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**THE UNIVERSITY OF MINNESOTA
AS AN
ENGINE OF ECONOMIC GROWTH**

April 1, 1992



**HUBERT H. HUMPHREY
INSTITUTE OF PUBLIC AFFAIRS**

UNIVERSITY OF MINNESOTA

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by a University-wide task force

convened by the

**Hubert H. Humphrey Institute of Public Affairs
University of Minnesota**

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PREFACE

The University of Minnesota is one of the major public institutions in this state. Not only is it an important focus of investment by state government and the citizens and organizations of this state, it also attracts substantial investments from outside the state's boundaries.

All of these investments in the University contribute to the development of the state's economy and to improving the standard of living of our citizens in a variety of ways, some of which are subtle and indirect. For that reason I asked my colleague, G. Edward Schuh, dean of the Humphrey Institute of Public Affairs, to chair a University-wide task force to address this issue. The task force's assignment was not to generate a polemic in favor of the University, nor to show that investments in the University had a higher payoff for society than other investments. Instead, I asked them to take on the more modest, but no less important task of explaining how the University contributes to the welfare of our citizens.

This report is the product of their labors. Those of us in the central administration of the University have found it to be insightful in informing us about the many ways investments in this vital institution contribute to the betterment of society and to helping the economy of the state remain competitive relative to the national and international economy. We commend it to our readers for the insights it provides on how vital the University is to our continued economic growth and development.

This is just the first chapter of what we expect to be a more ambitious study of the role of the University in the Minnesota economy. Dean Schuh and his colleagues have already started on a project designed to provide more empirical evidence on the rates of return to investments in the University and, more generally, in higher education. That more ambitious endeavor will also provide empirical evidence on such things as the opportunity costs of going to school, the extent to which higher education should be subsidized, and the rates of return on investments in research and the development and transfer of new technology.

We look forward to the results of that more ambitious study. In the meantime, I want to thank the members of the Task Force for this important fruit of their hard work. I hope our fellow citizens benefit as much from reading this interim report as have those of us in the University.

Nils Hasselmo
President
University of Minnesota

FOREWORD

Modern research universities contribute to the economic growth of our economy in many ways—by providing skilled workers and by developing new technology, to name only two. Many of their contributions are more subtle or indirect, however, and are not always fully captured by the voluminous statistics we in the university community can generate on our activities. Thus, I was pleased when President Hasselmo asked me to chair a university-wide task force to prepare an analysis of the contributions the University of Minnesota makes to the development of the state's economy. This gave us an opportunity to discuss and elaborate on these subtle contributions.

I took the responsibility for writing our report and thus bear the responsibility for its shortcomings. However, the members of the task force deserve credit for their contributions and are listed as co-authors. Together we agreed on the issues to be discussed, the outline, and much of the content. They reacted to what I set to paper and did their best to keep me on track and avoid errors of judgment.

We want to express our thanks to John Brandl of the Humphrey Institute for his helpful comments on earlier drafts of the report, and to Wendy Amundson for her excellent editorial assistance.

G. Edward Schuh, Dean
Hubert H. Humphrey Institute of Public Affairs
University of Minnesota
April 1, 1992

THE UNIVERSITY OF MINNESOTA AS AN ENGINE OF ECONOMIC GROWTH

Purpose of this Report

Funds allocated to the University of Minnesota are an investment in the future of Minnesota, its citizens and its economy. To put it symbolically, the University of Minnesota is an engine of economic growth. To cut the budget of this vital source of economic growth in a time of economic stress is to reduce its potential to contribute to the future development of the state's economy. Yet that is precisely what is happening.

The purpose of this report is to provide a description and analysis of how the University contributes to the vitality of the state's economy and to the vigor and creativity of its citizens and labor force. The report also provides evidence and documentation of some specific contributions the University has made, and continues to make, to Minnesota's economic health.

The report is organized into six sections. The first provides an overview of the University of Minnesota's economic contributions and the potential effect of budget cuts on these contributions. The second section includes data on the University's revenues and the State's expenditures on higher education. The third section discusses Minnesota's economy in the context of the national and international economy and outlines the challenges Minnesota faces in this more competitive economic environment. The fourth provides an analytical discussion of the ways in which the University contributes to the economic strength and vitality of the state's economy. A fifth section reviews some economic and educational issues that Minnesota faces in the years ahead. Finally, the appendix includes a variety of short examples of University contributions to the state's economy, as well as six longer case studies that more fully demonstrate the variety of ways the University strengthens the economy of the state.

Overview of the University's Economic Contributions and Current Budget Situation

The University of Minnesota is the state's Land Grant University. In this role the University has a mandate to provide undergraduate, graduate, and professional instruction to the people of the state, generate new knowledge through research, and extend that knowledge to both the private and public sector.

During times of budget stress, such as the State of Minnesota is now experiencing, every area of the budget must be reviewed for potential cuts. However, it is important to recognize that the services the University provides are not items of consumption whose existence or absence merely affect the present. Rather, expenditures on the University are investments, and **cuts to its budget sacrifice the competitiveness of the Minnesota economy, the future incomes of its citizens, and the state's ability to attract high quality, mobile resources from outside the state's boundaries.**

Land Grant universities are widely emulated in other countries because of their record of contributing to economic growth and development. The University of Minnesota is a strong example of the benefits that can accrue to communities served by Land Grant universities. Over time, it has grown into a major research university, the only one in the state; it is the source of much of the new knowledge and technology that helps keep Minnesota's private sector competitive, both nationally and internationally. It is also an integral link to research and academic activities in other parts of the world, and thus serves as an important mechanism by which knowledge generated in other parts of the world is made available to the citizens of Minnesota.

The University is a source of economic growth in another important sense. Its annual current funds budget is now approximately \$1.5 billion, which makes it a key economic player in its own right. **In a very real sense, the University itself is an investment center for the state. It is a source of both income and employment for its citizens.**

Failure to support Minnesota's major Land Grant University and the instructional, research, and service activities it provides may quickly lead to serious and significant job losses in the state. The immediate consequence of the current budget cuts at the University will be a loss of over 700 University jobs in the year ahead.

Perhaps even more important, the University is the source of *potential* income and employment for the state. Only about 31 percent of the University's budget comes from state tax revenue and approximately 10 percent from tuition revenue. The remaining 59 percent (approximately \$900 million) comes from other sources, including approximately \$250 million from the federal government and other sources outside the state.

This ability to attract out-of-state money is highly dependent on maintaining the quality of the University's faculty, its research and educational facilities, and the scope and quality of its programs. **Reductions in the University's resource base will make it less attractive to outside funding sources, which will further reduce the potential impact the University has on the state's economy.**

The impact does not stop with these direct effects, however. If the University loses its top faculty because it fails to provide salary increases, the quality of its educational programs

will deteriorate. This will cause the competitive potential of the state's private sector to decline over the longer term, and cause high-tech industries to locate in other parts of the country.

The associated decline in research activities at the University will also have direct effects on the performance of the state's economy. The state will no longer attract research-intensive companies to the state to take advantage of the University's capabilities. The significance of the University as a source of new productivity-enhancing technology will also decline.

Thus, budget cuts at the University of Minnesota will have *multiple* effects on the growth of the Minnesota economy. Within a fairly short period of time, the jobs and economic activities the state may lose because of its failure to support the University of Minnesota will most assuredly outweigh the estimated 2,000 gain in jobs expected from a recent subsidy to the private sector.

The University of Minnesota already has been hit hard by efforts to balance the State's budget. During the 1991 legislative session, the Legislature cut some \$27 million from the University's budget for the 91-93 biennium and also failed to appropriate money for inflationary increases. If a reasonable increase for inflation (2.5 percent per year to cover inflation over the biennium) is taken into account, the total reduction in the University's budget from these measures was approximately \$62 million. The total amount of tax money appropriated for the University in the post-cut biennium is presently \$447 million per year. Thus, in a relative sense, the cuts have been significant--roughly 7 percent of the budget.

Before these cuts, the University, sensitive to its fiscal responsibilities, had already begun reallocating resources internally to narrow its focus and increase program quality. In the second year of what is a five-year program, it has already retrenched and reallocated some 40 percent of a proposed \$60 million total. In addition, the University is undertaking another retrenchment of its programs and a further reallocation of its resources to provide salary increase money for the second year of the biennium.

It has identified three professional schools (the Law School, the Carlson School of Management, and the Humphrey Institute of Public Affairs) from which it will earn the money needed for salary increases by expanding enrollment and increasing tuition. It has also increased tuition for all its students by 9 percent in the first year of the biennium, and proposes to do the same in the second year. This spreading of the burden to its student body hits especially hard at middle-income students and is counter to the Land Grant philosophy of making quality education available to as many of its citizens as possible.

