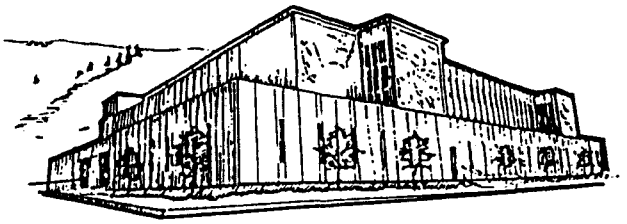
1994

Has computer technology brought economies of scope to service oriented businesses?| An analysis of architectural and engineering firms

Carol A. Wulfekuhle
The University of Montana

CAROL WULFEKUHLE



Maureen and Mike MANSFIELD LIBRARY

The University of Montana

Permission is granted by the author to reproduce this material in its entirety, provided that this material is used for scholarly purposes and is properly cited in published works and reports.

** *Please check "Yes" or "No" and provide signature***

Yes, I grant permission X
No, I do not grant permission ____

Author's Signature Carol A. Wulfekuhle

Date: 5/10/94

Any copying for commercial purposes or financial gain may be undertaken only with the author's explicit consent.

HAS COMPUTER TECHNOLOGY BROUGHT ECONOMIES OF SCOPE TO SERVICE ORIENTED BUSINESSES? AN ANALYSIS OF ARCHITECTURAL AND ENGINEERING FIRMS

By

Carol A. Wulfekuhle
B.S. University of Montana, 1976

Presented in partial fulfillment of the requirements
for the degree of
Masters in Business Administration
University of Montana
1994

Approved By:

Clyde W Ness
Chairman, Thesis Committee

Dean, Graduate School

May 3, 1994
Date

5-26-94

Wulfekuhle, Carol A., M.B.A., May, 1994 Business Administration

Has Computer Technology Brought Economies of Scope to Services Oriented Businesses? An Analysis of Architectural and Engineering Services.

Chairman: Clyde W. Neu

Economies of scope bring about efficiencies based on product variety and are derived from sharing costs across many products and using excess capacity. Economies of scope have been successfully exploited in the manufacturing process through the use of computer-aided manufacturing technologies. Integration via these technologies allows manufacturing plants to be more efficient, to improve quality of products, to lower the cost of individual products and to increase flexibility of both products and processes.

The existence of economies of scope in service oriented businesses is less clear. Studies of service oriented businesses suggest potential for economies of scope but do not conclusively demonstrate such economies actually exist. The role of computer technology in exploiting these economies is not addressed. This paper will evaluate the potential for -or existence of- economies of scope in architectural and engineering firms and assess the role computer technology may play in the exploitation of such economies.

In-depth interviews focusing on the role of computer technology in several Montana based architectural and engineering firms form the primary basis for the research. Secondary research and previous work completed by this student on the role of computer-aided manufacturing technologies in the displacement of economies of scale with economies of scope in manufacturing provide background information. Additional information acquired through a survey in the fall of 1992 of architectural and engineering firms in Montana regarding the impact of computer technology in their firms will be incorporated into this work.

This study demonstrates that the potential for economies of scope exists in architectural and engineering firms; however, the exploitation of these economies has just begun. Significant exploitation of scope economies will not occur until firms understand the true benefits of computer technology and adopt a management philosophy that allows those benefits to be realized.

TABLE OF CONTENTS

Economies of Scope 1

Applications of Scope Economies 3
The Role of Computer Technology 4

Scope Economies in Business 5

Manufacturing 5
Service Oriented Businesses 6
Evaluation Framework 7

Architectural and Engineering Services 9

Impact of Technology 9
Affects of Technology 21

Can Scope Economies be Exploited? 24

The Future of Computer Technology 26

Conclusions 27

References

Appendix A 28
Bibliography 35

LIST OF TABLES

Table 1 - Firm Size 10

Table 2 - New Services 11

Table 3 - Features Used 11

Table 4 - System Used as a Marketing Tool 12

Table 5 - Satisfaction of Project Owners 12

Table 6 - Staff Productivity 13

Table 7 - Acquisition of Larger Jobs 13

Table 8 - Project Owner Changes 13

HAS COMPUTER TECHNOLOGY BROUGHT ECONOMIES OF SCOPE TO SERVICE ORIENTED BUSINESSES? AN ANALYSIS OF ARCHITECTURAL AND ENGINEERING SERVICES.

ECONOMIES OF SCOPE

Traditional economies of scale are achieved through high volume production of a standardized product. The concept of economies of scale is based on the notion that a production facility's total manufacturing costs generally increase at a slower rate than its production volume (Groover 1984, 54). In contrast, economies of scope are achieved through variety in products and flexibility in processes. Scope economies are based on technologies that allow multiple product variations to be produced more cheaply in combination than separately (Jelinik 1983, 143).

Economies of scale are realized through the use of large manufacturing plants and special purpose machines that produce many units of a particular product. The product process focuses on long production runs and few changeovers. Through this high volume, smooth flowing process, the manufacturing plant is able to move down the long run average cost curve, increase throughput times and demand price breaks from suppliers. In order to achieve true economies of scale, companies must sacrifice flexibility (Noori 1990, 580). On the other hand, flexibility is a fundamental element of economies of scope. Economies of scope are realized through the use of smaller, decentralized facilities and general purpose machines that can produce a large variety of products (Noori, 581).

As traditional scale oriented companies have only a few products produced in large volumes, the focus of the company is on the manufacturing process rather than the products themselves. A process that can produce the largest possible volume for the lowest possible average cost per unit is pursued. In a scope oriented company, the focus in on the products, rather than the

process. The flexibility of the process allows the economic batch quantity to approach one, freeing the company from concerns over costly, time consuming changeovers and breakdowns.

Scale oriented companies use inventory stockpiling to lessen the impact of changeovers, breakdowns and seasonal demands for products. As products become obsolete and demand dwindles, the manufacturer is in a position of having to idle special purpose machines and possibly shut down large plants. In contrast, scope oriented companies are better able to fully use plant capacity and respond to changes in consumer demands. The general purpose machines can be reprogrammed to accommodate improvements and innovations in products. Scope oriented companies rely on the flexibility of the process to respond to changes in technology and product demand.

The scale oriented company offers a standardized product which is changed only with great difficulty and high cost. The trade-off to the consumer is few, if any, improvements in technology and quality in exchange for low cost and dependability. The scope oriented company, on the other hand, offers a higher level of quality and innovation instead of, or in addition to, low cost and dependability.

Economies of scale can be transitory and are often accompanied by associated diseconomies of scale. Increasing the scale to reduce certain costs causes other costs to increase. As a plant produces more of a product, the product must be distributed to a wider area, resulting in increased distribution costs. A larger plant requires a larger work force with resulting bureaucratization and confusion. Large, inflexible, single product plants are vulnerable to both natural disaster and obsolescence (Groover 1984, 64). Economies of scope tend to be "hard" economies. Variety within a product line allows the company to capture new customers within the same distribution area. Smaller plants operate with fewer layers of management and less "red

tape". General purpose machines and smaller, decentralized plants are less vulnerable to obsolescence or natural disasters.

