumented Factory program.

The main rotor spiral bevel gear in a helicopter is the longest lead time item reported by the gear sector. One helicopter firm reported a 97 week lead time as typical for this gear, stating that it takes 40 weeks just to get the forging blank. In a surge or mobilization emergency, the limited forging capacity in the United States would lengthen this item's (and others') lead times. One firm said that during high demand periods, a large buyer such as Boeing or General Electric may buy as much as six months of a forger's capacity, forcing others to form an extended "queue."

From date of order to delivery of the gearing, defense lead times for aerospace gears, mostly because of helicopters, averaged between 37 and 40 weeks overall during the period 1984-1988. Non-defense lead times averaged 26 or 27 weeks. No discernible trend, up or down, could be seen from these numbers.

Defense Lead Times, 1984-1988
(in weeks)

	1984	1985	1986	1987	1988
Motor Vehicle	13	13	13	13	13
Industrial	19	19	19	19	20
Aerospace	39	40	37	38	39
Marine	34	34	34	34	34

Non-Defense Lead Times, 1984-1988
(in weeks)

	1984	1985	1986	1987	1988
Motor Vehicle	10	10	10	9	9
Industrial	13	13	12	13	13
Aerospace	27	27	26	26	26
Marine	25	23	23	22	22

Source: Compiled from ITC/DOC Industry Survey Data

The marine sector also has high lead times with 34 weeks for defense production and between 22 and 25 weeks for non-defense. However, this may be acceptable considering the very large gears involved. Thirty-four weeks may be a reasonable time frame because the gearing is rarely the pacing item in the construction of new vessels, or the retrofitting of existing ones.

The industrial gear sector averaged about 19 or 20 weeks lead time on defense systems, and 13 weeks on non-defense systems. The motor vehicle gear sector reported an average 13 week lead time on defense items and 10 weeks on non-defense work.

SURGE AND MOBILIZATION

Scope and Definitions

Since gear systems are critical to the defense industrial base, the capabilities of domestic producers to expand gear production under emergency conditions was assessed. The assessment of surge/mobilization capabilities is divided into the four major sectors of the gear industry - aerospace, industrial, marine, and motor vehicle gearing. A composite view of the capabilities of these sectors would not provide useful results, as products and processes are generally not substitutable between sectors. This is particularly true of aerospace, which has engineering and precision requirements substantially different from the others, and marine, which includes very large dimensions as well as high precision for defense applications. Industrial and motor vehicle differ in terms of production lot sizes, typical gear size, and engineering inputs. To further complicate matters, the capabilities of individual plants within sectors differ substantially in terms of plant integration, plant size and customer orientation. Judgments drawn from the sector aggregates are not intended to be applied equally across all establishments included in a particular sector.

A surge/mobilization scenario based on specific target numbers of defense end-items was not used. Instead, as has been the practice in previous Commerce industrial capabilities studies, the focus was placed on the ability and speed of individual gear making establishments to ramp-up production, and their constraints in doing so. To help firms estimate this capability, target defense production levels for gears were provided for both surge (doubling the level of defense production by the end of a six month period) and mobilization (quadrupling the level of defense production by the end of a 24 month period).

Firms were asked to identify the first three bottlenecks, if any, they would encounter in a surge and mobilization situation and to estimate the time and cost to correct the constraints. To assist firms in responding to this question, and ensure consistent results, ten major gear processing operations were listed. These operations were presented in approximate sequential order as follows:

1. Forging/Casting
2. General Machining
3. Gear Cutting
4. Heat Treatment
5. Hard Finishing
6. Testing/Inspection
7. Assembly
8. Materials
9. Parts/Components
10. Other

Infrastructure Support

The gear industry is almost totally dependent on outside vendors for forgings/castings, fasteners, bearings, machine tools, and other items and services. The industry is also dependent on the availability of certain labor skills. These dependencies make forecasting surge and mobilization capability all the more difficult. Collectively, this infrastructure has deteriorated significantly in the last 10-15 years for a number of reasons, including considerable losses to imported products.

Forgings and castings were named as the number one bottleneck by the gear industry in both a surge and mobilization situation. The problem will be made worse if new designs are ordered that require construction of new dies and tooling. Both the forgings and castings industries have shrunk dramatically from historic levels in the past decade because of environmental and economic problems. In such capital-intensive industries, excess capacity is expensive to maintain, and has been eliminated by many manufacturers. Except under unusual circumstances, the military cannot count on the availability of excess forging or foundry capacity in times of emergency for the production of gears.

Bearings are used extensively in gear systems. At least two bearings are normally required for each shaft inside a gear box, and in many cases, additional bearings with toothed outer rings are used to form an integral part of individual gears, such as occurs in a planetary gear system. Most gear boxes have 10-20 bearings, and more elaborate systems may have two or three times that number.

The domestic bearings industry closed about 20 percent of its capacity during the 1980s because of declining markets and rising imports. In August 1988, bearings were placed under a 3-5 year Defense Federal Acquisition Regulation requiring defense related procurement from domestic manufacturers as a measure to preserve and hopefully enhance defense critical capacity.

Relatively few bearing producers supply literally thousands of end-users with tens of thousands of bearing part numbers. Even a small surge in demand for bearings as happened in 1988, can cause problems. In World War II, bearings delayed the production of machine tools, armaments and aircraft, as bearing production of all types had to be expanded more than six-fold over a five year period (1939-1944). Bearing shortages can be anticipated in future emergency surge or mobilization conditions.

Further, in the last five years, more than 40 percent of the machine tools needed to produce gears were imported, mostly from Germany and Japan, including several types which are not manufactured in the United States at all. This large percentage occurred despite a strong deutsche mark and yen, and would have been higher had the dollar remained strong. Machine tools suitable for defense production are long lead time and very expensive items that will pose a major constraint to expanding gear production in a mobilization. The abundance of older and used gear making equipment may help, but more skilled labor, repair parts, and material will be required for their operation.

Labor Requirements

As stated in the ITC gear study, the skilled labor needed by the gear industry is in short supply. For demographic reasons, and because of the perception that manufacturing in America is not a glamorous, prestigious career, this problem may worsen in the future. As a reflection of this condition, in a surge or mobilization emergency, a shortage in the availability of skilled labor for the gear industry is predictable, and will cause problems in both conversion to defense production and delivery of critical gear systems on a timely basis. If the gear industry modernized, the labor shortage would not be as serious.

Information was collected from the gear industry on the number of additional workers by job classification that would be needed in a surge and mobilization. These jobs were consolidated into ten major job groupings, and compiled by gear sector. The data appears on the table that follows.

An estimated 2,331 additional skilled workers would be needed in a surge situation, and 5,787 in a general mobilization. The two most critical job groupings reported were machinists and machine operators (other than gear cutting and grinding operators). In a surge, 531 additional machinists and 694 additional machine operators would be needed, while in a mobilization, an additional 1,518 machinists and 1,305 machine operators would be required. Not far behind these categories were engineers. An additional 255 engineers would be needed in a surge, and 824 in a mobilization.

The industrial gear sector reported the largest shortage of skilled labor in both a surge, at 1,091, and a mobilization, at 2,396. The motor vehicle sector was second at 507 in a surge, and 1,819 in a mobilization. The aerospace and marine gear sectors together, while more important to defense in total shipments, represented only 31 percent of the increased need for labor in a surge, and only 27 percent in a mobilization. The transition from commercial work to defense would be more burdensome on the more commercial-oriented industrial and motor vehicle sectors, as they would need to learn or hire the different skills needed in defense work.