When the legislature reconvened for the second session of the biennium, tax revenues continued to be below expectations and it seems almost certain that the University's budget will be cut again. The University is now doing contingency planning for further retrenchment, should it be needed.

The citizens of Minnesota and their policy makers face some important dilemmas about their economic future. A national recession has caused Minnesota's tax revenue to decline, while at the same time, demand for tax revenue continues to grow to meet Minnesota's commitment to a high level of service, health care, and aid to local governments. Tough decisions need to be made. However, as information in this report makes clear, any short-term benefits that might accrue from further budget cuts at the University of Minnesota will potentially have serious long-term impact on Minnesota, its economy and its citizens.

Background on the University of Minnesota's Revenues and the State's Expenditures on Higher Education

The University of Minnesota is, itself, a large economic enterprise. Data in Table 1 show a total revenue of nearly \$1.5 billion in fiscal year 1990-91. This makes the University one of the larger economic enterprises in the state, and one which induces further economic development. In terms of employment, it is the largest single employer in the state, with slightly over 35,000 employees, including student workers.

Data in the same table show that revenue from the educational and general operations of the University amounted to about \$1.1 billion. The operations of its hospitals alone amounted to \$270 million.

The University brings in substantial funds from outside the state. Table 2 shows the sources of the University's educational and general revenue, the largest revenue item from Table 1 (total revenue). These data show that state tax dollars account for only 42 percent of the educational and general revenue of the University, with tuition accounting for less than 13 percent. Federal tax dollars account for 20 percent of such revenue, while other educational and general revenue dollars account for another 25 percent.

If one considers the *total* revenue of the University (\$1.5 billion), state tax dollars account for only 31 percent of the total and tuition only 10 percent. The hospitals account for 18 percent of the total, federal tax dollars another 15 percent, and other educational and general, 18 percent.

Over time, the University has become increasingly dependent on nonstate tax dollars (see Table 3). In 1950, state tax dollars accounted for more than 51 percent of the University's educational and general revenue and 39 percent of its total revenue. By 1960, these proportions had declined to 43 and 34 percent, respectively. Since then, these percentages have stayed at approximately the same levels.

It may be tempting to use this data to conclude that continued support of the University with state tax dollars is unnecessary. That conclusion would be erroneous on two counts. First, the University has been able to attract funds from other sources only because it has a strong state-supported base. Second, the state's share has declined largely because the University has been aggressive and entrepreneurial in seeking funding from other sources, and has used these funds to grow and improve the University. **To serve an economy that is increasingly based on science and technology, the state needs its principal research university to grow in order to sustain its own economic growth.**

State contributions to higher education do not fully reflect this importance. Minnesotans like to describe their state as the "education state," with the clear implication that they give more emphasis to education than other states. Just how does the state rank on some fairly standard criteria compared with other states?

By at least three criteria, Minnesota ranks high. For example, in terms of high school graduations per thousand population, Minnesota ranked fourth in the nation as of 1990, and stood 20 percent above the national average. In terms of state appropriations per capita for higher education, Minnesota ranked sixth in the nation, and was 27 percent above the national average in that year. Minnesota also ranks high in terms of the number of campuses devoted to public postsecondary education in the state. It has 63 such campuses, which suggests it has tried

Table 1. Total Revenue by Operations Area, University of Minnesota, 1990-91

	\$ Millions	Percent
Educational and General	\$ 1,099.8	74.4
Hospitals	270.4	18.3
Auxiliary Enterprises ^a	<u>108.1</u>	<u>7.3</u>
Total	\$ 1,478.3	100.0

Source: Management Planning and Information Services

^aIncludes residence and dining facilities, bookstores, student extracurricular activities, intercollegiate athletics.

Table 2. Educational and General Revenue by Source, University of Minnesota, 1990-91.

	\$ Millions	Percent
State Tax Dollars	\$ 458.9	41.7
Tuition	149.3	13.6
Federal Tax Dollars	218.5	19.9
Other Educational and General ^b	<u>273.1</u>	<u>24.9</u>
Total	\$ 1,099.8	100.0^a

Source: Management Planning and Information Services

^aDoes not add because of rounding.

^bIncludes private gifts, grants, and contracts; endowment income; investment income; sales and services of educational activities.

Table 3. Tax Dollars as a Percentage of Educational & General Revenue and Total Revenue, University of Minnesota, 1950-1991

	Educational and General Revenue	Total Revenue
1950	51.1 %	39.2 %
1960	42.8 %	34.0 %
1970	42.4 %	33.1 %
1980	46.7 %	35.3 %
1985	42.3 %	31.0 %
1990	43.5 %	32.1 %
1991	41.7 %	31.0 %

Source: Management Planning and Information Services

to make postsecondary education widely available to its citizens. Missouri, a state with a larger population than Minnesota, has only 27 such campuses, and Wisconsin, with a slightly larger population, has only 43. Only California and New York, both much more populated than Minnesota, have more campuses.

By other criteria, however, Minnesota does not rank so well. For example, in education appropriations per student, Minnesota ranked 20th among all states, and was just below the national average for all states. In tax revenue per student, Minnesota ranked 25th in 1989, and was 13 percent below the national average.

Minnesota is known as a high-tax state. In 1990, it ranked 8th in terms of tax effort (share of per capita income collected in the form of state taxes) and 9th in terms of taxes collected per capita. This was 12 percent above the national average in terms of tax effort and 17 percent above the national effort in terms of taxes collected per capita.

However, in terms of the priority the state gives to higher education in its state budget, Minnesota ranks quite low. The preferred measure of the importance a state attaches to higher education funding is the ratio of educational appropriations per student to tax revenues per capita. Minnesota ranks very low using this measure. In 1990, it ranked 42nd in the nation by this criterion, and was 11 percent below the national average.

Equally surprising, Minnesota also ranks low in terms of family effort toward higher education. Net tuition revenues per student divided by disposable personal income per capita is a common way to measure this. By that standard, Minnesota ranked 30th in 1990, and was 2 percent below the national average.

Retaining Minnesota's Competitiveness in a National and International Economy

Dramatic changes in our national and international economies have had a significant effect on the economy of Minnesota. Perhaps the most important of these is the extent to which a truly global economy has evolved over the past 25 to 30 years. The United States, as well as most other countries in the world, has become increasingly dependent on international trade as a source of jobs and income, capital, raw materials, and producer and consumer goods. In turn, Minnesota has also been compelled to compete on an international scale to remain economically healthy.

The emergence of a well-integrated international capital market has helped link national economies and increased the extent to which there is a truly global economy. This capital market, as well as the shift to an exchange rate system in which the value of the dollar is determined by market forces, imposes real limits on the macroeconomic policies this country can pursue. It transfers the burden of adjusting to changes in monetary and fiscal policies from the general economy to specific economic sectors: those that export and those that compete with imports. Given the extent to which the Minnesota economy is dependent on exports and suffers competition from international sources, these developments make our economy more vulnerable to changes in monetary and fiscal policies, both here and abroad, than it was in the past.

The Minnesota economy has a large international component. Minnesota's top five exporting industries are industrial machinery, scientific instruments, electrical equipment, transportation equipment, and processed food products. Nearly 70 percent of the value of these manufactured exports comes from high-technology goods, and 40 percent from exports of computers and other industrial machinery alone. Minnesota's exports also reflect its important agricultural economy, which is measured not only by the number of farmers and the volume of output, but by the many companies in the state's manufacturing and processing sectors that are agriculture-based. These sectors produce modern agricultural equipment and materials that transform the output of Minnesota's farms and rural workers into processed products for shipment to other parts of the United States and abroad. At the very least, these important economic sectors that compete at an international level need to be sustained. Ultimately, for Minnesota's economic health, they must be helped to grow.

Minnesota's economy is especially vulnerable to competitive pressures from abroad. Minnesota is at the tail end of the distribution system that connects the U.S. economy to the international economy. Its distance from international markets means it has to overcome a larger share of transportation costs to remain competitive. Thus, Minnesota must give more attention than many other states to productivity-enhancing investments in its economy.

A significant part of the state's drop in tax revenue is due to declines in important economic activities. According to *Minnesota Job Statistics*, employment in the state's computer industry alone is down by more than 25 percent since 1986. The economic impact of this decline is estimated to be a loss of more than a billion dollars to the state's economy each year.

Reports of continuing losses, lower profits, and employment problems at companies such as Control Data, Honeywell and Unisys have been common occurrences. Cray Research, the world's most successful supercomputer company, has been experiencing decreased sales and earnings. ETA has been closed down.

The problems of the big companies have rippled downward, affecting numerous component and service suppliers throughout the Twin Cities metro area and outstate Minnesota. When the current recession is over, Minnesota's economy is unlikely to recover rapidly unless steps are taken immediately to improve its competitive base.