APPLICATIONS OF ECONOMIES OF SCOPE

Economies of scope are characterized by a product focus; consequently, the effects of economies of scope are applied to decisions about products rather than processes. Scope economies are exploited by changes in product design and product mix that allow the company to tap new markets, new customers and new channels of distribution. Product variety and product mix are changed by using alternative materials, introducing innovation, and improving product quality.

The effects of scope economies are applied to decisions about how the company responds to market demands. Market life cycles for products are shorter today, and new designs must follow one another more frequently. The marketplace is demanding a greater variety of products without increasing the volume desired. The marketplace is time sensitive and products must be produced on closely controlled schedules. However, the marketplace also is cost-sensitive; therefore, the production process must be highly efficient in addition to providing reliability and high quality (Noori 1990, 579).

The effects of economies of scope reduce or eliminate decisions about trade-offs between changeovers and inventory. Changeover times and the associated costs are negligible as the set up costs are moved backward into the design process. The machine set up process involves little more than reading a computer program. The flexibility inherent in scope oriented production economies allows the company to meet demand for product with minimal or no inventory stockpiling (Jelinik 1983, 143).

THE ROLE OF COMPUTER TECHNOLOGY

The notion that the cost of joint production is less than the cost of producing each output separately, and that joint production of two goods by one enterprise is less costly than the combined costs of production of two specialty firms, has been a factor in business decisions to expand the scope of the enterprise. The presence of specialized know-how and indivisible physical assets and the absence of adequate market incentive to effectuate inter-firm transfer results in vertical integration and/or diversification (Teece 1980, 226). Integration and diversification contribute to the exploitation of scope economies for those firms that have the capital, physical assets and specialized know-how to effectively achieve it.

Advances in computer technology, from the introduction of numerically controlled machines in the 1950's and 1960's to computer integrated manufacturing available today, have made available new tools and processes that can fundamentally change the way companies conduct business.

Numerically controlled machines decreased set up times and increased the amount of time machines were actually cutting materials. A second repercussion of numerically controlled machines was that the manufacturing knowledge moved from the workers to paper tapes and the workers became machine custodians. In the 1970's, computer controlled machines were developed, resulting in faster response times, increased throughput and reduced costs. The ability to run a variety of parts on the same machine at a reasonable cost became a reality.

Computer-aided design allows the design of better products through what-if analysis that maximizes both design strength and economy. Integration of computer-aided design and manufacturing results in reduced material costs due to better design and less waste. Computer-aided manufacturing eliminates learning curve effects and requires higher quality, more consistent raw materials which result in higher quality products. Computer-integrated manufacturing allows

all manufacturing tasks and processes to be put on computer programs. This provides more imaginative manufacturing and integrates the actual, physical production of goods with the information and control systems (Thompson 1982, 47).

The common denominator of the generations of automation is flexibility. From the ability to retool quickly and cheaply, to the ability to test design alternatives, to the ability to manage vast amounts of information in order to match production to market demand, the manufacturing system gained in its ability to respond efficiently and quickly to a variety of changes in the manufacturing environment. The flexibility provided by computer technology is the same flexibility that allows firms to exploit scope economies. Continued decline in the cost of automated systems has allowed more and more firms to introduce computer technology into the production process, resulting in movement from the traditional scale based decisions to those driven by scope economics.

SCOPE ECONOMIES IN BUSINESS

MANUFACTURING

Manufacturing lends itself readily to the exploitation of scope economies via computer technology designed to specifically address weaknesses in the traditional manufacturing process. Computer technology allows for the integration of manufacturing with engineering and marketing functions at a level never before possible. As the level of integration rises, process predictability improves such that new demands for timely delivery, quality and low cost can be raised without the traditionally accepted trade-offs in flexibility and variety (Jelinik 1985, 97).

Through automation of its plant in Bristol, Virginia, Electrolux was able to reduce the cost of its basic model vacuum cleaner by 50% and eliminate backup systems and standby parts inventories while producing six models of vacuum cleaners on the same assembly line (Rohan 1988, 34). Vought Corporation's flexible machining center produces 600 designs, one at a time

in random sequence. It is expected to save $25 million in machining costs by performing in 70,000 hours work what would take 250,000 hours by conventional methods (Jelinik 1985, 98). Cross & Trecker Manufacturing Co.'s flexible manufacturing system consists of six machining centers that routinely make more than 200 parts. The computer controlled system will select the machine sequence required for each part on the basis of the position of the right tool and the shortest waiting line (Rohan 1988, 50).

In each of the three manufacturing companies described above, economies of scope are exploited. The companies are able to produce a variety of products while maintaining or reducing costs. Flexibility is increased in that the products are produced in any sequence and in any number. Added flexibility results in better usage of plant capacity as machines produce a broad spectrum of products serving a variety of markets rather than few products with sporadic or limited demand.

SERVICE ORIENTED BUSINESSES

In service oriented businesses, the "product" is much more difficult to define and describe than the manufactured product. Services are a combination of multiple factors, both tangible and intangible. The quality of the service is more difficult to measure in quantifiable terms than a product. Quality is a function of the expectations of the person receiving the service rather than a function of durability, precision or operation. The existence of or the potential for scope economies in a service oriented business is less observable and less documentable than in the manufacturing arena.

Attempts have been made to determine the potential for - or existence of - economies of scope in the banking industry (Cebenoyan 1990, 115-125 and Kolari 1991, 82-96). These research efforts are not conclusive in providing an answer as to the existence of scope economies. The role of computer technology in the possible exploitation of scope economies is not addressed.

Other research has been conducted on the existence of scope economies in the provision of local public services (Grosskopf 1990, 61-74). The statistical data presented in this research suggests economies of scope may exist in the provision of such services, however, the research attributes any scope economies achieved to diversification and the sharing of some fixed costs. Any role played by technology is not addressed.

Large companies with available capital and know-how may be able to increase the variety of offerings to address the demands of multiple markets via diversification and/or vertical integration. Smaller companies typically cannot exploit scope economies in this fashion. The role of computer technology in the exploitation of scope economies in the smaller companies must be explored. Does computer technology exist which can provide the flexibility and quality control needed to exploit scope economies? Is the technology affordable to the business in question?

Recognition must be given to the fact that traditional methods of justifying the acquisition of automated equipment constitute a major barrier to the adoption of the new technologies. Computer technology must be evaluated on the basis of the benefits to be derived from doing things not previously possible rather than on what costs would have been had the technology been available (Jelinik 1985, 103). An extremely important factor in the exploitation of scope economies is the willingness of management to change the traditional way of conducting business and consider the strategic implications of the flexibility, variety and quality made possible by the computer technology.