Engineers, machinists, and tool makers constitute 86 percent of the motor vehicle sector's skill shortfall. The industrial gear sector reported the most skill shortages under machine operators and machinists, and far less so under "all others," such as assemblers, painters, welders, etc. These positions represent about 76 percent of the industrial sector's needs. The aerospace gear sector reported gear cutters, gear grinders, and machine operators as the top three skill needs, which represented 71 percent of their total labor shortage. Shortages of machinists would represent another 13 percent. In the marine sector, machinists represent more than half the shortfall at 51 percent. The all other category (support, maintenance, and assemblers) and gear cutters represent another 26 percent.

Additional Surge/Mobilization Skilled Labor Requirements by Gear Sector

Occupation	Motor Vehicle	Industrial Sector	Aero-Space	Marine	Total
Gear Cutters					
# needed in surge	0	55	124	28	207
# needed in mob	0	103	372	60	535
training time (mo.s)	-	12	15	7	13
Gear Grinders					
# needed in surge	0	74	66	33	173
# needed in mob	0	132	144	42	318
training time (mo.s)	-	14	20	17	15
Machine Operators (other than gear cutting/grinding)					
# needed in surge	84	473	105	32	694
# needed in mob	99	947	217	42	1,305
training time (mo.s)	11	9	18	12	11
Heat Treaters					
# needed in surge	0	4	0	5	9
# needed in mob	0	14	0	9	23
training time (mo.s)	-	8	-	8	8
Other (Support, Assembly, Maintenance)					
# needed in surge	12	40	26	45	123
# needed in mob	14	229	34	82	359
training time (mo.s)	na	11	19	19	14
Machinists					
# needed in surge	100	249	81	101	531
# needed in mob	465	645	129	279	1,518
training time (mo.s)	22	19	16	12	21
Tool Makers					
# needed in surge	92	14	11	7	124
# needed in mob	416	28	18	7	469
training time (mo.s)	22	31	20	48	22
Engineers					
# needed in surge	169	59	21	6	255
# needed in mob	677	90	39	18	824
training time (mo.s)	30	14	25	20	29
Supervisors					
# needed in surge	0	78	15	0	93
# needed in mob	0	122	31	0	153
training time (mo.s)	-	46	12	-	44
Inspectors/Testers					
# needed in surge	50	45	21	6	122
# needed in mob	148	86	43	6	283
training time (mo.s)	20	13	18	18	19
Grand Totals					
# needed in surge	507	1,091	470	263	2,331
# needed in mob	1,819	2,396	1,027	545	5,787
training time (mo.s)	24	16	17	14	20

Source: Compiled from ITC/DOC Industry Survey Data

Machinists will be needed in large numbers by each gear sector to maintain the old equipment. Given the 21-month long training period for the machinist trades, the competition between the sectors for the available pool of machinists in a surge or mobilization emergency would be intense. In such an eventuality, the motor vehicle sector would probably have the upper hand because of a higher general payscale. It may be necessary to prioritize machinists to ensure the other sectors are not compromised. The motor vehicle gear sector will also require 82 percent of all the additional engineers reported as needed. Engineers reportedly require about 29 months for training. It may be necessary to prioritize engineers also.

* * * *

Sector Capabilities

MOTOR VEHICLE GEAR SECTOR

Surge Capabilities - In a surge situation, the motor vehicle gear sector reported it could increase defense production by 67 percent in three months and 121 percent after six months. In dollar terms, the group could increase production from an initial monthly rate of $5.0 million to $8.4 million in three months, and to $11.1 million in six months. This exceeds surge target levels by more than $1.0 million dollars, or 10.4 percent.

Only six motor vehicle gear plants reported their surge capabilities. Two of these could not double defense production within the prescribed six months, while four others could. Several major companies did not participate.

Surge Capabilities
(target: 2x in 6 months)

	Monthly Rate of Production (in $000s)	Increase
Monthly Defense Shipments (1988)	5,032	--
Surge at 3 Months	8,385	67%
Surge at 6 Months	11,111	121%
Target Level	10,064	100%

Surge Bottlenecks - Of six firms reporting, three named parts/components from outside vendors needed for transmission assembly as their number one bottleneck. Two named forging blanks as their number two problem. Other bottlenecks included labor constraints on overtime hours, and acquisition of various components, such as bearings, cover plates, rear cases, and differential pinions.

The time and cost associated with resolving surge bottlenecks is shown on the table that follows. The single most expensive problem concerns a head tester for the assembly operation, that will cost $3 million and take eight months to acquire. Several

Motor Vehicle Surge Bottleneck Analysis

Operation	Bottleneck #1	Bottleneck #2	Bottleneck #3
Forging/Casting			
a. Times Mentioned......		2	
b. Months to Correct....		8	
c. Cost (in $000s)......		400	
General Machining			
a. Times Mentioned......	1	1	1
b. Months to Correct....	5	12	15
c. Cost (in $000s)......	na	1,300	250
Gear Cutting			
a. Times Mentioned......	1	1	1
b. Months to Correct....	12	5	18
c. Cost (in $000s)......	1,500	na	1,500
Heat Treatment			
a. Times Mentioned......			1
b. Months to Correct....			5
c. Cost (in $000s)......			na
Hard Finishing			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Testing/Inspection			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Assembly			
a. Times Mentioned......			1
b. Months to Correct....			8
c. Cost (in $000s)......			3,000
Materials			
a. Times Mentioned......	1		
b. Months to Correct....	12		
c. Cost (in $000s)......	150		
Parts/Components			
a. Times Mentioned......	3		
b. Months to Correct....	5		
c. Cost (in $000s)......	1,730		
Other			
a. Times Mentioned......		1	1
b. Months to Correct....		1	1
c. Cost (in $000s)......		na	na
Total Cost to Correct:	3,380	1,700	4,750
Grand Total:	9,830		

firms will need gear cutting equipment estimated to cost another $3 million and take five to 18 months to get. Resolution of the parts and components bottlenecks will cost $1.7 million, but can be resolved in five months. All other surge bottlenecks will cost $2.1 million and take from one to 15 months to resolve. In total, resolution of the first three bottlenecks will cost a minimum of $9.8 million. However, this cannot be accomplished in a timely manner. Advance planning, including locating and pre-establishing alternative suppliers, would be prudent.

Mobilization Capabilities - Only four firms estimated their mobilization capabilities. In a general mobilization, the motor vehicle gear sector reported it could increase production 220 percent in six months, 365 percent in 12 months, and 512 percent after 24 months. Measured in dollar value, the increases would be to monthly rates of $16.1 in six months, $23.4 million in 12 months and $30.8 million in two years. The industry exceeded mobilization target levels of $20.1 million in monthly defense production by $10.7 million, or by almost 53 percent.

Mobilization Capabilities
(target: 4x in 24 months)

	Monthly Rate of Production (in $000s)	Percent Increase
Monthly Defense Shipments (1988)	5,032	--
Mobilization at 6 Months	16,115	220%
Mobilization at 12 Months	23,411	365%
Mobilization at 24 Months	30,780	512%
Target Level	20,128	300%

Mobilization Bottlenecks - Six firms reported mobilization bottlenecks, and as in surge, three named parts and components bought from outside vendors as their number one bottleneck. Four mentions were also made of the general machining operation, and of gear cutting. General machining was named number one once, and number two twice. Gear cutting was named number one once, number two once, and number three twice.