Contrary to common perceptions, the high technology sector of Minnesota's manufacturing base has not been well diversified. Minnesota manufacturing is highly concentrated in the production of mainframe computers and related components. Nearly a third of the state's high tech employment is in computers, which is only one of 35 industrial segments commonly identified as "high technology." The most recently available data show that more than 50 percent of Minnesota's high technology manufacturing exports to other states and foreign markets come from the computer industry.

Similarly, there is a general failure to understand the ripple effects of high technology on other industries such as agriculture. Agriculture is this nation's original high tech industry. Total factor productivity in this sector has consistently out-performed the manufacturing sector throughout the post-World War II period. (Total factor productivity measures productivity of all resources, not just labor.)

Minnesota has retained its share of total agricultural output in large part because of its investment in agricultural research, which has helped its farmers remain competitive. For the most part, biological technology for agriculture has to be developed under local ecological conditions. With few exceptions, it cannot be transferred in from outside. By consistently lowering the cost of production through productivity-enhancing new technology, the University Minnesota has made it possible for many agricultural-related industries to remain in the state, thus producing jobs and income.

The challenges the state faces is how to retain the competitive edge it now has in some economic sectors, recover in those areas that appear to be slipping away, and broaden the economic base on which it will compete in the future. That means the state must continue to invest in a highly skilled labor force and attract high tech industries from other states and nations. Through investments in both research and technology, it must remain committed to achieving the productivity increases necessary to gain a competitive edge, nationally and internationally.

Minnesota has a strong economic base on which to build. The Twin Cities and its surrounding area has become a growth center for the Upper Midwest. It has the potential to become a base for even further growth. There are many advantages that come from being such a basis of economic growth, not the least of which is an expanding tax base. Failure by the State to sustain its investments in its major research university could cause the loss or decline of this economic base. Once an economic exodus starts, a downward economic spiral will surely follow. Efforts to recover will be costly and take time, especially since many of the highly trained and qualified members of the labor force will seek employment elsewhere. **Hence, it is important that the state not let its commitment to science and technology falter at the very time competitive pressures are growing.**

Another consequence of economic globalization is that **more and more economic policy making and implementation shift down to the state and local level.** That downward shift is already taking place at a rapid pace in this and other countries, and has important implications for Minnesota and other states.

Public sector activities that were once supported at the federal level increasingly will become state and local responsibilities. This will not only include social programs, such as care for the disadvantaged, but economic activities, such as investments in the quality of its labor force and natural resource base, and in the capacity to generate new knowledge and technology. These are all activities in which the University currently plays an important role and, with additional resources, could contribute even further.

As a result, the state will need to develop the capacity to analyze its own economic policies and to devise new policies for the future. At present, the state has a very limited capacity to undertake such analyses. The University has the potential to contribute in this area also, if certain departments and colleges that address policy issues are strengthened.

Perhaps most importantly in the short term, there is a substantial lag in the rate at which fiscal resources are being transferred down to the state and local level. In short, the public services our citizens demand are being transferred to the state and local level at a much faster pace than the tax revenue to support them. That explains in part why so many states are experiencing severe budget problems during the current recession, even though it has been far from the most severe economic decline in recent history.

Until ways are found to transfer a larger share of tax revenue collected at the national level to the state and local level, states like Minnesota face hard choices. One choice is to raise additional tax revenue from local sources. That, of course, could have long term impact on the state's ability to attract business and investments from outside sources. Another choice is to pare back services to citizens until the state receives more resources from the federal level. Other solutions include privatizing public functions or charging fees for certain public services. None of these choices is easy.

In making these decisions, policy makers and citizens need to be aware of the long term consequences if the state fails to sustain its investments in the quality of its labor force, and in its capacity to produce new knowledge and new technology. The specific contributions the University of Minnesota makes to these ends will be discussed in the next section of this report. In general, however, it needs to be stressed that a failure to invest in the quality of the labor force and in the state's science, technology, and broader knowledge base will have a negative impact on Minnesota's economy. These investments in our future income and employment base should not be cut as if they were consumption items subject to belt-tightening in a time of budget stress.

How the University of Minnesota Contributes to the Growth of the State's Economy

The University of Minnesota plays a crucial role in the growth of the state's economy. It creates new knowledge which serves as the basis for new process and product technology. It seeks to develop solutions to pressing problems that face the state. It helps produce and sustain a highly skilled labor force and a pool of professional talent which serves its citizens in multiple ways. It provides the means of attracting talented and skilled people to the state. It helps sustain a vital arts and humanities sector. It provides the means by which new knowledge and technology from other states and nations are brought to and adapted to the conditions of the state. And through its synergistic relationships with the private and public sectors of the state, it helps keep those sectors vital and strong.

Scientific and technological advancements are among the University of Minnesota's most significant contributions to the growth of the state's economy. At Minnesota's present stage of economic development, an ever-larger share of increases in future economic output must be based on investments in science and technology. Contrary to conventional wisdom, increases in economic output are no longer related primarily to increases in conventional physical capital or the size of the labor force. Instead, it is accounted for in large part by increases in productivity. These increases in productivity are the result of improvements in technology, in organizational and institutional performance, and in the knowledge of the labor force. Through technological and social science research and through its educational programs, the University of Minnesota makes significant contributions to productivity improvement in all three of these areas.

The role of technology in improving economic output is perhaps most easily demonstrated in the area of agriculture, a sector of the economy more closely associated in people's minds with natural resources and hand labor than technology. However, historical records show an enormous exodus of labor from this sector, with the result that agricultural employment today is only a small proportion of what it was 40 or 50 years ago. During the same time period, there was a great deal of land withdrawn from agricultural use, but an increase in use of capital in the form of improved crop varieties, fertilizers, pesticides, and machinery.

In accounting for increases in agricultural output over time, it turns out that very little can be attributed to increases in conventional inputs, such as labor or land. Instead, the increases in agricultural output are the result of more knowledgeable management and labor, the development of better and more efficient ways of doing things, and improvements in seeds, fertilizers, pesticides, machinery and equipment.

The agriculture industry is also a good demonstration of the many subtle ways University-developed technology can improve the income and employment opportunities of Minnesota citizens. The University of Minnesota's Agricultural Experiment Station produces, among other things, improved seed varieties that increase the productivity of both land and labor by raising yields. By raising productivity, these improved varieties lower the cost of production for these crops. For early adopters of these improved varieties, this reduction in costs translates into increased income. However, as the improved variety becomes more widely used, the output of the commodity increases and eventually causes the price of the commodity to decline.

Farmers will not usually be happy with this decline in price because it means some of them will not be able to survive as farmers and will have to shift to alternative employment. **Consumers, however, benefit widely from the new technology. A decline in the price of food is equivalent to an increase in their real income.** Because everybody eats food, the benefits of the new production technology are widely distributed in the economy. Moreover, given that poor families spend a larger share of their budget on food than do middle and upper income families, poor people tend to benefit relatively more from such new technology.

The distribution of economic benefits in this way is far-reaching. Not only do large numbers of the state's population benefit, but there can be a significant induced effect of additional development. As per capita incomes rise in this broad-based way, demand is created for additional goods and services. **Thus, there can be second and third rounds of employment and increased incomes induced by the introduction of this new technology.**

Because these effects are so diffuse, however, it makes them very difficult to identify. Nonetheless, the effects are real. **That is why all attempts to estimate the social rate of return to such investments end up showing very high rates of return--50 to 100 percent.** These are very high rates of return, and usually much higher than can be obtained from investing in other sources of income.

The extent of these subtle effects goes even further. For example, farmers may not like the decline in price associated with their increase in productivity. **However, in the longer term, that is the very means by which they can compete with producers in other states and other countries, which are making similar investments in new production technology.** Locally produced new technology is the key to Minnesota farmers being able to retain their competitive edge. Although in the short-term, advanced technology may cause a few farmers to leave agriculture, in the long-term, it sustains employment for many more. In addition, the decline in agricultural commodities prices also improves the competitiveness of Minnesota's food processing and distribution firms, an important sector of the state's economy.

Consumers are the primary beneficiaries of new production technology in many industrial sectors beyond agriculture. For example, consider the substantial decline in the real price of computers over the last 10 to 20 years. Computer purchasers, both individual consumers and businesses, have benefitted directly from these lower prices. Even more consumers have benefitted indirectly from businesses who were able to lower their costs by using computers. When the cost of production declines, the cost savings are generally passed on to the consumer in the form of lower prices.

To cite another example, in 1930 the price of a three-minute long distance phone call from Los Angeles to the Twin Cities was \$231.00 (in 1990 dollars). In 1990, it was \$2.45, for what was undoubtedly a quicker, higher quality connection. Such declines in real prices, as widely diffused and subtle as they may be, constitute increases in incomes for both the consumer and the producing sectors that use these products. **They also help keep our economy more competitive, thus preserving jobs.**

Quality improvements are another benefit of new technology. Improvements in the quality of computers and health care equipment are just two examples. Many times these improvements amount to effective declines in the real price of the services from these goods, since more service is delivered for the same price.