EVALUATION FRAMEWORK

By reviewing the economies of scope which exist in particular industries or businesses, and by analyzing the role computer technology plays in the exploitation of those scope economies, a framework can be developed to evaluate the potential for - or existence of - economies of scope

in other industries or businesses. The first step in the evaluation process is to precisely identify the product and to clearly separate the product from the services that surround that product (Albrecht 1985, 4). The separation of "product" from "service" is particularly important in service oriented businesses in that the tangible offering needs to be isolated from the "way the company does business."

The distinction between the tangible offering and the "way the company does business" is important. The way the company does business is a function of organizational values and objectives and is affected only indirectly by processes and technologies that allow scope economies to be exploited. Several questions can then be posed to determine whether the potential to exploit scope economies exists in that business or industry.

A. Variety of Offerings:

1. What are the current and potential variations of the existing tangible offering?

2. What other services might the firm be able to offer as a result of information made available by the computerized system?

3. Does the variety of offerings allow for the sharing of certain costs across those offerings?

4. What is the extent of the market for each of those variations?

5. What is the volume of each type or variation of service that must be provided in order for it to be economically feasible for the firm to offer that service?

B. Flexibility of Delivery System:

1. Does the existing delivery system have the flexibility necessary to economically produce each of the variations and/or new services?

2. Does the existing staff have the training and ability necessary to utilize the computerized system to its full potential?

3. Is the delivery system better utilized if the variations are provided?

C. Available Computer Technology:

1. Is the computer technology available to provide the flexibility needed in the delivery system?

2. Is computer technology available to improve the quality of the offerings?

D. Attitude Toward Change:

1. What is management's attitude toward change?

2. Is management willing to consider the need to redefine the way work is accomplished?

3. Is management willing to consider the need to redefine the nature of the business and the services provided by the firm?

4. What are the real reasons the firm has implemented computer technology?

5. How well does management understand the computer technology available in the firm?

Thoughtful answers to each of these questions can provide a basis for evaluating the potential for economies of scope in a particular business and determining the extent to which those economies may be exploited.

ARCHITECTURAL AND ENGINEERING SERVICES

In order to effectively analyze the role of computer technology in exploiting economies of scope in service oriented businesses, the scope of this paper will be limited to a specific service oriented industry - consulting architects and engineers in Montana.

IMPACT OF TECHNOLOGY

In the late 1950's, Dr. Patrick J. Hanratty wrote the first graphics algorithms that allowed points, lines and circles to be displayed on CRTs. That spelled the beginning of the end for manual drafting and of the move to computer-aided design (The Promise of 1987, 48). The past forty years have seen the development of technology to automate virtually every aspect of the design and engineering process from initial conceptual sketches to three dimensional modeling to finite element analysis to mechanical simulation.

Technological Changes

A survey conducted in the fall of 1992 by this author indicates that computer-aided technology has impacted architectural and engineering firms in Montana. A sample of one hundred fifty-six architectural and engineering firms were selected from the total population of two hundred seventy-seven firms in the major metropolitan areas of Billings, Great Falls, Butte, Helena, Bozeman, Missoula and Kalispell. Ninety-seven, or 62 percent of the questionnaires were returned. Of the 97 architectural and engineering firms responding to the survey, 69 (71%) had computer-aided systems in their firms. Sixty-seven (97%) of the computer-aided systems were personal computer based with an average system cost of about $35,000.00. The following summary of data gathered in the 1992 survey is concerned only with the 69 firms with computer-aided systems.

Twenty-six (38%) firms had five or fewer employees, sixteen firms (23%) had between six and ten employees, twenty-two (32%) had between 11 and 50 employees and the remaining five (7%) had 50 or more employees. Thirty-four (49%) firms had gross annual sales of less than $500,000.00, ten (15%) had sales of between $500,000.00 and $1,000,000.00, thirteen (19%) had sales between $1,000,000.00 and $2,000,000.00 and the remaining eleven firms (17%) had gross annual sales over $2,000,000.00 (see Table 1 - Firm Size).

TABLE 1 - Firm Size

# of Employees	# of Firms	% of Total	Gross Annual Sales		% of Total
1 - 5	26	38	<$5,000,000	35	49
6 - 10	16	23	$500,000 to $1,000,000	10	15
11 - 50	22	32	$1,000,000 to $2,000,000	13	19
50 & Over	5	7	$72,000,000	11	17
Total	69	100		69	100

Respondents were asked if the computer-aided system assisted them in offering to clients services that were not cost effective to provide prior to implementing the system. The responses are summarized in Table 2.

TABLE 2 - New Services

Responses	# of Responses	Percent of Total
No new services	18	26
Some new services	41	59
Several new services	7	10
Many new services	3	4
Total	69	100

In order to determine the extent to which computer-aided systems are used, respondents were asked to indicate how many features were actually used by the design and/or engineering staff. The responses are summarized in Table 3.

TABLE 3 - Features Used

Responses	# of Responses	Percent of Total
Less than 25%	1	1
25% to 50%	31	45
51% to 75%	26	38
76% to 100%	11	13
Total	69	100

Table 4 summarizes the extent to which responding firms used the computer-aided system as a marketing tool.

TABLE 4 - System Used As A Marketing Tool

Responses	# of Responses	Percent of Total
Never	11	16
Occasionally	29	42
Often	20	29
Always	9	13
Total	69	100

Forty-three (62%) of the respondents indicated moderate to significant change in the satisfaction of project owners, while nineteen (28%) indicated only minimal change and seven (10%) indicated no change, as summarized in Table 5.

TABLE 5 - Satisfaction Of Project Owners

Responses	# of Responses	Percent of Total
No Change	7	10
Minimal Change	19	28
Moderate Change	32	47
Significant Change	11	15
Total	69	100

A potentially significant indicator of the affects of computerization is the change in staff productivity. Table 6 summarizes the change or lack of change in productivity reported by respondents.

TABLE 6 - Staff Productivity

Responses	# of Responses	Percent of Total
No Change	4	6
Minimal Change	12	17
Moderate Change	23	34
Significant Change	30	43
Total	69	100

Fifty-four firms (78%) indicated the computer-aided system has had little or no affect on the firm's ability to acquire larger jobs, while fifteen (22%) firms indicated they were able to acquire moderately to significantly larger jobs as summarized in Table 7.

TABLE 7 - Acquisition of Larger Jobs

Responses	# of Responses	Percent of Total
No Change	33	48
Minimal Change	21	30
Moderate Change	8	12
Significant Change	7	10
Total	69	100

Changes in the willingness of the project owner to ask for changes to the project are summarized in Table 8.