Motor Vehicle Mobilization Bottleneck Analysis

Operation	Bottleneck #1	Bottleneck #2	Bottleneck #3
Forging/Casting			
a. Times Mentioned......		2	
b. Months to Correct....		8	
c. Cost (in $000s)......		400	
General Machining			
a. Times Mentioned......	1	2	1
b. Months to Correct....	18	11	15
c. Cost (in $000s)......	3,675	2,990	250
Gear Cutting			
a. Times Mentioned......	1	1	2
b. Months to Correct....	12	18	16
c. Cost (in $000s)......	1,500	900	3,170
Heat Treatment			
a. Times Mentioned......			1
b. Months to Correct....			na
c. Cost (in $000s)......			na
Hard Finishing			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Testing/Inspection			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Assembly			
a. Times Mentioned......			1
b. Months to Correct....			6
c. Cost (in $000s)......			4,000
Materials			
a. Times Mentioned......	1		
b. Months to Correct....	12		
c. Cost (in $000s)......	150		
Parts/Components			
a. Times Mentioned......	3		
b. Months to Correct....	6		
c. Cost (in $000s)......	2,570		
Other			
a. Times Mentioned......		1	1
b. Months to Correct....		2	2
c. Cost (in $000s)......		10	na
Total Cost to Correct:	7,895	4,300	7,420
Grand Total:	19,615		

Resolution of the general machining bottlenecks will cost a reported $6.9 million, and require 11 to 18 months. Bottlenecks in the gear cutting operation are estimated to cost $5.6 million and take 12 to 18 months to resolve. Warehouse and assembly space shortages will cost $4 million and take six months to resolve. Resolution of the parts and components problem is expected to cost $2.6 million and take six months. In total, the resolution of the first three motor vehicles related mobilization bottlenecks will cost a minimum of $19.6 million and could be accomplished in a timely manner under emergency conditions.

INDUSTRIAL GEAR SECTOR

Surge Capabilities - In a surge situation, the industrial gear sector reported it could increase defense production by 246 percent in three months and 492 percent after six months. In dollar terms, the group could increase production from an initial monthly rate of $5.9 million to $20.4 million in three months, and to $34.9 million in six months. This greatly exceeds surge target levels of $11.8 million, by nearly 200 percent, or about $23.1 million. Of 24 firms reporting their surge capabilities, 18 could meet surge production targets, while six others could not.

Surge Capabilities
(target: 2x in 6 months)

	Monthly Rate of Production (in $000s)	Percent Increase
Monthly Defense Shipments (1988)	5,900	--
Surge at 3 Months	20,428	246%
Surge at 6 Months	34,917	492%
Target Level	11,800	100%

Surge Bottlenecks - The most frequently named bottleneck by the industrial gear sector was the availability of forgings, castings, and bar stock. Seventeen firms, 47 percent of those reporting, named this operation as their number one bottleneck. Far behind forgings and castings in times mentioned were gear cutting, and general machining. Gear cutting was named first four times, second eight times, and third five times. General machining was also named first four times, second six times, and third seven times.

Less frequently mentioned bottlenecks were hard finishing, the availability of assembly materials, and qualified people to conduct testing and inspection operations. Hard finishing was mentioned four times as the number one bottleneck, twice as number two, and four times as number three.

Resolution of the forging, casting, and bar stock bottlenecks will cost an estimated $2.3 million, and take a reported seven months. While this seems optimistic, the requirements for forgings and castings by the industrial gear sector are not as

Industrial Surge Bottleneck Analysis

Operation	Bottleneck #1	Bottleneck #2	Bottleneck #3
Forging/Casting			
a. Times Mentioned......	17		1
b. Months to Correct....	7		na
c. Cost (in $000s)......	2,295		na
General Machining			
a. Times Mentioned......	4	6	7
b. Months to Correct....	16	4	8
c. Cost (in $000s)......	770	2,746	1,330
Gear Cutting			
a. Times Mentioned......	4	8	5
b. Months to Correct....	7	11	8
c. Cost (in $000s)......	2,525	8,700	4,730
Heat Treatment			
a. Times Mentioned......	1	7	2
b. Months to Correct....	na	14	8
c. Cost (in $000s)......	na	3,800	3,500
Hard Finishing			
a. Times Mentioned......	4	2	4
b. Months to Correct....	23	16	14
c. Cost (in $000s)......	6,300	5,000	6,200
Testing/Inspection			
a. Times Mentioned......	2	3	3
b. Months to Correct....	4	20	5
c. Cost (in $000s)......	1,050	130	230
Assembly			
a. Times Mentioned......			1
b. Months to Correct....			6
c. Cost (in $000s)......			60
Materials			
a. Times Mentioned......	1	6	6
b. Months to Correct....	12	7	6
c. Cost (in $000s)......	na	107	300
Parts/Components			
a. Times Mentioned......	2	1	3
b. Months to Correct....	8	na	3
c. Cost (in $000s)......	1,230	na	2
Other			
a. Times Mentioned......	1	1	1
b. Months to Correct....	6	6	6
c. Cost (in $000s)......	na	750	100
Total Cost to Correct:	14,170	21,233	16,452
Grand Total:	51,855		

specialized or demanding as aerospace or marine gear producers. Some firms reported having several suppliers, and others indicated that second and third sources could be found and qualified without much difficulty. In a real surge situation, much would depend on the general level of business activity and amount of unused capacity available in the forging/casting/bar stock sectors. Correction of the gear cutting bottleneck would cost $16 million and require seven to 11 months, while general machining would cost $4.8 million and require four to 16 months.

Though mentioned fewer times, hard finishing is the most expensive constraint to fix at $17.5 million, and would also take the longest at 14 to 23 months. The total cost of resolving the first three surge bottlenecks is estimated to be $51.9 million. Advanced planning should be arranged with firms that could not reach surge targets. Additional sources could probably be pre-established from a large pool of potential suppliers for use under emergency conditions.

Mobilization Capabilities - In a general mobilization, the industrial gear sector reported it could increase production 476 percent in six months, 676 percent in 12 months, and 822 percent after 24 months. Measured in dollar value, the increases would be to monthly rates of $34.0 million in six months, $45.8 million in 12 months and $54.4 million in two years. The industry exceeded mobilization target levels of $23.6 million in monthly defense production by almost 2.5 times. Of 16 firms responding, 14 believe they would be able to meet targets, while two failed.

Industrial Gears
Mobilization Capabilities
(target: 4x in 24 months)

	Monthly Rate of Production (in $000s)	Percent Increase
Monthly Defense Shipments (1988)	5,900	--
Mobilization at 6 Months	33,976	476%
Mobilization at 12 Months	45,777	676%
Mobilization at 24 Months	54,386	822%
Target Level	23,600	300%

Industrial Mobilization Bottleneck Analysis

Operation	Bottleneck #1	Bottleneck #2	Bottleneck #3
Forging/Casting			
a. Times Mentioned......	14	1	1
b. Months to Correct....	8	na	6
c. Cost (in $000s)......	2,105	na	na
General Machining			
a. Times Mentioned......	3	6	9
b. Months to Correct....	7	7	7
c. Cost (in $000s)......	1,280	2,800	2,430
Gear Cutting			
a. Times Mentioned......	5	7	5
b. Months to Correct....	11	16	16
c. Cost (in $000s)......	3,300	8,100	8,200
Heat Treatment			
a. Times Mentioned......	4	7	2
b. Months to Correct....	13	18	18
c. Cost (in $000s)......	3,350	6,800	3,600
Hard Finishing			
a. Times Mentioned......	4	2	3
b. Months to Correct....	27	15	25
c. Cost (in $000s)......	7,100	3,000	8,500
Testing/Inspection			
a. Times Mentioned......	1	4	3
b. Months to Correct....	18	5	10
c. Cost (in $000s)......	2,000	200	173
Assembly			
a. Times Mentioned......			1
b. Months to Correct....			6
c. Cost (in $000s)......			60
Materials			
a. Times Mentioned......	1	4	5
b. Months to Correct....	12	8	1
c. Cost (in $000s)......	na	110	na
Parts/Components			
a. Times Mentioned......	1	1	1
b. Months to Correct....	12	na	2
c. Cost (in $000s)......	1,230	na	5
Other			
a. Times Mentioned......	2	2	1
b. Months to Correct....	9	6	6
c. Cost (in $000s)......	2,250	na	100
Total Cost to Correct:	22,615	21,010	23,068
Grand Total:	66,695		

Mobilization Bottlenecks - As in the surge situation, the availability of forgings and castings was named the major constraint to a general mobilization, followed at a distance by gear cutting operations, heat treatment, and general machining. Forgings and castings were named the number one bottleneck 14 times, and as number two or three twice. Gear cutting was named five times as the number one bottleneck, and 12 times as number two or three. Also mentioned fairly often were hard finishing and heat treatment.