Other times, new technology results in the creation of a completely new product. The variety of new products introduced into our economy as a consequence of new technology is enormous. The addition of these new goods and services to the consumer's consumption bundle amounts to another increase in their real income, even if it does nothing more than to displace a previously consumed good or service. For example, in a very short time, VCRs have pervaded our society because they allow consumers to experience entertainment similar to movies at a lower cost. **However, the most important contribution of new product technology may be the additional employment it generates and thus, the role it plays in sustaining a fully employed economy.**

New technology takes still other forms. For example, the research program of the University's Medical School is constantly searching for new forms of prevention and treatment of disease and illness. Some of this new knowledge is used directly in treatment. Much of it is incorporated into new medical equipment, resulting in dual benefits similar to that described above. First, there are direct benefits to the consumers from improved quality and service. In addition, new sources of employment are created when new equipment and measuring devices are developed, patented and licensed by the University.

The knowledge base represented by the University has other economic applications beyond that of producing new technology, important as that is. **It provides the means of attacking the pressing problems of a modern society, problems that have both social and economic costs.** The list is long, but it is worth singling out some examples. Research programs at the University address the acute problems of cancer, AIDS, and other health problems. Its hospital is not only an important treatment center, but the source of new knowledge to treat diseases. Through an all-University committee the University addresses the problems of aging, and assures that professionals are trained to deal with the problems of the elderly. A commission established in 1990, involving more than 30 academic units from across the University, is addressing social and other problems of our children and youth. The School of Social Work designs new ways of dealing with social problems and also trains social workers to use the latest knowledge in addressing these problems.

Environmental problems have recently moved high on the public's agenda and several University academic units are addressing these issues. These include air and water pollution, global warming, acid rain, and the disappearance of the ozone layer. Other academic units develop knowledge on how economic policy affects the economy and how the performance of the state's and nation's economy can be improved. Several units seek to understand the major political and economic developments taking place in the global society and relate them to our own economy and political system. Still other units seek to understand the changes in our own political system and to devise ways by which we can have a more representative and effective democracy.

Organizational and institutional improvements are as important as new technology as a source of economic growth. Organizational improvements make it possible to bring together larger numbers of people and resources from disparate locations to realize economies of size. Some times this involves firms or units of public government. Other improvements focus on bringing together and more effectively integrating various sectors of the economy.

Institutions are the social means by which members of society relate to each other. They include such things as our schools and universities, the non-profit sector, labor unions, and public policy—minimum wage laws, for example. If these institutional arrangements can be made more efficient and effective, Minnesota will make better use of its resources and thus

promote economic growth. The social sciences and our multidisciplinary academic units such as the Carlson School of Management and the Humphrey Institute of Public Affairs address these issues.

The University of Minnesota's educational programs also make essential contributions to the state's economy. In order to have viable high tech industries that produce and use the new technology the University helps to create, a highly skilled labor force is needed. If such people are trained locally (and there is a significant pool of such people), industries, entrepreneurial talent, and capital from other states and countries will be attracted to the state of Minnesota. This contribution applies at all levels, from the production worker to the scientist or researcher who does R & D in the private sector.

In today's world, high tech industries are on the cutting edge of employment creation. However, the University's contribution to the state's economy by providing skilled labor is pervasive. A major share of the dentists, doctors, lawyers, morticians, nurses, public sector employees, and other professionals are educated at the University. A significant share of the entrepreneurs and top echelon staff of local businesses are educated at its school of management. Moreover, the University's various professional schools, through the Continuing Education and Extension program, offer courses and programs on a regular basis that enable professionals and other citizens to update their skills and remain current with the latest knowledge.

If the University of Minnesota remains among the top ranking research and education universities, it will help keep sons and daughters of this state employed here at home. Equally important, the University will be able to attract a large number of out-of-state students to its programs. These students become candidates for local employment. By having the capability to provide such high-level training, the University becomes a means of attracting human capital from other parts of the nation, and sometimes, other countries.

The University of Minnesota's arts and humanities programs also contribute to the state's economic health and quality of life. The Twin Cities' renowned arts community, possible in part because of the University's vital arts and humanities program, has important spillover effects to the state's economy. The wide variety of quality cultural activities helps make Minnesota an attractive place to live, and thus enables local industry and business to attract and retain scientists and professionals for employment in the local economy.

The University, besides being a cultural center in its own right, also supports the statewide arts community by giving Minnesotans the opportunity to develop their artistic skills. Its respected arts programs also attract talented people from other states and nations and thus add to the local stock of talented people.

The University of Minnesota also contributes to the economy through the capture of new knowledge and technology developed elsewhere. In today's world, an ever larger share of global research and development expenditures is being spent in other countries. The United States is no longer the dominant force in science and technology that it once was. If Minnesota is to remain competitive, it has to have the means of capturing the new technology and knowledge being produced in other countries. The University, as a major research institution, is an important mechanism for doing that.

Finally, scientists and professionals in the University have over the years developed synergistic relationships with the state's private and public sectors. The University's faculty advise and consult with companies in the private sector as well as with the various elements of

state and local government. The private sector taps the resources of the University and provides financial support for its research activities. This helps attract high quality faculty and thus, enriches the teaching programs of the University as well.

The research programs local companies finance at the University are often highly complementary with those they conduct in-house. This is an efficient way of seeking and developing new knowledge, finding solutions to pressing problems, and creating new technology. **These complementary economic activities with the private sector would not be possible if the University were not vital and strong.** If the University is allowed to decline, firms in the private sector will take such activities elsewhere, to the disadvantage of our students. Some of the firms may simply relocate to other states where a stronger knowledge base is more readily available.

In conclusion, the University of Minnesota contributes to the development of Minnesota's economy in multiple and pervasive ways. Through the scientific and technological advancements that result from its research activities, through the highly skilled labor force it has helped develop, and through many more subtle contributions, the University plays a crucial economic role in the state.

Economic and Educational Issues in the Decade Ahead

This section reviews some of the economic and educational issues that will remain important to the University and state policy makers during the years ahead.

1. *The Importance of Promoting Economic Growth*

The demand for public services financed by state government, whether due to demographic changes in the state or direct political pressures, are growing faster than the state's ability to finance them. These services include elementary and secondary education, higher education, physical infrastructure, and medical care, which combined account for the major share of the state's budget.

Dividing a shrinking budget poses extremely difficult choices for policy makers. Given their apparent difficulty in making such choices, society has but two realistic solutions. First, it can allocate its resources in ways that will promote the higher rate of economic growth needed to generate the additional revenue. Second, it can insist that public services effective and efficient—in short, that the public receives what it pays for. For the University's part, this will require more awareness of the efficiency with which it provides services, and more serious attempts to measure its outputs. One of its challenges for the future will be to provide more measurable results for the dollars it receives.

2. *On Being More Efficient*

The economic environment in which the University of Minnesota operates is far more competitive than that in which elementary and secondary school systems operate. Those competitive forces keep the pressure on for the University to strengthen its programs, deliver them more effectively, and keep them focused on the relevant problems in society. In the past five years, these efforts have taken the form of a successive process of program retrenchments and resource reallocations, a process which began before the recent state budget crisis and has been based on careful planning. Nevertheless, the University needs to continue to strengthen its programs, reorganize itself to deliver its services more efficiently, and continue honing its priorities.

3. *The Increasing Cost of Higher Education and Research*

The costs of higher education have been growing over time, and tuition has been increasing at a faster pace than general education in the economy. There are two primary reasons for these increases in cost. The first is the growing regulation of educational and research enterprises in this country and the increasing demands for accountability. This requires universities to employ a correspondingly larger bureaucracy just to monitor activities, fulfill regulatory requirements, and fill out appropriate forms. There is little an individual university can do about these requirements.

Second, the cost of education necessarily rises as average salaries in the economy increase. Teaching comes close to being a pure economic service; it is difficult to increase its productivity while maintaining the same quality of the service. It is true that capital

equipment, such as video technology, can be used along with the services of the teacher to reach a larger audience and some times increase teaching effectiveness. However, so far it has not been possible to raise productivity in this sense without sacrificing quality. When these measures have been attempted at the University, students complain about what they perceive as a decline in quality. Some seek education elsewhere (at higher cost), in institutions where class sizes are smaller and the association with the professor is more direct. The University of Minnesota has been reducing the size of some of its classes as a means of improving the quality of instruction, but this obviously raises the cost of instruction as well.