TABLE 8 - Project Owner Changes

Responses	# of Responses	Percent of Total
No Change	27	38
Somewhat More Willing	25	37
Much More Willing	14	21
Significantly More Willing	3	4
Total	69	100

Benefits of the computer-aided system listed most often by respondents were the ability to make quick, easy changes to the design and the increased productivity of staff. Disadvantages listed most often were a steep learning curve and the cost of acquiring a system.

While profound change is not always indicated, the survey provides convincing evidence that the implementation of computer-aided systems in architectural and engineering firms in Montana has had an impact on the firms that use them. The survey suggests the firms with computer-aided systems have had to wrestle, as least minimally, with changes in their firms brought about by the computerization of a fundamental part of their business.

An evaluation of the potential for - or existence of - economies of scope in architectural and engineering firms necessitates a review of how computer technology has affected profitability, productivity, efficiency, dependability and quality of services in these firms. In order to understand and evaluate the affects computer technology has had on architectural and engineering firms in Montana, in-depth mail interviews were conducted with Montana based architectural and engineering firms. Fourteen firms from the five largest metropolitan areas of Montana: Billings, Great Falls, Helena, Bozeman and Missoula, were contacted by telephone. A principal in each firm was asked to complete an in-depth mail interview form (see Appendix A). Of the fourteen, ten (71%) completed and returned the questionnaire. The interviews posed a series of questions to the respondents in regard to these areas of concern by paralleling the affects of computer technology in the manufacturing arena.

Through the use of computer-aided systems, manufacturers are able to provide a variety of products for the same or less cost per unit than large volumes of a single product. Thus, the respondents were asked first whether the variety of services offered by their firms had changed since the firm began using a computer-aided system. Five respondents indicated no change in variety of services and that CAD is simply another media to present the same services. The other

five respondents, however, indicated the variety of services has increased at least minimally. New services mentioned were 3-D imagery, future space planning and maintenance of existing floor spaces for accuracy.

Respondents also were asked if the computer-aided system had assisted their firm in providing more services to their clients than prior to implementation of the system. Three respondents indicated they did not provide more services to their clients. Seven firms indicated the computer-aided system had assisted them in providing additional services, such as reduced plans, enlarged plans, updated record drawings and facility maintenance.

Finally, respondents were asked if they were able to provide services that were too costly to provide prior to the implementation of the computer-aided system. Seven firms indicated they were not able to offer such services, while three indicated that, to a limited degree, they were able to offer some services that were too costly to provide prior to the implementation of the system.

In manufacturing, computer-aided systems also have resulted in up-front design and testing work being used for many products and the associated costs spread over those many products. Thus, respondents were asked if the computer-aided system has assisted their firm in sharing design and/or engineering costs across more services. Five respondents indicated they were not able to share such costs across more services while five others indicated they were able to share costs in areas of file management and data retrieval and change, in cut and paste techniques, and through transferring data from one file to another or to consultants.

Respondents also were asked if the computer-aided system has affected the timing in which the firm recovers overhead costs. Five respondents indicated that such timing had not changed. Even though the computer had improved efficiency, any savings were offset by higher overhead costs brought about by the system. In addition, the improved accuracy of services provided with

the computer-aided system were not acknowledged by users of the services in terms of higher fees. One respondent indicated the timing of overhead recovery had decreased because of the increased cost associated with the system. Four respondents indicated the computer-aided system had assisted the firm in improving the timing of overhead cost recovery primarily because of the increased efficiency brought about by the system.

The ability to cost-effectively produce a large variety of products allows the manufacturer to better utilize excess capacity. When demand for one product diminishes, production of another product is begun or increased. Therefore, respondents were asked if their computer-aided systems had assisted the firm in smoothing out variations in work volume due to seasonal factors. Three respondents indicated that seasonal factors do not affect their business. Six others, however, indicated the computer-aided system had not assisted their firms in smoothing out seasonal variations in work volume. One respondent indicated that while variations in work volume had not changed, the firm had been able to operate with fewer personnel and eliminate hiring and firing to meet work demands as a result of the implementation of the computer-aided system.

Respondents also were asked if the computer-aided system had assisted the firm in managing project acquisitions and completion deadlines. Three respondents indicated the computer-aided system had not assisted the firm in such management or is not used for this purpose, while five others indicated the computer-aided system had assisted the firm in managing project acquisitions and completion deadlines. The use of standard details and base drawings for new projects helped to meet tight deadlines. One respondent indicated that while the computer-aided system had improved management of marketing materials, the availability of computer-aided systems resulted in increased expectations from users of the service. Another respondent indicated that while the firm expected to realize improvements in managing project acquisitions and completion deadlines,

the computer-aided system had only recently been implemented and specific measurable benefits had not yet been documented.

Additionally, respondents were asked if manpower requirements were more stable with the computer-aided system. Four respondents indicated their manpower requirements were not more stable and training and monitoring of the work effort had resulted in increased manpower requirements. One respondent indicated the affects of the computer-aided system on manpower requirements was unknown. Another respondent indicated that as the firm was in a definite growth curve, the affects of the computer-aided system on manpower requirements could not be assessed. Four other firms had experienced more stable manpower requirements as one man's capacity was greater and employees could work harder to meet high demand and shift to research and maintenance during slow times.

Finally, respondents were asked if the computer-aided system had assisted them to bid against larger firms and win. Seven respondents indicated the computer-aided system had not assisted the firms in bidding successfully against larger firms. However, without the computer-aided system, the firm would not be perceived as able to compete at all. The industry has matured to the point where computerized systems are considered "table stakes". Three others indicated they were able to bid against larger firms and win, primarily because of the firm's commitment to computer-aided design.

Computer-aided systems have assisted manufacturers in producing higher quality products. Designs can be tested and compared to design alternatives. The manufacturing process is more consistent and requires higher quality raw materials. Learning curve changes are eliminated as the machine is as smart on the first unit produced as it will ever be. Respondents were asked if the quality of service provided by their firms had changed since the implementation of the computer-aided system. One respondent indicated the quality of services had decreased because

drawings are held in the memory of the system and were not readily available while working on a particular detail. Three others noted no change in the quality of service. Six respondents indicated the quality of services had increased as the computer-aided system assisted in creating more accurate drawings and allowed changes to be made more quickly and efficiently.

Respondents also were asked if the level of design versus engineering conflicts had changed since the implementation of the computer-aided system. Five respondents indicated that such conflict had not changed. Five others indicated the level of conflict between design and engineering had changed as the computer-aided system enabled conflicts to be identified sooner and resolved quicker. The system had greatly enhanced coordination between all disciplines of a design team. However, the speed in which changes could be made with a computer-aided system could wreak havoc on the work of supporting consultants if last minute changes requested by the customer were accommodated.