Resolution of the forging and casting bottlenecks will cost a reported $2.1 million, and require six to eight months to resolve. The gear cutting operation is estimated to cost $19.6 million, and take 11 to 16 months to resolve. General Machining will cost $6.5 million, and take seven months to correct. Hard finishing will cost $18.6 million and take 15 to 27 months. And heat treatment will cost $13.8 million and require 13 to 18 months. In total, the correction of the first three industrial gear sector mobilization bottlenecks could be achieved in a timely manner under emergency conditions at a minimum cost of $66.7 million.

AEROSPACE GEAR SECTOR

Surge Capabilities - The aerospace gear sector cannot reach surge targets. In a surge situation, the sector reported it could increase defense production by 35 percent in three months and 83 percent after six months. In dollar terms, the group could increase production from an initial monthly rate of $39.7 million to $53.5 million in three months, and to $72.6 million in six months. This falls short of surge target levels by $6.8 million dollars.

Of 21 firms reporting their surge capabilities, 12 could not double defense production within the prescribed six months, while nine others could. Generally, those that could reach targets were operating at a low rate of capacity.

Surge Capabilities
(target: 2x in 6 months)

	Monthly Rate of Production (in $000s)	Percent Increase
Monthly Defense Shipments (1988)	39,670	--
Surge at 3 Months	53,529	35%
Surge at 6 Months	72,590	83%
Target Level	79,340	100%

Surge Bottlenecks - The frequency and months required to rectify various surge bottlenecks are shown on the table below. The most frequently named bottleneck by the aerospace gear sector was "hard finishing," which primarily involves grinding operations. Six firms named hard finishing their number one bottleneck, while seven others named it their second or third bottleneck. Heat treating was mentioned 13 times, five times as the number one bottleneck.

Other frequently mentioned bottlenecks were the availability of forgings and castings, mentioned nine times as a bottleneck, and general machining, mentioned eight times. Back-end operations - assembly, the purchase of other materials, and parts and components such as bearings and seals used in the assembly of a finished gearbox were mentioned less frequently.

Aerospace Surge Bottleneck Analysis

Operation	Bottleneck #1	Bottleneck #2	Bottleneck #3
Forging/Casting			
a. Times Mentioned......	5	1	3
b. Months to Correct....	9	6	8
c. Cost (in $000s)......	1,900	na	200
General Machining			
a. Times Mentioned......	3	3	2
b. Months to Correct....	6	8	8
c. Cost (in $000s)......	1,251	3,275	1,100
Gear Cutting			
a. Times Mentioned......	1	3	6
b. Months to Correct....	3	7	5
c. Cost (in $000s)......	40	618	2,301
Heat Treatment			
a. Times Mentioned......	5	4	4
b. Months to Correct....	9	9	7
c. Cost (in $000s)......	2,620	3,000	2,300
Hard Finishing			
a. Times Mentioned......	6	4	3
b. Months to Correct....	11	14	11
c. Cost (in $000s)......	6,818	6,500	2,300
Testing/Inspection			
a. Times Mentioned......		2	3
b. Months to Correct....		3	20
c. Cost (in $000s)......		11	4,300
Assembly			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Materials			
a. Times Mentioned......		3	2
b. Months to Correct....		7	6
c. Cost (in $000s)......		503	50
Parts/Components			
a. Times Mentioned......	1	1	
b. Months to Correct....	na	na	
c. Cost (in $000s)......	200	na	
Other			
a. Times Mentioned......	3		
b. Months to Correct....	18		
c. Cost (in $000s)......	na		
Total Cost to Correct:	12,829	13,907	12,551
Grand Total:	39,287		

Correction of the hard finishing bottlenecks will cost an estimated $15.6 million and take a reported 11 to 14 months. Heat treatment bottlenecks will cost an estimated $7.9 million and require a reported seven to nine months to resolve. Resolution of the first three bottlenecks cannot be achieved in the allotted six months. Advance preparation is needed and will cost a minimum of $39.3 million.

Mobilization Capabilities - In a general mobilization, the Aerospace Gear Sector reported it could increase production 39 percent in six months, 105 percent in 12 months, and 182 percent after 24 months. Measured in dollar value, the increases would be to monthly rates of $55.2 million in six months, $81.2 million in 12 months, and $111.8 million in two years. The industry failed to reach target levels of $158.7 million in monthly defense production by $46.9 million. Ten firms reported they could meet mobilization targets, while six indicated they could not.

Mobilization Capabilities
(target: 4x in 24 months)

	Monthly Rate of Production (in $000s)	Percent Increase
Monthly Defense Shipments (1988)	39,670	--
Mobilization at 6 Months	55,249	39%
Mobilization at 12 Months	81,152	105%
Mobilization at 24 Months	111,811	182%
Target Level	158,680	300%

Mobilization Bottlenecks - Mobilization bottleneck data are shown in the table below. Hard finishing was named as the major bottleneck in a general mobilization, followed by general machining, and heat treatment. Hard finishing was named the number one bottleneck five times, and another six times as the second or third bottleneck. General machining was named ten times as a bottleneck, and heat treatment was named seven times.

Aerospace Mobilization Bottleneck Analysis

Operation	Bottleneck #1	Bottleneck #2	Bottleneck #3
Forging/Casting			
a. Times Mentioned......	4		1
b. Months to Correct....	10		na
c. Cost (in $000s)......	2,600		na
General Machining			
a. Times Mentioned......	4	4	2
b. Months to Correct....	21	12	12
c. Cost (in $000s)......	42,450	3,545	10,750
Gear Cutting			
a. Times Mentioned......	2	3	4
b. Months to Correct....	10	10	14
c. Cost (in $000s)......	1,040	425	1,800
Heat Treatment			
a. Times Mentioned......	3	3	1
b. Months to Correct....	11	14	6
c. Cost (in $000s)......	2,120	3,700	600
Hard Finishing			
a. Times Mentioned......	5	4	2
b. Months to Correct....	18	12	14
c. Cost (in $000s)......	9,825	5,500	1,800
Testing/Inspection			
a. Times Mentioned......		2	2
b. Months to Correct....		3	18
c. Cost (in $000s)......		10	3,300
Assembly			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Materials			
a. Times Mentioned......		2	1
b. Months to Correct....		8	6
c. Cost (in $000s)......		1,000	50
Parts/Components			
a. Times Mentioned......	1		1
b. Months to Correct....	12		na
c. Cost (in $000s)......	na		na
Other			
a. Times Mentioned......	1		1
b. Months to Correct....	36		15
c. Cost (in $000s)......	200		5,000
Total Cost to Correct:	58,235	14,180	23,300
Grand Total:	95,715		

The availability of forgings and castings, and gear cutting equipment, were also mentioned several times. As with surge bottlenecks, the back-end operations were mentioned infrequently, and presumably would not pose a problem to mobilization. Resolution of the hard finishing bottlenecks will cost an estimated $17.1 million, and require 12 to 18 months to resolve. The general machining operation is estimated to cost $56.7 million, and take 12 to 21 months to resolve. Heat treatments will cost $6.4 million, and take six to 14 months. In total, resolution of the first three aerospace related mobilization bottlenecks will cost a minimum of $95.7 million, but could be achieved in a timely manner under emergency conditions. Advance planning would be prudent. The dependence on foreign made machine tools is cause for concern.