In the area of research, there is the related issue of increased costs of instruction and laboratory equipment as the frontier of knowledge advances. Thus, while the cost of a computer that delivers given services has declined over time, the demand for a computer with greater capacity increases as the state of knowledge increases. This is a pervasive phenomenon in research enterprises. Failure to meet these increasing demands for ever-more effective (and expensive) equipment means that the University's research enterprise will lose its ability to compete. Equally as important, the University will not be able to train its students in the use of society's modern research and analytical equipment.

4. *Is the State's Educational System Over-Extended?*

It was noted earlier in this report that the State of Minnesota has one of the most extensive systems of higher education in the nation. With budget pressures not likely to decrease in the foreseeable future, it may be a policy imperative to examine the efficiency of the state's higher education system, and discuss whether a judicious reorganization and paring down of the system might provide the resources needed to sustain quality efforts. As noted above, the University of Minnesota has taken steps in that direction. The problems in the entire system are more extensive, however.

5. *The Link Between Education and Income*

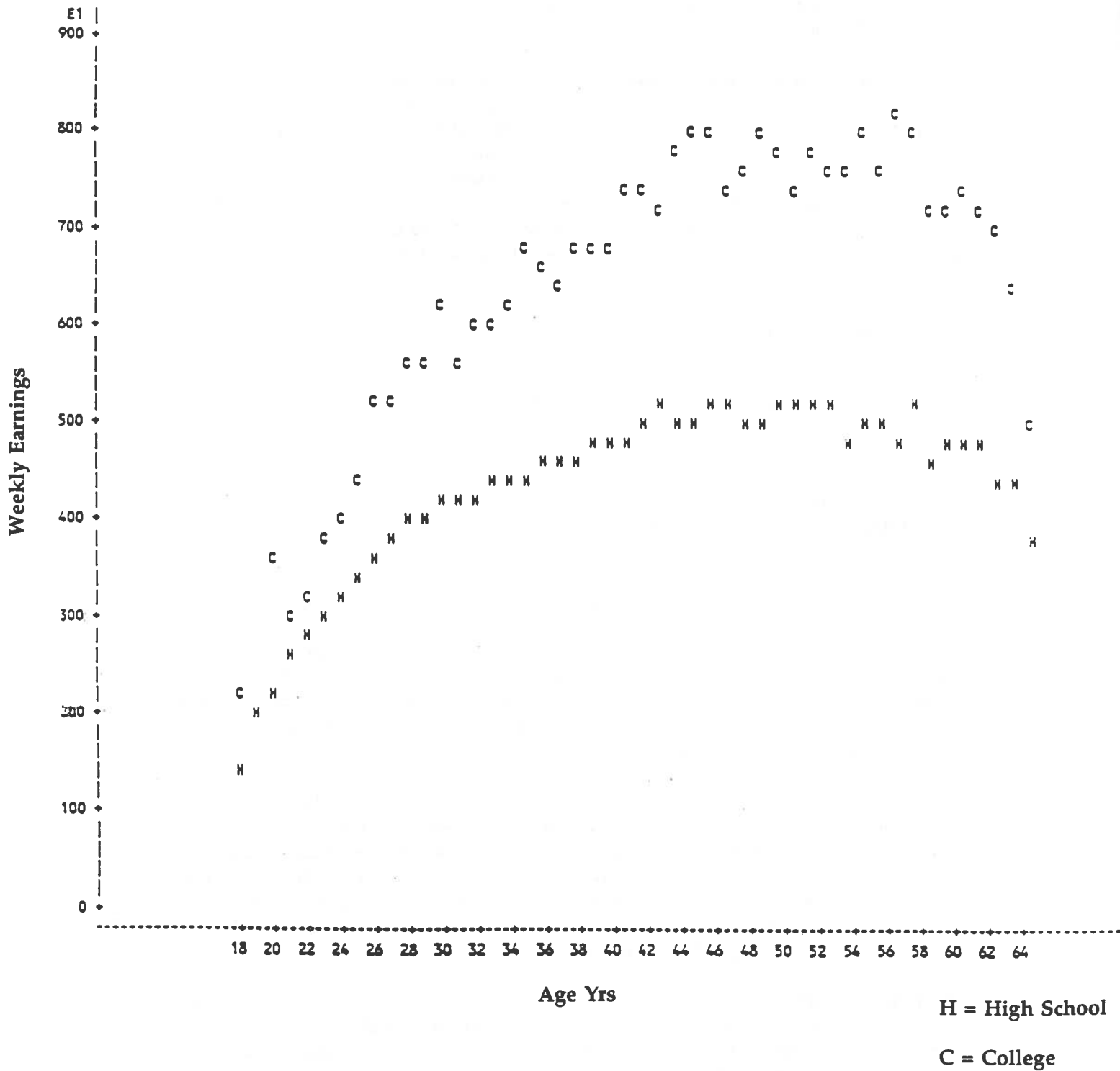
Economists have long shown that both the private and social rate of return on educational investments is quite high. For some years these data were challenged on the grounds that high rates of return were a reflection of selective factors which enabled some children to go on to school. These challenges suggested that there were compounding effects in going on to school that resulted in over-estimated rates of return.

Arley Ashenfelter at Princeton University recently brought new data to bear on this issue which suggests that past studies have actually *under*-estimated the private rates of return. Before considering his research results, it is useful to review the data on which the usual argument in favor of higher education is based. Figure 1 charts weekly earnings against age for those with a high school education and those with a college education. Weekly earnings are uniformly higher for those with a college education, with the differential being the largest during the middle years.

The issue is whether this differential can be attributed to education alone. Ashenfelter addressed this issue by working with identical twins who had different educational experiences. He found that, on average, an additional year of education has a very sizable effect on the earnings of twins and may be as large as 14 percent for each

Relationships Between Age and Weekly Earnings for Different Levels of Education

Figure 1



Source: Ashenfelter, Arley, "How Convincing Is the Evidence Linking Education and Issues?" George Seltzer Distinguished Lecture, Industrial Relations Center, University of Minnesota, 1991.

additional year. Cumulating this for the four years of an undergraduate education results in a very large effect on earnings in later years.

It is important to note that this is a return that an individual can capture. It explains why the demand for higher education is increasing. It also has an important bearing on the issue of what share of their education young people should pay for.

6. *The Importance of Opportunity Costs in Going to School*

The major costs of obtaining a higher education is not the cost of tuition or the other direct costs of going to college. It is, instead, the opportunity costs, or the earnings foregone while going to school.

From society's perspective, an important advantage of the University of Minnesota is that it is located in a large labor market. Students are thus able to work part- or full-time while they go to school, in turn lowering the major cost of obtaining a higher education.

A significant consequence of working while going to school, however, is that students often have to take a reduced course load, thus stretching out the time it takes to obtain a degree. This is a key reason the University of Minnesota has a longer average time for degree completion than comparable universities. The extent to which people are able to work their way through school is a strength of the University, not a deficiency. More students are able to go on for this income-enhancing education than would otherwise be the case.

7. *The Complementary Roles of Research and Teaching at the University*

Outside observers often believe that teaching and research activities in major research universities compete with each other. Research on these issues suggest the contrary. When high quality faculty and adequate facilities are available, undertaking the two functions by the same faculty is a complementary situation. The students' learning experience is enriched if they are taught by faculty conducting effective research programs that place them at the cutting edge of new knowledge. The students themselves contribute to the research effort, increasing their own knowledge and experience, and also benefiting the research through contributions that are cost-effective relative to their skill level. Moreover, the faculty have access to the latest in new knowledge, and can deliver it promptly and easily to their students. The challenge the University faces is to provide incentives for teaching so that good teachers will have the motivation to contribute in the classroom.

8. *Can the State of Minnesota Afford a Major Research University?*

In light of the pressing budget problems the state faces as it looks to the future, some observers question whether the state can afford a first-class research university. It is important to put this issue in perspective. State appropriations for the University for the fiscal year ending June 30, 1991, were \$462.5 million, or \$106 per Minnesota citizen. Legalized gambling in Minnesota in that same year came to \$2.24 billion, or \$463 per

citizen. Thus, for every dollar invested in appropriations for the University, \$4.37 was expended on gambling.

Which of these expenditures is likely to do more for the state? The choice is between consumption and investment. Gambling is good entertainment for those who have a taste for it, but it does little for the future income and employment of the state. In terms of assuring a growth economy for the future, the state *must* make investments in its flagship university sufficient to continue its role as a key source of statewide economic growth.

9. *Do the Citizens of the State Reap the Benefits of the Investments it Makes in the University of Minnesota?* There is a certain amount of leakage associated with any major educational and research enterprise. Not all students remain in the state after graduation, and the benefits spill over to other states, and even to other countries. However, these "losses" are offset by "spill-ins" of knowledge and trained people from other states.