The interview questionnaire asked respondents to describe any changes in the ratio of overhead costs to total costs, billing rate structure or cost overruns that resulted from the implementation of the computer-aided system. Five respondents indicated the ratio of overhead costs to total costs had increased. Without considering the initial investment, the costs of operating an automated office were two to four percent higher than a non-automated office. Learning curve effects of computer-aided systems have resulted in higher overhead costs. Two respondents indicated the ratio of overhead to total costs had not changed, while one indicated that overhead costs seemed to be coming down and two others indicated they did not know how the implementation of the computer-aided system had affected such costs.

Six respondents indicated there had been no change in billing rate structure, while four others indicated there had been changes in such structure. A new billing rate level was added strictly

for CAD services. Billing rates had increased because of the increased costs associated with the system.

Additionally, two respondents indicated there had been no change in cost overruns, while two others indicated there were fewer and smaller overruns. Three others indicated that lack of familiarity with the system, the high learning curve associated with computerized systems and lower productivity during the transition from the manual system resulted in higher cost overruns. Two others indicated improvement in cost overruns as costs for production of design and documentation have decreased and the firm is more efficient. Finally, one respondent indicated the firm's computer-aided system was new and it was still to early to determine what affect the system would have on cost overruns.

The questionnaire asked for a description of any changes in productivity levels resulting from the implementation of the computer-aided system. One respondent indicated no change in productivity, while another indicated lower levels of productivity initially due to the high learning curves associated with computer-aided systems. Another respondent indicated the firm did not yet know how productivity would be affected by the implementation of the system. Seven others indicated an increase in productivity ranging from a slight to a significant improvement. The end product was completed sooner and higher volume was achieved.

Successful implementation of computer-aided systems in manufacturing requires manufacturers to make changes in organizational structure, marketing methods and finance and accounting methods. Respondents were asked to describe any changes made to the firm's organizational structure. Six respondents indicated that no changes were made to the organizational structure of their firms, while four others indicated that changes were made to such structure. Changes included adding a CAD manager to the staff, replacing a draftsman position with a CAD

manager, requiring both designers and draftsmen to use the computer-aided system and defining office and production standards.

Respondents also were asked to describe any changes their firms made in marketing methods. Three respondents indicated no changes to marketing methods, while seven others indicated changes were made in such methods. The computer-aided system was used to great advantage as a marketing tool, allowing the firm to compete with larger firms and for larger jobs. The computer-aided system assisted the firms in developing better quality presentations and in incorporating the graphics available in desktop publishing into the presentation. The system assisted firms to interview for federal jobs which require computer-aided systems in order to qualify.

Finally, respondents were asked to describe any changes their firms made in accounting and finance methods. All ten respondents indicated no changes in such methods. Three respondents indicated the computer-aided system allowed them to more closely track costs and to provide quicker, easier billing.

Implementation of computer-aided systems has resulted in manufacturers redefining their business strategy. They have changed the way they view customers, markets and products. Respondents were asked if the implementation of a computer-aided system has changed how their firm defines "the business they are in". Eight respondents indicated they had not changed the definition of their business. Two others indicated that the definition of the business had changed as the computer system allowed the firm to enlarge services and be more competitive. While the computer system allowed firms to expand, architectural and engineering firms are, out of necessity, very people oriented and without a "one-on-one" relationship with clients, the firm could not survive.

The questionnaire asked respondents to list those factors believed to be most important to the success of the firm, whether related to the computer-aided system or not. All ten respondents listed customer service as important. Customer service took the form of a personal interest in the client, continuity of service, thoroughness of service and customer satisfaction. Eight respondents listed quality services in the form of knowledgeable, well executed, creative designs created by competent professionals as important to the success of the firm. Accuracy, completeness and appropriateness were included as important to the quality of designs. Six respondents listed productivity and efficiency including timeliness in meeting deadlines and the ability to improve productive capacity in order to control overhead costs as important.

The computer-aided system was listed as an important factor in the success of the firm by three of the respondents. The computer-aided system assisted the firm in providing accuracy and clarity in designs and to successfully compete for projects with quick and accurate bids. Other factors listed as important included integrity, well trained personnel, dependability, fair cost, pro-active marketing, minimal problems in the construction process, availability of work, problem resolution, economy and proper management.

AFFECTS OF TECHNOLOGY

Of primary interest in this research is the affect computer technology has on the profitability and efficiency of the architectural and engineering firms studied. Additionally, the affect of technology on the dependability and quality of services is of concern.

It was found that among the firms surveyed, overhead costs had generally increased, primarily because of the costs of acquiring and maintaining a computer-aided system. While those firms with computer-aided systems view the system as an important part of the business, fierce competition and the client's unwillingness to acknowledge improvements in services have precluded architectural and engineering firms from increasing fees in order to recover higher

overhead costs. The high learning curve associated with the implementation and ongoing use of a computer-aided system affects the firm's ability to recover the costs of the system. Many features available with the computer-aided system are never used as the time needed to effectively learn to use these features is not available to the firm. Consequently, the firm has invested in equipment it may never use to its full capacity.

The interviews provided little indication of improvement in profitability as a result of the implementation of the computer-aided system. Computer-aided systems have typically been justified based on a desire to experience the technology, because clients expect firms to be computerized, or because of intuitive reasoning that computers should bring about improvements in the business. Studies have failed to find any firms in engineering or architecture that have conducted a comprehensive post purchase economic evaluation of their computer-aided system. Most firms simply do not know how the computer-aided system has affected profitability (Stevens 1991, 141).

The affect of computer-aided systems on manpower requirements, the ability to better manage project acquisitions and deadlines and the smoothing of seasonal variations in work load appears to be moderate. Manpower requirements have increased in some firms in response to increased training and supervision needs required by the computer-aided system. Other firms have been able to avoid hiring during upswings in workload due to greater individual capacities.

As documented in this research, computer-aided systems have assisted architectural and engineering firms to be more efficient in their ability to handle changes to a project design. The computer-aided system allows instantaneous and simultaneous changes to all drawings associated with the project. Projects owners tend to be more satisfied with the project as a result. The survey conducted in the fall of 1992 indicated that sixty-two percent (62%) of the respondents

felt their clients were moderately to significantly more satisfied with projects completed since the implementation of the computer-aided system.

The quality of the architectural and engineering services also has been affected to some degree by the implementation of computer-aided systems. A higher level of accuracy is achieved in less time and inter-disciplinary conflict is reduced through sharing of data files and immediate project updates. However, quality of service has as much to do with the underlying business philosophy of the firm as with the level of technology used in the firm. As one respondent pointed out, "Computers allow thorough users to be more thorough and allow lazy users to still be lazy but look better on the surface." (Cartier, 1992)

The computer-aided system's greatest potential benefit to architectural and engineering firms may be as a marketing tool. Advanced generation technologies, such as computer-aided design with 3-D perspectives, create impressive presentations (Lee 1991, 45). The value of the computer-aided system as a marketing tool is not widely recognized. Only thirteen percent (13%) of the architectural and engineering firms in Montana responding to the 1992 survey consistently used the computer-aided system to compete for projects, while sixteen percent (16%) of the firms never used the computer-aided system as a marketing tool. Often, bids lost by a firm were not due to any technical incompetence, high cost quoted for the proposed project, or the quality of the proposal. Bids were lost because the competition used state-of-the-art technologies. The competing firm that appears to be sophisticated and reliable finds the bid often is awarded on the basis of the impression left by the presentation on the project owners.