MARINE GEAR SECTOR

Surge Capabilities - The marine gear sector cannot reach surge targets. In a surge situation, the sector reported it could increase defense production by 34 percent in three months and 69 percent after six months. In dollar terms, the group could increase production from an initial monthly rate of $10.5 million to $14.0 million in three months, and to $17.7 million in six months. This falls short of surge target levels by $3.3 million dollars, or 15.6 percent.

Only five firms reported their surge capabilities. Two estimated they could meet surge targets within the prescribed six months, while three could not. Those that could reach targets were operating at a low rate of capacity.

Surge Capabilities
(target: 2x in 6 months)

	Monthly Rate of Production (in $000s)	Percent Increase
Monthly Defense Shipments (1988)	10,481	--
Surge at 3 Months	14,030	34%
Surge at 6 Months	17,699	69%
Target Level	20,962	100%

Surge Bottlenecks - Four firms reported surge bottlenecks. Two of these cited forgings as their number one bottleneck. The operation mentioned most frequently was hard finishing, which was named as the second bottleneck by two firms, and the third by one. General machining and assembly were each named the number one bottleneck once.

The time and cost associated with resolving surge bottlenecks is shown on the table that follows. Resolution of the hard finishing bottlenecks will cost an estimated $11.0 million and take a reported 12 to 27 months. The general machining bottleneck will cost an estimated $2.0 million and require a reported 18 months to resolve. Resolution of all other surge bottlenecks will cost an additional estimated $755 thousand.

Marine Surge Bottleneck Analysis

Operation	Bottleneck #1	Bottleneck #2	Bottleneck #3
Forging/Casting			
a. Times Mentioned......	2		
b. Months to Correct....	4		
c. Cost (in $000s)......	50		
General Machining			
a. Times Mentioned......	1		
b. Months to Correct....	18		
c. Cost (in $000s)......	2,000		
Gear Cutting			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Heat Treatment			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Hard Finishing			
a. Times Mentioned......		2	1
b. Months to Correct....		27	12
c. Cost (in $000s)......		7,000	4,000
Testing/Inspection			
a. Times Mentioned......			1
b. Months to Correct....			24
c. Cost (in $000s)......			600
Assembly			
a. Times Mentioned......	1		
b. Months to Correct....	18		
c. Cost (in $000s)......	5		
Materials			
a. Times Mentioned......			1
b. Months to Correct....			na
c. Cost (in $000s)......			na
Parts/Components			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Other			
a. Times Mentioned......		1	
b. Months to Correct....		4	
c. Cost (in $000s)......		100	
Total Cost to Correct:	2,055	7,100	4,600

Grand Total: 13,755

The first three bottlenecks cannot be resolved in a timely manner. However, a six-month surge, even under emergency conditions, may be unrealistic for this sector. This may not pose a constraint to the construction of new war vessels (which can take several years). Some consideration should be given to matching the marine gear sector's ramp-up time with (real) surge requirements. A doubling of defense production will cost a minimum of $13.8 million.

Mobilization Capabilities - The marine gear sector cannot reach mobilization targets without emergency assistance from the Federal Government. In a general mobilization, the sector reported it could increase production 60 percent in six months, 72 percent in 12 months, and only 87 percent after 24 months. Measured in dollar value, from initial defense production of $10.5 million, increases were reported to monthly rates of $16.7 in six months, $18.0 in 12 months, and $19.6 million in two years. The industry failed to reach target levels in monthly defense production by $22.3 million, which amounts to over a 53 percent shortfall.

Mobilization Capabilities
(target: 4x in 24 months)

	Monthly Rate of Production (in $000s)	Percent Increase
Monthly Defense Shipments (1988)	10,481	--
Mobilization at 6 Months	16,735	60%
Mobilization at 12 Months	18,002	72%
Mobilization at 24 Months	19,562	87%
Target Level	41,924	300%

Mobilization Bottlenecks - Four firms reported mobilization bottlenecks. All four mentioned hard finishing as a bottleneck in a general mobilization. Forgings as in surge were identified as the number one bottleneck twice. Other operations mentioned included general machining, gear cutting, testing, and assembly materials.

Marine Mobilization Bottleneck Analysis

Operation	Bottleneck #1	Bottleneck #2	Bottleneck #3
Forging/Casting			
a. Times Mentioned......	2		
b. Months to Correct....	4		
c. Cost (in $000s)......	50		
General Machining			
a. Times Mentioned......	1		1
b. Months to Correct....	18		24
c. Cost (in $000s)......	5,000		2,500
Gear Cutting			
a. Times Mentioned......		1	
b. Months to Correct....		24	
c. Cost (in $000s)......		11,000	
Heat Treatment			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Hard Finishing			
a. Times Mentioned......	1	2	1
b. Months to Correct....	24	27	12
c. Cost (in $000s)......	12,000	10,000	6,000
Testing/Inspection			
a. Times Mentioned......			1
b. Months to Correct....			24
c. Cost (in $000s)......			2,000
Assembly			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Materials			
a. Times Mentioned......			1
b. Months to Correct....			na
c. Cost (in $000s)......			na
Parts/Components			
a. Times Mentioned......			
b. Months to Correct....			
c. Cost (in $000s)......			
Other			
a. Times Mentioned......		1	
b. Months to Correct....		4	
c. Cost (in $000s)......		100	
Total Cost to Correct:	17,050	21,100	10,500

Grand Total: 48,650

Resolution of the hard finishing bottlenecks will cost a reported $28.1 million, and require 12 to 27 months to resolve. The general machining operation is estimated to cost $7.5 million, and take 18 to 24 months to accomplish. The gear cutting operation will cost $11 million, and take 24 months to fix. All other mobilization bottlenecks will reportedly cost $2.2 million, and take four to 24 months to resolve. In total, resolution of the first three marine gear related mobilization bottlenecks will cost a minimum of $48.7 million, but could be achieved under emergency conditions. Advance planning is essential for the sector to meet mobilization targets.

FINDINGS

National Security Assessment of the U.S. Gear Industry

The continued viability of the domestic gear industry is critical to U.S. national security and economic competitiveness. Gears are basic components of most industrial machinery, and are critical to the performance and construction of nearly all weapon systems. A domestic gear industry provides a secure source of supply, maintains a U.S. presence in the continuing development of gear technology. As a highly specialized intermediate product, gear customers benefit strategically from a domestic source by having greater control over product quality and delivery schedules, lower transaction, transportation and inventory costs.

The U.S. gear industry experienced significant decline during the 1980s. Gear industry sales and profitability declined as most gear end-markets experienced their worst contraction of the post-World War II period.

Alternative technologies have further eroded market opportunities for the U.S. gear industry. Increases in machinery productivity have also served to decrease market opportunities for the gear industry.

The outlook for the 1990s is for continued decline in gear end-market industries.

By most measures (e.g.) shipment volume, employment, and investment), 'captive' producers dominate the gear industry.