It is this last phenomenon that makes the University an attractive component of the state's budget to cut—can't Minnesota just let other states develop the technology and train the labor it needs? It is short-sighted to think this way. Both the University and the state exist in a competitive environment. Lack of support for the University will cause the best of its faculty to seek employment elsewhere. The quality of its educational and research programs will decline. **Eventually, the economy of the state will lose its competitive edge and employment and economic activities will shift to other states.** Our citizens will be the worse off for the consequences, and it will be a costly and long process to rebuild both the University and the economy.

A Concluding Comment

The University of Minnesota contributes to the economic development of the state in many ways. One way of summarizing these various contributions is to note that in delivering its various services to the state the University helps to attract labor and capital to the state. These resources, in turn, are the basis of future economic growth.

At any point in time there are many people who are willing to relocate from one place to another. Skilled workers, professionals, and entrepreneurs are willing to move to gain more attractive employments, and investors of capital are always seeking more attractive and productive places to invest their resources. These investors and highly skilled members of the labor force may come from other states in the nation, or they may come from abroad.

The University of Minnesota makes the state an attractive place to live by delivering quality education at reasonable cost, much lower than many universities in other states. The contributions of the University's arts and humanities programs help strengthen the cultural amenities the state has to offer to highly skilled employees. The University's quality health care services also make this state an attractive place to live. Its educational programs attract large numbers of students from other states and countries, thus increasing the local pool of talent for a modern economy.

The University's research and technology transfer programs contribute in similar ways. High tech companies like to be located close to research universities. This gives them easier access to information about new technology. It also gives them easy access to highly trained specialists (the University's faculty) who can help them resolve their technical and business problems. These contributions are especially important for new start-up firms that generally do not have the in-house expertise to address such problems. These new firms are the major source of employment expansion in the economy. This expansion can be a source of additional tax revenue for the state.

The state of Minnesota has important choices before it. It can make the investments needed to sustain its highly productive economy and to compete in a national and international economy that is increasingly based on science and technology. Or it can allow its economy to lose its competitive edge and drift into economic decline and decay, with its highly qualified labor force and capital shifting to other states in the nation and to other countries. If it chooses the former, it needs to continue to protect and enhance the investments it has already made in the University of Minnesota.

APPENDIX

Supporting Examples

This section provides some statistics and specific examples of how University activities affect the Minnesota economy, in support of the analytical discussion in previous sections. These empirical data are for illustrative purposes only and are not intended to be either representative or exhaustive.

The University's Research & Development Activities

Research and development (R & D) activities are essential to the state's economic health. In this important area, the National Science Foundation ranked the University of Minnesota seventh in the nation in 1990. It is ranked behind Johns Hopkins University, Massachusetts Institute of Technology, the University of Michigan, the University of Wisconsin at Madison, Stanford, and Cornell. It is ranked ahead of Texas A & M, Pennsylvania State University, the University of California at Los Angeles, and the University of Washington.

Patent applications are another indication of the vitality of an institution's R & D activities. In 1990 the University of Minnesota received 41 patents from the U.S. Patent and Trademark Office, including three patents for new plant varieties. This placed it fourth among U.S. universities, behind the Massachusetts Institute of Technology, the University of California, and the University of Texas. The data in Table 4 show that the University of Minnesota ranks high on patenting even when a longer-term perspective is taken. It ranked sixth among U.S. universities for the number of patents issued during the five-year period between 1986 and 1990. This situation may change, however. Due to financial constraints the University's Office of Patents and Licensing has had to drop some international patents and reduce the number of U.S. patent applications. As a result, the number of patents fell 25 percent to 31 in 1991.

License agreements, under which companies acquire rights to use, produce, and/or market an invention originated at the University, are one measure of the direct effect patent activity can have on the private sector. At the end of 1991, the University had 163 license agreements with 137 companies, 47 of which were in Minnesota, 81 in other states, and 9 in other countries. The University's Office of Patents and Licensing currently has more than 150 new technologies available for licensing.

The University of Minnesota's high ranking in R & D activities is due in part to its ability to attract resources from outside sources. Consequently, these outside resources are part of what helps Minnesota retain its competitive edge. Therefore, it is important to reiterate that the University needs a strong state-funded base if it is to continue to attract such outside funds.

Staffing a High Tech Company

John Rollwagen, CEO of Cray Research computer company, recently noted that the \$20 million Cray computer is made up mostly of sand. That emphasizes the extent to which the output of our economy is increasingly based on science and technology. He went on to note the strong connection between high tech industries and a skilled labor force by stressing that the value of the computer is determined by who uses it, not the raw material that went into it.

Some 380 people on the payroll of Cray Research received their education in Minnesota, with 200 of them receiving their degree from the University of Minnesota. Some 60 have advanced degrees from the University. Rollwagen noted that Cray is now facing more

Table 4. Top Ten Universities in Patents Issued, 1986-90.

Massachusetts Institute of Technology	388
University of California System	324
Stanford University	214
University of Texas	163
California Institute of Technology	159
University of Minnesota	151
Cornell University	122
Johns Hopkins University	102
Iowa State University	97
University of Wisconsin	93

Source: Office of Research and Technology Transfer

competition than it has ever faced before, and stressed the need for a vital University to help sustain its competitive edge.

3M is another example of a company that is heavily dependent on highly skilled people. A high technology company, it is Minnesota's largest private employer.

The University Hospital -- Serving the State

During fiscal year 1990-91 the University Hospital and Clinic admitted 18,161 patients for 145,665 patient days. In addition, there were 327,000 clinic visits, including those to the Community University Health Care Center. The operating expenses of the Hospital and Clinic were \$294 million and total net revenue was \$306 million. Forty-four percent of in-patient admissions were from the seven-county metro area, 35 percent from outstate Minnesota, and 25 percent from other states. During 1990-91, the University Hospital served patients from every county in the state, as it has in most years.

Supplying Minnesota with a Skilled Labor Force

The University of Minnesota regularly produces between 10,000 and 11,000 graduates from its programs each year (Table 5). A large proportion of these graduates remain in the state. To cite some examples from the health care area:

- Of the 3,969 dentists licensed in the State of Minnesota, 3,188 (80 percent) are graduates of the University's School of Dentistry;
- Of the 1,551 licensed morticians in the State of Minnesota, 1,366 (87 percent) are graduates of the University's Program of Mortuary Science; and
- Of the 3,391 pharmacists licensed in the State, 2,306 (68 percent) are graduates of the University's College of Pharmacy.

In a somewhat different vein, approximately 25 percent of the faculty in the state's other universities are graduates of the University of Minnesota. Thus, the University's educational programs have a significant multiplier effect in the state.

Extending Service to the Community

In addition to students, a large number of Minnesotans receive direct services or benefits from the University of Minnesota. For example, in 1990:

- More than 776,863 people were served by the Minnesota Extension Service. This includes nutrition education to a wide variety of citizens, advice on lawns and gardens to urban people, information on technology transfer to farmers, and public affairs seminars and lectures to citizens across the state. The Extension Service also serves our youth through 4-H clubs;
- More than 14,000 animal visits were made to the College of Veterinary Medicine;
- More than 4,500 calls were made to the Poison Control Center on poison and substance abuse;

Table 5. Degrees Granted by the University of Minnesota, 1975-76 to 1990-91

	ASSOC	BACH	MAST	PHD	PROF	TOTAL
1975-76	815	6,977	1,899	512	667	10,870
1979-80	890	6,786	1,726	485	682	10,569
1980-81	934	6,770	1,762	513	778	10,757
1981-82	872	6,746	2,015	460	933	11,026
1982-83	779	7,148	1,975	466	740	11,108
1983-84	810	7,004	1,949	495	700	10,958
1984-85	728	7,041	2,040	515	743	11,067
1985-86	632	6,559	1,952	556	751	10,450
1986-87	653	6,773	2,083	508	697	10,714
1987-88	533	6,781	2,127	527	730	10,698
1988-89	495	6,582	2,145	543	672	10,437
1989-90	481	6,772	2,247	633	702	10,835
1990-91	438	6,976	2,229	706	634	10,983

Source: Management Planning and Information Services

- Nearly 100,000 clinic visits were made to the School of Dentistry, two-thirds of which were uninsured patients; and
- 179,000 University books and articles were lent to libraries, 70 percent of which were in Minnesota.

In addition, Institute of Technology graduates have been instrumental in the start-up of 271 Minnesota companies, and more than 400 companies worldwide. This illustrates the extent to which new business activities are rooted in people who have a high level of technical knowledge.

Service to the World

The contributions of the University of Minnesota go far beyond the borders of Minnesota.