The implementation of technology in architectural and engineering firms has had a positive affect on the quality and dependability of services but the affects are not consistent nor widespread. In some cases, improvements in efficiencies have been achieved. Profitability has been affected only minimally or not at all.

CAN ECONOMIES OF SCOPE BE EXPLOITED?

Economies of scope are derived from sharing costs across many products or services and using excess capacity. Economies of scope bring about efficiencies based on variety in products or services. Can architectural and engineering firms in Montana exploit economies of scope? Can architectural and engineering firms provide a broader variety of services to their clients while achieving efficiencies derived from better utilization of professionals within the firm?

While evidence exists that the potential for exploitation of scope economies exists in architectural and engineering firms, it appears the actual existence of scope economies within these firms has only just begun. Only sixty-nine percent (69%) of the firms surveyed in late 1992 had implemented computer-aided systems. Many of these firms have had the technology for several years and had yet to realize the full potential of the system. Of those with systems, only sixteen percent (16%) fully utilized all the available features. Historically, it has taken companies a generation or more to truly master major new waves of technology (Carey 1993, 57). The learning curve for a computer-aided system is very high. Educational institutions are several years behind in providing training to graduates in the use of the more advanced computer-aided systems. The work often is performed on outdated computers (too few in number) and is taught by "computer experts rather than design instructors" (Neeley 1991, 59).

Many firms have purchased computer-aided systems not because they understood and expected to realize the true benefits of computer technology but because they felt they had to in order to remain competitive or because their clients expected them to do so. Also, firms have purchased computer-aided systems expecting to realize immediate and significant increases in productivity. In some cases productivity increased, but generally the improvements were less than hoped for. True, users are able to modify drawings more quickly and easily, but the real benefits of a computer-aided system lie in the storage of large amounts of information about a project in a

manner that makes it available to all who are involved in the project. Benefits lie in the ability to use that stored data again and again to assist the client with ongoing project related needs. Benefits lie in the ability to reuse the stored data from one project for many future projects with similar design specifications. Benefits also lie in the firm's ability to present its talents and services visually to the client that does not understand blue prints. Finally, benefits lie in the ability of the computerized firm to differentiate its services from competitors by using capabilities and features other firms do not have.

In architectural and engineering firms, the potential to exploit economies of scope exists in the presence of computer technologies. Computer technologies provide the fundamental tools necessary to use architectural and engineering data in new and creative ways. Without computer technologies available to architectural and engineering firms, economies of scope cannot be exploited. However, computer technology alone cannot provide architectural and engineering firms with the ingredients necessary to realize benefits of scope economies. In the broadly defined service sector, from banks to health care clinics, capital spending on computers and office equipment has boomed over the last decade and productivity has languished (Carey 1993, 58). Exploitation of scope economies requires the firm to do more than just improve the economy of present activities. Firms must consider the expanded options the technology makes available and the costs of not adopting it.

A major barrier to the effective use of computer technology is lack of understanding of its impact on strategy. Harvesting the potential of scope economies may mean changing the "business we are in". It will certainly mean a new responsiveness to customers and a willingness to compete in new markets. New technologies imply a major shift in power such that traditional divisions of work no longer make sense. Marketing strategies must change to focus on a wider variety of services and on services not previously provided. Accounting and finance methods that

recognize shared resources, that reflect more accurately the risks and opportunities of technological investments, and that avoid a built-in bias toward short-term business as usual are needed (Lee 1991, 47-48).

Those firms that understand computer technology as merely a tool to enhance the good qualities already possessed by the firm rather than a panacea for all that ails the firm are those that will reap the benefits of scope economies. Computer technology sets the stage for the exploitation of scope economies, but sound business strategies and competent and creative management are the attributes that bring about results.

THE FUTURE OF COMPUTER TECHNOLOGY

In the 1980's, United States businesses invested $1 trillion in information technology, $800 billion in the service sector alone (Carey 1993, 58). Fast and efficient gathering and sharing of data is not only desirable but necessary for businesses to remain competitive in the world economy. Although some firms have begun to remove automation from their firms, implementation and upgrading of computer systems will continue at a significant rate.

The expected increases in productivity as a result of the significant investments in technology in the 1980's, with notable exceptions, failed to materialize. The exceptions, where expected increases were realized or surpassed, were those firms where advanced technology was melded with sweeping changes in management and organizational structure (Carey, 58). Some firms have concluded that too much technology actually impedes productivity and the long-term solution to productivity is to redesign or "reengineer" the work to provide more flexibility, more information and more responsibility to the worker. Technology plays a key role in providing the worker with the information needed to act quickly and to support new ideas in the business process. The key to mastering the technological revolution is a combination of technological and managerial innovation (Carey, 57).

As technological advances produce new computerized tools and systems, which architectural and engineering firms are compelled to purchase for whatever reason, the necessity to understand the true benefits of computerization becomes even more important. Emerging technologies, such as three dimensional imaging, visualization and virtual reality, require substantial investments in both time and money. Firms must understand and reap the true benefits of the computerized system in order to recover the investment in a timely fashion and provide the momentum necessary to sustain a successfully business.

CONCLUSIONS

Scope economies, fueled by computer technology, have played a significant role in the rejuvenation of the manufacturing industry in the United States over the last decade. The exploitation of scope economies in the architectural and engineering service sector has just begun, in part, because computerization in this sector is relatively new, and in part, due to the high learning curve associated with the computerized systems available to these firms.

The potential for exploitation of scope economies in architectural and engineering firms is significant. A few progressive firms have begun to exploit scope economies with the assistance of the computer-aided systems. A Montana firm interviewed by this author maintains its gross output per employee at seventy-five percent (75%) higher than the national average. The firm offers expanded services to both domestic and foreign customers. A total quality management philosophy coupled with a strong customer focus, supported by ongoing efforts to maximize the potential of computer technology, is the foundation of the firm's success (Ruppert, 1992).

This Montana firm and others like it demonstrate the potential for exploitation of scope economies exists in firms that possess the right combination of computer technology and creative management abilities.

APPENDIX A
IN DEPTH INTERVIEW FORM AND COVER LETTER
CONDUCTED IN SUMMER/FALL 1993

July 8, 1993

1~
2~
3~
4~

Dear 5~:

Research has demonstrated that computer technology, via computer-aided design, engineering and manufacturing, has played a significant role in the efficiency of manufacturing plants and the quality of products produced by these plants. As part of my graduate studies through the University of Montana, I am studying the impact of computer technology on businesses that produce services rather than products.