Gear industry statistics are split between several unrelated SIC industry codes, making it difficult to measure industry-wide economic performance.

Gear industry shipments improved in 1987 and 1988, but remained below earlier peaks reached in 1979-1980.

In 1988, the gear industry experienced a trade deficit of about $318 million, with the trade balance in the industrial gear sector continuing to deteriorate at an alarming rate.

Industry employment has declined since 1980. By 1987, total employees had fallen by 37 percent, with production workers down nearly 40 percent.

Gear industry pre-tax profitability declined each year from 1984 to 1988, and has been very unevenly distributed, reflecting the segmented and diversified nature of the industry.

The largest U.S. gear producers (those with more than 500 employees) were disproportionately damaged by the industry's decline in the 1980s.

The increasingly global nature of the industry makes it imperative that gear firms invest in new machinery to achieve technical parity with international competitors. Investment in plant and equipment has fluctuated in tandem with shipments from 1972 through 1987, but has been inadequate for the industry to remain internationally competitive.

Gear industry research and development expenditures (about one-half of one percent of sales in 1988) have also been inadequate.

The decline in gear industry competitiveness has led, in part, to a situation where the industry would be unable to meet potential gear production demands in a national security emergency. Specifically, the defense-intensive aerospace and marine gear sectors would be unable to reach emergency surge and mobilization production targets.

Within existing manufacturing facilities, the constraints to increasing production cited most frequently were heat treatment and (post heat treatment) grinding operations. We further anticipate shortages of skilled labor, castings, and forgings during a surge or mobilization.

RECOMMENDATIONS

We recommend the following program of industry-specific actions targeted to the gear industry's unique needs.

ACTION: BXA will convene a meeting with representatives from the American Gear Manufacturers Association and the Department of Commerce's Technology Administration (TA) to introduce interested companies to TA's industry support programs. Programs that may be of particular interest include:

1. **Shared flexible centers for integrated manufacturing**, and **R&D consortiums**. These programs are designed to help smaller firms form joint venture groups to create and lease production time on state-of-the-art factory flexible manufacturing systems (FMS); and to promote cooperative participation in shared risk R&D ventures;

2. Vertically oriented **strategic partnerships** that seek to bring together representatives up and down the gear supply chain (i.e., from gear producers, forging and casting suppliers, and gear users) to encourage cooperation in R&D, improve communications, and discuss common problems; and

3. Development of a closer working relationship with TA's **National Institute of Standards and Technology** (NIST). NIST (formerly known as the National Bureau of Standards) is the sole Federal laboratory directly concerned with aiding industry and commerce. The new and expanded purpose of NIST, established by the Trade Act of 1988, includes assisting industry in the development of technology and procedures to improve quality, the modernization of manufacturing processes, and the promotion of cost effective production.

ACTION: BXA recommends maximum use of Defense's Industrial Modernization Incentive Program to assist in industry modernization. BXA also recommends that gear companies work with the Small Business Administration and other Government loan authorities to actively pursue sources of low interest loans available for gear industry revitalization.

ACTION: BXA recommends that the Defense Logistics Agency expand the scope of its INFAC (Instrumented Factory) program to include the entire gear sector and infrastructure. We also encourage greater cooperation between INFAC and other existing research programs, and urge the individual Services to participate in the INFAC program.

ACTION: To address the gear industry's inability to meet anticipated requirements for gears in a national security emergency, DOD and Commerce should monitor the troubled firms in all sectors. If one or more should fail, we recommend developing the capabilities of other U.S. firms to meet defense-critical needs.

ACTION: BXA will convene a meeting with Bureau of the Census, Trade Development, and American Gear Manufacturers Association statistical representatives to seek to rectify current data shortcomings and to explore the need for better Government monitoring.

ACTION: Finally, we encourage the industry to take action to consolidate into larger more technologically efficient firms that can both afford and justify investment in the latest technologies.

APPENDIX A - THE PRODUCT

The Product

Gears are compact toothed wheels used as positive-engagement, power transmission elements to determine the speed, torque, and direction of rotation of driven machine elements. The tooth form is usually based on the "involute" curve, which is tolerant of small variations in center to center distance of mating gears, such as may arise during manufacture of gear boxes, or which may be due to flexing of gear shafts during operation. Another advantage of involute gears is manufacturing economy. A single cutter can be used to cut a range of gears. Involute gears have been shown through practice to accommodate rolling and minimize sliding contact of the tooth surfaces. Rolling contact produces less heat and increases the mechanical efficiency with which gears operate. Gear types may be grouped into five main categories: spur, helical, bevel, hypoid, and worm gears.

Spur Gears - Spur gears have straight teeth cut parallel to the rotational axis. Spur gears are the least expensive to manufacture and the most commonly used, especially for drives with parallel shafts. Spur gear teeth have an external, internal, or rack-and-pinion arrangement. The most common type is external teeth on the perimeter of mating cylindrical wheels, with the larger wheel called the "gear" and the smaller wheel the "pinion." The pinion and its mating gear rotate in opposite directions.

Internal gears, as the name implies, have teeth cut on the inside surface of a cylindrical ring, and their rotation is in the same direction as the input pinion. An internal gear is often set up with an internal "planetary" system in which a set of three or four smaller external toothed spur gears called planets mesh with the teeth of the internal gear, while also meshing with and surrounding a smaller central pinion (sun).

Rack-and-pinion gears have a straight bar with teeth cut across it which is driven by a pinion. This converts rotary motion into linear motion (or the reverse). The rack and pinion is used extensively in machine tools, lift trucks, power shovels and other heavy machinery.

SPUR AND HELICAL GEARS
(figure 1-6)

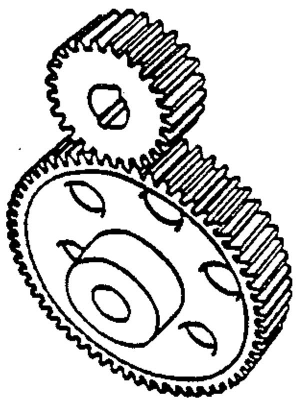


Figure 1. Spur gears.

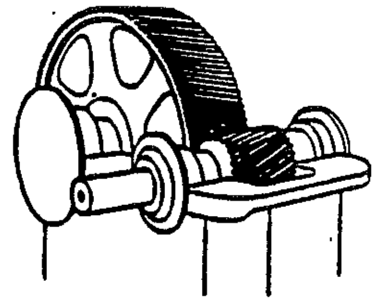


Figure 2. Helical gears.

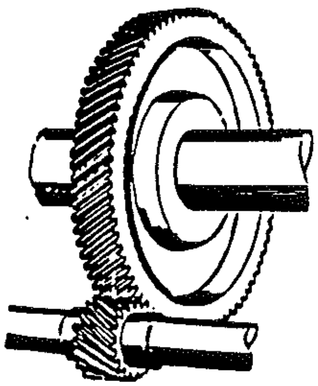


Figure 3. Single helical gears.

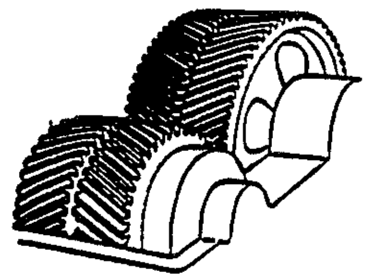


Figure 4. Double helical gears.

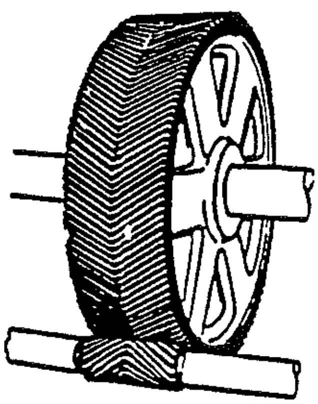


Figure 5. Herringbone gears.