- The "Black Box" airplane flight recorder was developed by James J. Ryan, a mechanical engineering professor at the University from 1931 to 1963.
- A six-year study by the University's Water Resources Research Center is the country's first and only full-scale study on the impact of acid rain on freshwater lakes.
- The Minnesota Multiphasic Personality Inventory (MMPI), the personality inventory widely used by counselors and employers, was developed at the University in 1942 and updated in 1989.
- The University's Human Factors Laboratory studies how driving habits contribute to car accidents, and how car design can better take into account the human element. This information is used in driver education programs and by automobile companies in designing safer automobiles.
- The first successful open-heart surgery was performed at the University in 1952; the first successful heart-lung machine was developed in 1955; the first pancreas transplant was performed in 1966; the first successful bone-marrow transplant was performed in 1968; and the first total-body CAT-scanner was developed in 1978.

Case Studies

The Birth of Minnesota's Biomedical Industry

In 1956, Earl Bakken, a young electrical engineering graduate of the University of Minnesota Institute of Technology, was walking down the hall in the University Hospital. He had a garage-based business repairing electronic medical equipment, and was headed to the operating room to repair the ECG machine. As he passed the office of the "Father of Open Heart Surgery," C. Walton Lillehei, he heard these words: "Hey Earl, I've got a problem for you."

Ten percent of Lillehei's open-heart surgery patients were dying of heart block. His experiments with dogs had shown that a wire sutured to the surface of the heart could keep the heart beating using a small electrical current--what is now known as a pacemaker. He hired an electrical engineering graduate student to build a battery-powered pacemaker, but after six months, the engineer had made no progress. In frustration, Lillehei turned to Bakken, who had gained a reputation for his ability and ingenuity with the new-fangled electronic gadgets that were becoming part of hospital care.

Six weeks later Bakken returned with a box 4 inches square by 2 inches high. Lillehei's research team of surgical residents found that it worked wonderfully on dogs, and the famous surgeon was soon saving nearly 90 percent of his patients who would have died of heart block. In reporting his success in treating heart block, Lillehei referred surgeons to Earl Bakken for the device, giving him the income with which to start Medtronic and develop the first implantable pacemaker.

Lillehei credits the pioneering efforts at the University of Minnesota in the 1950s with setting the stage for the explosive growth of Minnesota's medical industry. Owen H. Wangensteen, then Chief of Surgery, insisted that his surgeons and their trainees learn basic subjects such as physiology and biochemistry, and apply that knowledge in research to find solutions to surgical problems. He himself developed the Wangensteen Suction Pump, a simple device that used siphon principles to drain abdominal wounds, reducing mortality by 80 percent.

Another basic principle, that of bubbles rising to the surface of blood, was applied by Lillehei, Richard DeWall and Vincent Gott in inventing the disposable bubble oxygenator, which they used to replace the function of the heart and lungs during surgery. This first "heart-lung machine" was built of plastic tubing Lillehei obtained from a local company, Mayon Plastics, one of the state's first suppliers of plastic products, such as mayonnaise containers and dairy industry tubing. The company became a supplier of plastic medical tubing as a result of requests from hundreds of heart surgeons referred to them by Lillehei, who quickly spread the word about the open-heart surgery success at Minnesota.

At Medtronic, Bakken created an environment of support for innovative ideas and creative people--sometimes to the company's eventual disadvantage. Thirty-five medical companies have been started by former Medtronic employees, and many of them have looked to the University for help with research, development, and testing of their products. These companies and others have grown to form the core of the Minnesota Medical Alley Association, a trade organization of biomedical companies and health care providers. Medtronic is the largest, with 8,200 employees and 1991 revenues in excess of \$1 billion.

Lillehei has been closely involved with one of Medtronic's "descendants," St. Jude Medical, the leading supplier of artificial heart valves. The company was started by Manny Villafana, a former Medtronic employee who left to start a competing heart pacemaker company, Cardiac Pacemaker, Inc., which he sold to Eli Lilly & Company. With the proceeds of that sale, Villafana looked to the artificial heart valve industry, just beginning to evolve from research at the University of Minnesota. He settled on one of four heart valves developed by Lillehei and his colleagues. The St. Jude valve has since become the leader in its field, with a 70 percent share of the market and annual sales of over \$125 million.

Several other Minnesota medical companies owe their start to University research or assistance from University faculty. They include Medical, Inc., another producer of heart valves; Waters Instruments, founded in Rochester to produce a kidney preservation system invented at the University; and Bio-Medicus (recently acquired by Medtronic), maker of a heart assist pump tested at the University and improved over the years with assistance from senior scientist Frank Dorman and Professor Perry L. Blackshear, Jr. Medtronic recently signed a license for a new version of this implantable pump developed by Dorman.

The Medical Alley Association presented its 1991 Award for Outstanding Contribution in Research and Development to Warren Warwick, director of the University's Cystic Fibrosis Center. Warwick and scientist Leland Hanson invented a therapeutic vest that helps people with cystic fibrosis administer their own physical therapy to clear mucous secretions from their lungs. One of 41 inventions patented by the University's Office of Patents and Licensing in 1989, the vest was licensed to a company in Stillwater, Minnesota, American Biosystems, Inc. Marketed as the ThAIRapy Bronchial Drainage System, it has already generated more than \$3 million in sales.

Eight other medical inventions patented by the University have become the basis for start-up companies in Minnesota, and about 25 existing Minnesota companies have licensed rights to produce other University-patented medical inventions. In addition, many of Minnesota's biomedical companies sponsor research at the University, led by Medtronic's \$150,000 of sponsored research in 1991 and the Medtronic Foundation's \$3 million pledge to help start a Biomedical Engineering Center and establish a Bakken Chair in Biomedical Engineering. Earl Bakken privately donates \$500,000 to support four M.D.-Ph.D. students each year, saying, "Our industry needs the biomedical engineers that will come out of the Center, because we're going to be facing a critical shortage in the near future."

Inventing the Taconite Process

In 1913, when high-grade ore from Minnesota's Iron Range seemed limitless, a young University of Minnesota researcher began a lifelong interest in low-grade ore from taconite rock. For the rest of his life Theodore Davis pursued an ideal that many thought was ludicrous. His detractors cited the lack of any foreseeable need for the low-grade ore, as well as the experience in the 1890s of none other than Thomas Edison, whose efforts to process similar ores on the East Coast were dealt a fatal blow by the emergence of Minnesota's Iron Range. Undaunted, Davis began what would turn out to be more than 40 years of research and development of the taconite process.

Davis began by inventing a Magnetic Tube Separator, which could pull iron out of finely crushed materials, revolutionizing the process of determining iron content. This device was scaled up at the Mines Experiment Station to produce 60 percent iron concentrate from larger amounts of taconite. With support from a group of investors called the Mesabi Syndicate, Davis put together an experimental plant where he developed new machinery and processes that could crush, grind, and wash ore and retrieve at least 60 percent iron concentrate without quickly wearing out machinery components. The plant produced the first commercial taconite ore, which was used to make steel for the noses of armor-piercing projectiles in World War I.

That first taconite plant could not compete with plants processing high grade ores, however, and it was closed in the 1920s. Davis, however, remained committed to the belief that Minnesota would eventually need to rely on its taconite resources. In 1925, he and William R. Appleby, dean of the University's School of Mines, presented to the Minnesota Legislature the first public projections of the state's declining high-grade ore deposits. They succeeded in gaining state funding for research and development work to make taconite processing more competitive in the iron industry.

Over the next 20 years, Davis and colleagues Henry Wade, John J. Craig, and Charles V. Firth succeeded in developing commercial machinery to extract iron ore from taconite and to form the iron dust into pellets. This was a crucial step in making the process economical, because the round pellets increased the efficiency of the steel industry's blast furnaces. This added value made them worth more than similar amounts of high-grade ore.

Technical expertise and economics weren't enough to win the case for taconite. The state mineral tax had to be revised to encourage mining companies to invest in taconite plants. Again, Davis rose to the occasion, convincing Iron Range communities and the legislature to make the needed revision in 1941. The University of Minnesota donated its rights to the process royalty-free to any company using it in Minnesota. The value of those moves was quickly confirmed when the demands of World War II nearly depleted the state's high-grade iron ore.

Minnesota's first taconite processing plant was built at Silver Bay in 1954, by a company that ironically called itself Reserve Mining, thinking that its output would be only a small portion of Minnesota's iron ore shipments for many decades. By the late 1950s Minnesota's mining industry was completely dependent on taconite processing. Peak capacity of 65 million tons/year, worth over \$2 billion, was reached in 1979, with

employment at 15,500. Despite nearly 50 percent reductions in employment in the early 1980s, taconite processing has continued at more than 40 million tons of pellets per year.

In 1990 the Lake Superior Industrial Bureau calculated that Minnesota's seven taconite plants spent more than \$900 million in the state that year: \$270 million to employees, \$575 million for goods and services from other companies, and \$87 million in state and local taxes. Total taconite-related state and local taxes surpassed \$1 billion in 1989, a direct return on the state's approximately \$3 million investment. State special appropriations to the Mines Experiment Station averaged \$22,000 per year from 1925 to 1945. From then on most of the funding, about \$69,000 per year from 1946 through the 1960s, came from the Iron Range Resources and Rehabilitation Board, established with and still funded by taconite tax revenues. (This fund recently provided the loan guarantee that clinched the Northwest Airlines maintenance facility deal.)