Thank you for agreeing to complete the enclosed questionnaire. The information gathered through this questionnaire will be used to study the role of computer technology in architectural and engineering firms and to analyze the changes that may have occurred as a result of computerization within the firm.

A stamped, return envelope is enclosed for your convenience. All information provided by your individual firm will be held in strict confidence.

Again, thank you for taking the time to respond to this questionnaire. If you are interested in the results of this study, a copy of my completed project will be on file in the library at the University of Montana. Also, you may request a copy by writing to the address on this letterhead.

Sincerely,

Carol Wulfekuhle, Graduate Student
Billings MBA Program
University of Montana
Billings, Montana

QUESTIONNAIRE ON ECONOMIES OF SCOPE

1. Through the use of computer-aided systems, manufacturers are able to provide a variety of products for the same or less cost per unit than large volumes of a single product.

   * Has the variety of services offered by your firm increased or decreased since your firm began using a computer-aided system?

   * Has the computer-aided system assisted your firm in providing more services to your clients than you provided before?

   * Is your firm able to offer services that were too costly to provide prior to the implementation of the computer-aided system?

2. In manufacturing, computer-aided systems have resulted in up front design and testing work being used for many products and the associated costs spread over those many products.

   * Has the computer-aided system assisted your firm in sharing design and/or engineering costs across more services?

   * Has the computer-aided system affected the timing in which your firm recovers overhead costs?

3. The ability to cost-effectively produce a large variety of products allows the manufacturer to better utilize excess capacity. When demand for one product diminishes, production of another product is begun or increased.

   * Has the computer-aided system assisted your firm in smoothing out variations in work volume due to seasonal factors?

   * Has the computer-aided system assisted your firm in managing project acquisitions and completion deadlines?

* Are manpower requirements more stable with the computer-aided system?

* Is your firm able to bid against larger firms and win?

4. Computer-aided systems have assisted manufacturers in producing higher quality products. Designs can be tested and compared to design alternatives. The manufacturing process is more consistent and requires higher quality raw materials. Learning curve changes are eliminated as the machine is as smart on the first unit produced as it will ever be.

   * Has the quality of the services provided by your firm changed since the implementation of the computer-aided system?

   * Has the level of design vs. engineering conflicts changed since the implementation of the computer-aided system?

5. Please describe any changes in the following areas that resulted from the implementation of the computer-aided system.

   * Ratio of overhead to total costs.

   * Billing rate structure.

   * Costs overrun.

   * Productivity levels.

6. Successful implementation of computer-aided systems in manufacturing required manufacturers to make changes in organizational structure, marketing methods and finance and accounting methods. Please describe any changes your firm has made in the following areas as a result of the implementation of a computer-aided system.

* Organizational Structure.

* Marketing Methods.

* Accounting and Finance Methods.

7. Implementation of computer-aided systems has resulted in manufacturers redefining their business strategy. They have changed the way they view customers, markets and products.

   * Has the implementation of a computer-aided system changed how your firm defines "the business you are in"?

8. Please list those factors you believe are the most important to the success of your firm whether related to the computer-aided system or not. List the most important first.

Thank you very much for taking time to answer these questions.

BIBLIOGRAPHY

Acs, Zoltan J. and Audretsch, David B. 1990. Innovation and the Small Firm. MIT Press.

Albrecht, Karl and Zemke, Ron. 1985. Service America!. Warner Books, Inc.

Alberts, William W. 1989. The Experience Curve Doctrine Reconsidered. Journal of Marketing. (July): 36-47.

Alderman, N. and Fischer, M. M. 1992. Innovation and Technological Change: An Austrian-British Comparison. Environment and Planning 24. (February): 273-288.

Allman, William F. 1992. The Ultimate Widget. U. S. News & World Report. July 20: 55-56.

Baker, Jerry, principal with CTA Architects and Engineers. 1992. Interview by author. November.

Beatty, Carol A. and Gordon, John R. M. 1988. Barriers to the Implementation of CAD/CAM Systems. Sloan Management Review (Summer): 25-32.

Bell, C. Gordon. 1989. The Fewer Engineers Per Project, the Better. IEEE Spectrum. (February): 22.

Bennett, Robert E. and Hendricks, James A. 1987. Justifying the Acquisition of Automated Equipment. Management Accounting. (July): 39-46.

Carey, John. 1993. The Technology Payoff. Business Week, June 14: 57-79.

Cartier, Scott, Vice President for Hi-Tech Construction. 1992. Telephone interview by author. November.

Cebenoyan, A. Sinan. 1990. Scope Economics in Banking: The Hybrid Box-Cox Function. The Financial Review. (February): 115-125.

Clark, Douglas W. 1990. Bugs are Good: A Problem-Oriented Approach to the Management of Design Engineering. Research Technology Management 33. (May-June): 23-27.

Cohen, Alex. 1990. Survey: The Road to Independence. Progressive Architecture 71. (July): 100-101.

Coleman, Mathew J. 1985. Future Engineers Will Rely on More Computer-Aided Support. Pulp & Paper. (September): 127-129.

Dixon, John R. and Duffey, Michael R. 1990. The Neglect of Engineering Design. California Management Review. (Winter): 9-23.

Eaton, B. Curtis and Lemche, S. Q. 1991. The Geometry of Supply, Demand and Competitive Market Structure with Economies of Scope. The American Economic Review. 126. (September): 901-911.

Ebel, Karl H. and Ulrich, Erhard. 1987. Some Workplace Effects of CAD and CAM. International Labour Review 126. (May/June): 351-369.

Eshelman, Paul and Tatchell, Kesia. 1992. How Beneficial a Tool is Computer-Aided Design? Forum. (Winter): 15-19.

Finkin, Eugene F. 1990. Use Technology to Reduce Manufacturing Costs. The Journal of Business Strategy. (May/June): 51-54.

Fisher, Dan, owner of Fisher Construction. 1992. Telephone interview by author. November.

Frater, James J. 1991. New Profits From Your Current Product Lines. Appliance Manufacturer. (September): 29-30.

Freiman, Ziva. 1990. Reader Poll: Architect-Client Relations. Progressive Architecture 73. (February): 63-65.

Friscia, Anthony J. 1989. Strategies for Using Computers. Automation. (March): 80.

Gagnob, Roger J. and Mantel, Jr. Samuel J. 1987. Strategies and Performance Improvement for Computer-Assisted Design. IEEE Transactions on Engineering Management EM-34. (November): 223-235.

Gold, Bela. 1985. Analyzing the Effects of Computer-Aided Manufacturing Systems on Productivity and Competitiveness. Managerial Issues in Productivity Analysis. 133-159.