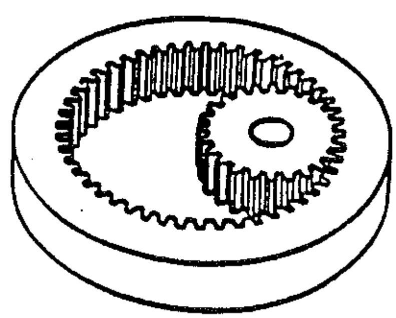


Figure 6. Internal gears.

BEVEL GEARS
(figure 7-12)

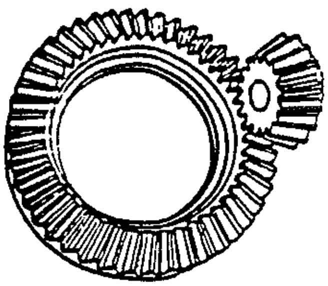


Figure 7. Straight bevel gears.

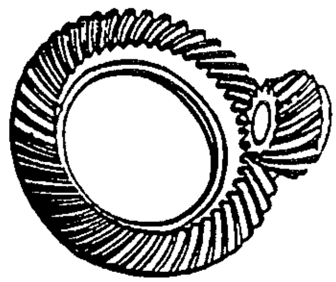


Figure 8. Spiral bevel gears.

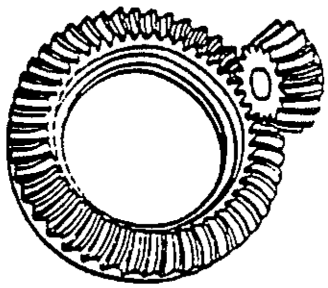


Figure 9. Zerol bevel gears.

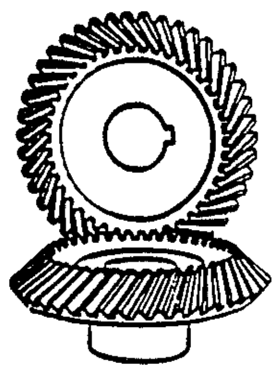


Figure 10. Skew bevel gears.

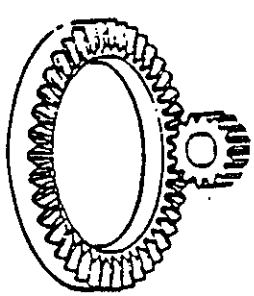


Figure 11. Face gears.

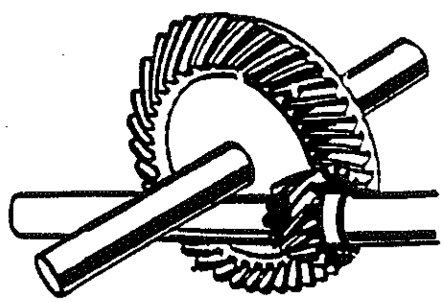


Figure 12. Hypoid gears.

WORM AND OTHER GEARS
(figure 13-19)

Figure 13. Cylindrical worm.

Figure 14. Hour glass worm.

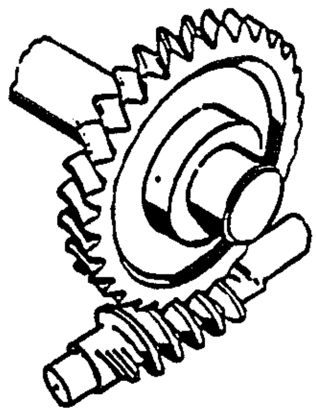


Figure 15. Single enveloping worm gears.

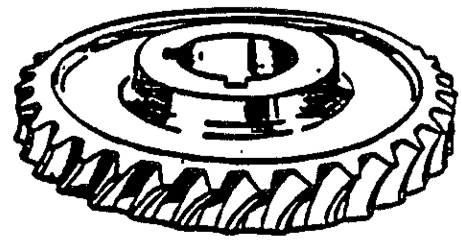


Figure 16. Double enveloping worm gear.

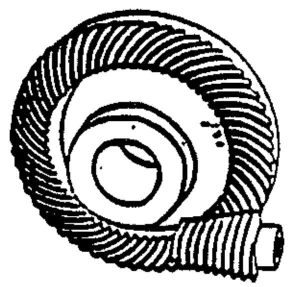


Figure 18. Spiroid gears.

Figure 17. Crossed axis helical gears.

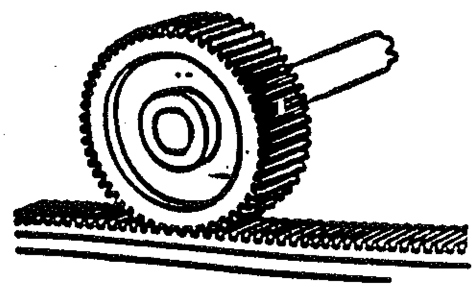


Figure 19. Spur rack and pinion.

Helical Gears - Helical gears have teeth cut at an angle to the axis of rotation, rather than straight like spur gears. Thus, the contact line of the meshing teeth progresses across the face from the tip of one end to the root of the other, reducing noise and vibration characteristic of spur gears. Also, several teeth are in contact at any one time, producing a more gradual loading of the teeth that reduces wear substantially. An increased amount of sliding action between helical gear teeth places greater demands on lubricants to prevent metal-to-metal contact. And, since the teeth mesh at an angle, a side thrust load is produced along each gear shaft. Thus, thrust bearings must be used to absorb this load and maintain proper alignment.

A double helical gear, with tooth angles opposed can be used to cancel out the trust. These are usually manufactured with a small space between the opposing angles. An arrangement with no space between the opposed angles is called a "herringbone" gear. This is more compact. However, a herringbone gear is more difficult to produce, and it must be precisely aligned with its mating pinion to avoid interference.

Bevel Gears - Unlike spur or helical gears with teeth cut from a cylindrical blank, bevel gears have teeth cut on a tapered or conical blank. Bevel gears are used where the centerlines of the input and output shafts intersect. Teeth are usually cut at an angle so the shafts (if extended) would intersect at a 90 degree angle.

It is often difficult to support bevel gears at both ends because the shafts intersect. As a result, one or both gears overhang their supporting shafts. This may cause the shaft to deflect, misaligning gears and accelerating wear. Shaft deflection may be overcome by straddle mounting the gear (not the pinion) with a bearing placed on each side where space permits.

Bevel gears may be straight toothed or spiral toothed. Straight toothed bevels have teeth cut straight across. They are subject to much of the same operating conditions as spur gears in that straight-tooth bevels are efficient but somewhat noisy. They produce thrust loads in a direction that tends to separate the gears. Spiral bevels have curved teeth that make an action somewhat like a helical gear.

This produces smoother, quieter operation. Thrust loading depends on the direction of rotation and whether the spiral angle at which the teeth are cut is positive or negative.

Hypoid Gears - Hypoid gears resemble spiral-bevels, but the shaft axes of the pinion and driven gear do not intersect. This configuration allows both shafts to be supported at both ends. Although hypoid gears are stronger and more rigid than most other types, they are also one of the most difficult to lubricate because of high tooth contact pressures.

High levels of sliding between tooth surfaces reduces efficiency. In fact, the hypoid combines the sliding action of the worm gear with the rolling movement and high tooth pressure often associated with the spiral bevel. In addition, both the driven and driving gears in the hypoid set are made of steel, which further increases the demands on the lubricant. Special lubricants with both oiliness and anti-weld properties are required to withstand the high contact pressures and rubbing speeds in hypoids.

Despite these demands for special lubrication, hypoid gears are used extensively in rear axles of automobiles with rear wheel drives. And they are being used increasingly in industrial machinery.

Worm Gears - Worm gears consist of a screw like worm or pinion that meshes with a larger gear, usually called a "wheel." The worm acts as a screw, and may make many revolutions to pull the wheel through a single revolution. In this way, a wide range of speed ratios up to 60 or 70 to one (and higher) can be obtained in a single reduction.

Most worms are cylindrical in shape with a uniform pitch diameter. However, a double-enveloping worm has a variable pitch diameter that is narrowest in the middle and greatest at the ends. This configuration allows the worm to engage more teeth on the wheel, increasing load capacity. In most worm gears, the wheel has teeth similar to those of a helical gear, but the tops of the teeth curve inward to envelop the worm. As a result, the worm slides rather than rolls as it drives the wheel. Because of this high level of rubbing between the worm and wheel teeth, the efficiency of worms gearing is lower than other major gear types.

APPENDIX B - MANUFACTURING PROCESS

Manufacturing Process

The manufacture of high precision gears can involve over 200 steps if all inspections and tests, finishing and plating operations are counted. It is also one of the most difficult. The process begins with a forged, cast or cut from bar stock gear blank roughly in the size and shape of the finished gear. The blank is normally made of steel alloy, or bronze depending on its application. Nickel, Chromium, Vanadium, and Molybdenum are important alloying agents. Various considerations in the selection of materials include its toughness, wear and fatigue resistance, responsiveness to heat treatment, machinability and corrosion resistance. Bronzes are frequently used with worm gears because of the metal's good self-lubrication qualities, and the problems associated with sliding contact in worm gears.

The gear blank is first machined, normally on a lathe or machining center, to establish perpendicularity between the bore and the face of the gear, and between the outside diameter and the bore. This operation establishes reference surfaces which are used to register the part during the remainder of the manufacturing process. Machining may also make oil channels, splines, and other features in the blank as needed. After this initial machining, teeth are generated by any of several methods depending on the type of gear being manufactured.

Teeth generators are known as shapers, hobbers, bevel generators, and broaching machines. Shapers have a cutting tool that reciprocates up and down to cut a tooth profile into the gear blank. The gear blank is indexed to rotate synchronously with the motion of the cutting tool. Shapers are used to cut spur gears and straight internal gears.

Hobbers have a cutting tool, called a hob, that rotates synchronously with the gear blank, and may be used to cut spur type or helical gear teeth. A cylindrical hob has numerous flat cutting teeth jutting up from its surface that profile and cut the teeth on the gear blank as they rotate. Bevel generators operate similarly to a hobbing machine, except the relative position of the cutting tool to the gear blank is set at an angle. The angle can be adjusted to the required position.

THE GEAR MANUFACTURING PROCESS

GEAR BLANK FORMING	Forging, Casting or Cut Bar
MACHINE BLANK	Lathe or Machining Center
FORM TEETH	Milling, Shaping, Hobbing, Broaching or Bevel Generating
HEAT TREAT	Carburizing or Nitriding
HARD FINISH	Grinding, Lapping, Shot Peening
INSPECT	Gear Inspection

Broaching machines use hydraulic pressure to push a tapered pole up to eight feet in length -the broach- through a cylindrical ring (the gear blank) to cut internal gears. The broach contains columns of serrated cutting edges along its length that gradually build up to the profile of the teeth it is cutting. A broach is very expensive, and requires high volumes for efficient use. It is commonly used in the auto industry, where a broaching machine may be dedicated to making a single gear. In one auto plant, a six inch internal gear (the "annulus" gear) was being pumped out every 32 seconds, or about 112 copies an hour. A broach may be designed to cut straight or helical teeth.

A machine called a shaver is often used to remove additional "shavings" from teeth already generated, to get teeth closer to final profile before heat treatment. The shaver has serrated teeth that rotate with the tooth blank.

After the teeth are generated, most workpieces are heat treated. Heat treatment is necessary to harden the gear which gives it longer life and better performance. It also relieves stresses built up in the gear during previous operations. Heat treatment may be used to through harden or surface harden the gears depending on the application. Through hardening hardens the gear throughout its interior to Rockwell 30-50 by heating the blank to about 1500-1600 degrees Fahrenheit, and then quenching. Hardness will vary with the molecular composition of the material. When through hardening the surface is at temperature longer than the interior of the workpiece, and will be somewhat harder than the interior. With surface hardening, only the surfaces of the gear teeth are hardened (to about Rockwell 60). Surface hardened gears can acheive significantly greater power densities, and thus be made smaller and lighter, and still transmit more torque than through-hardened gears. Most aerospace and increasingly, large marine gears are surface hardened, while automotive and most industrial gears are generally through hardened.

For surface hardening, two methods of heat treatment are commonly used in the gear industry, carburizing and nitriding. Carburizing is done in a carbon rich atmosphere at temperatures elevated to 1600-1800 degrees Fahrenheit, and can take anywhere from an hour to more than a day depending on surface area, desired depth of hardening, temperature, and furnace capability. Carbon is gradually fused into the surface of the teeth. When the desired depth is reached the gear is quenched (quick frozen) to stabilize and hold the molecular structure. Quenching invariably causes distortions that will later require grinding. Sometimes a "quench press," or mold of the gear, is inserted over the gear to minimize this distortion. This is the most difficult operation in gear making, and one of the most diffcult in metal working because of the numerous number of teeth, all of which must be within specified limits. In many respects heat treating remains a "black art."

Nitriding is done at lower temperatures, but takes longer than carburizing. Instead of carbon, nitrogen is fused into the tooth surfaces. Temperatures of

1,000 degrees Fahrenheit are commonly used. Special alloys containing such elements as Nickel or Aluminum are required to optimize the treatment. An advantage, which derives from the lower temperatures, is less distortion to the gear teeth in the quenching operation.

Post heat treatment operations take several forms. For many applications, lapping with abrasive compounds is used to remove minor distortions and burrs, and polish the teeth surfaces. A lapping tool with the same teeth and the same size as the gear may be run in place with the gear for several hours. This is common for through hardened gears.

Grinding is necessary when tolerances must be held below .001 inches. Grinding removes dimensional distortions caused by heat treatment and quenching processes. Grinding must be precise. If too much surface is removed, the effects of heat treatment can be negated. Generally, grinding involves using a wheel contoured, or "dressed" to the desired tooth form. Cubic boron nitride is rapidly gaining acceptance as an abrasive for higher volume applications[1].

Grinding to precise tolerances requires special environmental conditions. In some instances, rooms have floors physically detached from the rest of the factory to prevent vibrations from interfering with the grinding process. Measures must also be taken to control the temperature of the gear and surrounding area to prevent thermal distortion. And some action may be needed to reduce levels of suspended dust in the air. Production costs rise rapidly with greater precision. Dimensional measurements and inspections are conducted throughout the production process. The finished gear will be tested for vibration, noise, load, fatigue and wear resistance.

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[1]In 1958, an abrasive called "Cubic Boron Nitride (CBN)" was first synthesized. In 1969, the material was commercialized, and first saw wide use in Europe. It is almost as hard as diamond. To obtain the full benefits, it is necessary to have specialized grinding machines. Honda is using CBN ground gears. CBN grinding sets up a beneficial compressive stress in the gears, which Honda has taken into account during the design process, and Honda's gears are smaller than they would have to be using conventional processes.

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