Gold, Bella. 1982. CAM Sets New Rules for Production. Harvard Business Review. (November-December): 88-94.

Gold, Bela. 1989. Computerization in Domestic and International Manufacturing. California Management Review 31. (Winter): 129-143.

Gorman, Ian E. 1985. Conditions for Economics of Scope in the Presence of Fixed Costs. Rand Journal of Economics 16. (Autumn): 431-436.

Groover, Mikell P. and Zimmers, Jr., Emory W. 1984. CAD/CAM Computer-Aided Design and Manufacturing. Prentice-Hall, Inc.

Grosskopf, Shawna and Yaisawarng, Suthathip. 1990. Economies of Scope in the Provision of Local Public Services. National Tax Journal (March): 61-74.

Hardy, Greg, owner of Hardy Construction. 1992. Telephone interview by author. November.

Hax, Arnoldo C. 1989. Building the Firm of the Future. Sloan Management Review. (Spring): 75-81.

Helgott, Roy B. 1988. Computerized Manufacturing and Human Resources. Lexington Books.

Hudson, C.A. 1985. Factory Automation. The Information Technology Revolution. First MIT Press.

Jelinik, Mariann and Goldhar, Joel D. 1985. Computer Integrated Flexible Manufacturing: Organizational, Economic and Strategic Implications. INTERFACES. (May/June): 94-105.

Jelinik, Mariann and Goldhar, Joel D. 1983. Plan for Economies of Scope. Harvard Business Review. (November-December): 141-148.

Jelinik, Mariann and Goldhar, Joel D. 1984. The Strategic Implications of the Factory of the Future. Sloan Management Review. (Summer): 29-36.

Johnson, Endosomwan. 1989. Integrating Innovation and Technology Management. Wiley.

Koch, Timothy W. and Williams, Mark L. 1990. Lending to Architectural and Engineering Firms. The Journal of Commercial Bank Lending. (November): 34-44.

Kolari, James and Zardkoohi, Asghar. 1991. Further Evidence of Economies of Scale and Scope in Commercial Banking. Quarterly Journal of Business and Economics. (Autumn): 82-96.

Krouse, John; Mills, Robert Beckert, Beverly and Potter, Caren. 1989. CAD/CAM Planning Guide '89. How to Successfully Implement Computer-Aided Design and Manufacturing. Industry Week. July 17: CAD/CAM1-CAD/CAM63.

Krouse, John; Mills, Robert; Beckert, Beverly and Dvorak, Paul. 1990. CAD/CAM Planning: 1990. Gaining the Competitive Edge. Industry Week. July 2: CC1-CC61.

Krouse, John; Mills, Robert; Beckert, Beverly; Carrabine, Laura and Berardinis, Lawrence. 1991. CAD/CAM Planning: 1991. Breaking Down the Barriers to Integration. Industry Week. July 15: CC1-CC39.

Larson, Kent. 1991. Computer Modeling as a Design Tool. Progressive Architecture. (October): 117-119.

Lee, John Y. 1991. Investing In New Technology to Stay Competitive. Management Accounting. (June): 45-48.

Mintz, Jack M. 1981. A Note on Multiproduct Economies of Scale and Economies of Scope. Economic Letters. North-Holland Publishing Company.

Mullins, Peter J. 1988. Power to the Design Engineer. Automotive Industries. (February): 95-96.

Monk, Julia. 1992. Design Firms Offer Owners One-Stop Shopping. Hotel and Motel Management 27. November 2: 102+.

Neeley, Dennis. 1991. Computers: CAD Practice and Education. Progressive Architecture. (September): 59.

Nichols, David George, Sales Representative for Intergraph Software. 1992. Telephone interview by author. November.

Noori, Hamid. 1990. Economies of Integration. International Journal of Technology Management 5: 577-587.

Nussbaum, Bruce. 1993. Hot Products Smart Design is the Common Thread. Business Week. June 7: 54-76.

Panzer, John C. and Willig, Robert D. 1981. Sustainability Analysis Economies of Scope. AEA Papers and Proceedings. (May): 268-272.

Peters, Tom. 1992. Rethinking Scale. California Management Review. (Fall): 6-29

Peters, Tom. 1989. New Products, New Markets, New Competition, New Thinking. The Eonomist. March 4: 19-22.

Port, Otis; King, Resa and Hampton, William J. 1988. The Productivity Paradox. Business Week. (June 6): 100-108.

Robb, Walter L. 1992. Don't Change the Engineers - Change the Process. Research Technology Management 35. (March-April): 8-9.

Rohan, Thomas. 1988. Factories of the Future. Industry Week. March 21: 33-66.

Rothwell, Roy and Gardiner, Paul. 1988. Re-Innovation and Robust Designs: Producer and User Benefits. Journal of Marketing Management 3: 372-387.

Ruppert, Keith, principal with CTA Architects. 1992. Interview by author. November.

Ryan, Hugh W. 1990. Productivity Through Automation. The Journal of Information Systems Management. (Fall): 57-60.

Schriener, Judy. 1991. Expert's Sage Advise: Spend More, Customize. ENR. September 16: 13-14.

Sequeira, Jean. 1987. Computer-Aided Design: A Powerful Tool at the Disposal of the Designer. Impact of Science on Society 146: 133-138.

Shostack, G. Lynn. 1989. Six Lessons for Managing Technology. The Journal of Business Strategy. (July/August): 52-55.

Small is Beautiful Now in Manufacturing. 1984. Business Week. (October 22): 152-156.

Sparks, Phil, director of engineering for St. Vincents Hospital. 1992. Telephone interview by author. November.

Stevens, Garry and Kish, Emil. 1991. How Computers are Used in Practice and How to Select a CAD System. Progressive Architecture 72. (May): 141-143.

Teece, David J. 1980. Economics of Scope and the Scope of the Enterprise. Journal of Economic Behavior and Organization. 223-247.

Teresko, John. 1988. CAD, CAE or Chaos? The Costs of Not Managing CAD Data. Industry Week. September 19: 73-74.

Teresko, John. 1990. A Report Card on CAD/CAM. Industry Week. March 19: 44-50.

Teresko, John. 1990. EDM: The Next Step Toward CIM. Industry Week. February 5: 55-57.

Teresko, John. 1985. Planning For the Factory of the Future. Industry Week. June 10: 42-45.

The Promise of CAD/CAM/CAE. 1987. Industry Week. March 23: 48-53.

Thompson, Harry and Paris, Michael. 1982. The Changing Face of Manufacturing Technology. Journal of Business Strategy. (Summer): 45-52.

Vandell, Kerry D. and Lane, Jonathan. 1989. Does Good Design Pay? Architecture 158. (July/August): 17-21.

Walter, Bob, director of facility services for School District 2. 1992. Telephone interview by author. November.