Researchers at the University's Natural Resources Research Institute in Duluth, partially funded by a state special grant, continue to develop ways to reduce processing costs and add value to the taconite product, which is gradually losing market share to high grade ore from other countries.

Soybean Research in Minnesota

Although Chinese farmers were harvesting soybeans for use in food and medicine more than 5,000 years ago, the crop's American history is only in its second hundred years. Originally grown mostly in the south and harvested as a forage crop, the soybean has since expanded its potential as a high-protein feed and oil source. Varieties have grown hardier, allowing it to push steadily northward, thanks in large part to the efforts of soybean researchers at the University of Minnesota's Department of Agronomy and Plant Genetics.

Dr. Jean Lambert came to head the University's soybean breeding project in 1946. He led an ambitious team, dedicated to producing diverse varieties that could thrive across the state's three growing regions and 5-1/2 degrees of latitude. Lambert's team brought 33 new soybean varieties to Minnesota farmers, each taking up to ten years to develop.

If not for the breeding program's efforts, soybeans may well have languished. Private industry saw little reason to invest in a crop that commanded so few acres. Without commercial support, it was up to the University to assume an active role in its development. Minnesota-developed varieties thus became the regional crops of choice. The breeding program can take due credit for the rise and success of the soybean in the state.

Just how far has the soybean come? In the 36 years before his retirement in 1982, funding for Dr. Lambert's breeding program increased from \$2,130 to \$128,000 per year. Over the same span, total soybean acreage grew more than 11 times to nearly 5 million acres.

Heading into the 1990s, Minnesota ranked third among soybean-producing states, and the breeding program budget had climbed to \$250,000. Today, soybeans account for nearly 20% of the state's farm marketing cash receipts. Soybean exports exceed \$500 million, 25% of the state's total agricultural exports.

There is some disagreement concerning soybeans' potential. Some contend it is near its biological limits. Others argue that the potential exists for increases up to 40 times present yields. The true potential probably lies somewhere between the extremes.

There can be no disagreement, however, about the value of an active and assertive breeding program. Yields are greater than ever before and new varieties are more able to endure adverse weather conditions. These qualities lend stability to the soybean market and provide a more predictable yield for farmers.

Across the state, new Minnesota-developed varieties consistently outshine their predecessors. Minnesota's two most recent releases, Parker and Lambert, are out-yielding the varieties they replaced in the state's southern production zone by 9% and 14%. Another new release for 1991, Alpha, is resistant to soybean oyst menatode and yields 27% more than a susceptible variety on infested fields.

Minnesota Crop Improvement Association records estimate that the registered and certified seed of Minnesota-developed soybean varieties grown in 1991 could plant enough acres to yield a 44 million bushel crop. At \$5.50 per bushel, this could generate \$242 million from on-farm sales of these varieties alone.

There are, of course, a number of factors that affect soybean yields, including weather, economic stimuli and technical change. Taking these varied influences into account, the internal rate of return for investments made in Minnesota's soybean research has been estimated at between 55 and 58 percent, a handsome rate of return indeed.

Although the figure is subject to some adjustment, the clear indication is that agricultural research is a wise investment, and that dollars placed in the Minnesota soybean program have been particularly well spent.

Engineering a Major Corporation

In the period following World War II, the United States converted much of its classified military research system into an academic enterprise focused primarily on basic research. The University of Minnesota was one of the benefactors of this new enterprise. Its Rosemount Research Laboratories, established on a planned federal ammunition production site in Rosemount, Minnesota, was a leading example of academic research supported by the Department of Defense.

One part of Rosemount Laboratories quickly became a leading site in the nation for aeronautical research, under the direction of Professor John D. Akerman, head of the Department of Aeronautical Engineering. The jet aircraft era was dawning, and the race into space was on the horizon. To meet those challenges and opportunities, Akerman helped put together a plan to attract some of the most talented technical people to the Rosemount Aeronautical Laboratories. He offered them the chance to pursue an advanced degree through the Institute of Technology while doing research at Rosemount. Soon undergraduate and graduate students were working side by side with faculty and staff researchers, several of whom had come to the United States after helping engineer Germany's missile program in World War II.

Out of that setting came a device that would launch one of Minnesota's leading corporations. In the early 1950s an instrumentation project group, led by Ph.D. student Frank Werner, had been studying ways to measure temperature and pressure under the extreme conditions of supersonic flight. Under a contract from the U.S. Air Force, they developed a Gas Temperature Probe capable of providing jet pilots with crucial engine measurements at high temperatures and low pressures. After failing to find an existing company to manufacture the device, the Air Force asked Werner if he would be interested in starting a company to do so. After the University's patent office and an advisory committee decided that the device did not have enough commercial potential to merit patenting and retaining the rights to it, those rights were assigned to the inventors: Werner and Robert E. Keppel at the Rosemount Laboratories, and Marwin A. Bernards, an Air Force scientist.

The timing was right for Werner, who had received his Ph.D. in 1955 and was looking for a career opportunity in aeronautical engineering. He asked Keppel and Vernon Heath, business manager of the laboratory, to join him in forming the Rosemount Engineering Company, which they did on a part-time basis with University approval. After 18 months they were ready to launch the company to provide sensors for Air Force and Navy jets. By 1957, the space program had begun and the company received special requests for sensors of all types. Rosemount sensors have been part of all U.S. space flights, including the moon mission and today's shuttle missions. There were more than 300 Rosemount sensors on the maiden voyage of the space shuttle Columbia.

The commercial market opened to Rosemount in the 1960s, when the Boeing Company installed the Rosemount Total Temperature Sensor on its 707 aircraft. Now all commercial jets in the free world rely on Rosemount.

In the 1970s Rosemount diversified into process control and measurement systems for the chemical, oil and gas, pulp and paper, and food and beverage industries. In 1976 it accepted a merger with St. Louis-based Emerson Electric Company in order to avoid takeover

attempts by less friendly corporations. Today Rosemount, Inc., still based in Minnesota, employs more than 10,000 people around the world and has revenues in excess of \$1 billion.

On August 26, 1991, Rosemount, Inc., celebrated 35 years of partnership with the University by presenting two major gifts. In honor of CEO Vernon Heath's retirement, Emerson Electric endowed the Vernon H. Heath Chair in the Carlson School of Management's Department of Strategic Management and Organization. To underscore the corporation's belief that biotechnology represents the future of many industries, Rosemount donated a \$130,000 System 3 Distributed Control System to the University's Biological Process Technology Institute (BPTI). The control system gives BPTI dual advantages. It can now train undergraduate and graduate students on the same control system currently being installed at major biological process manufacturing plants, and also allow researchers from throughout the University to carry out new types of fermentation research that had not been feasible on current systems.

In an address to the University of Minnesota Board of Regents in April 1991, Heath emphasized the importance of offering students the ability to do research with leading faculty scientists while expanding their knowledge and preparing for careers. "That was the environment offered by the Rosemount Laboratories, and that is why so many innovative people and technology companies came out of it," he said. Besides Rosemount, Inc., companies founded by former Rosemount Laboratories faculty or students include MTS Systems Corporation, Research, Inc., DataMyte Corporation, Fluidyne Engineering Corporation, and Micro Dynamics Corporation.

Heath cited several benefits the University provides Rosemount and other local companies, the most important being the highly prepared and motivated graduates who make up a large proportion of Rosemount's new hires each year. "There is an inside joke that to get ahead at Rosemount, you have to have a University of Minnesota connection. It's only partly true, of course, but I do think it reflects the high value our people place on the education students can get from this university."

The Contributions of the University Libraries

Our emerging economy has alternately been called the information society, the post-industrial age, and the information age. Regardless of the name, the fact is that the global economy is increasingly based on information and brain power rather than on machines, muscles, and natural resources. In order to maintain its productivity and competitiveness, Minnesota will need to make greater investments in information technology and provide greater support for libraries and other agencies that store and deliver information.

The University Libraries' mission is to be the major provider of information needed for University-wide research, educational and service programs. The Libraries support the information needs of the University's researchers, teachers and service providers. The Libraries also directly contribute to meeting the information needs of the entire state and participate actively in the development of information literacy through formal and informal education of students and users at all levels. In short, the Libraries play an integral role in supporting the creation, transmission, application, storage, and preservation of recorded knowledge for all Minnesotans.

The University Libraries' collections contain not only the largest information resource in the state, but one of the largest in the country. The collection ranks 15th nationally in collection size and third within the Big 10. The Twin Cities Campus Libraries contain more than 4,000,000 cataloged volumes, 1,800,000 microforms, 3,000,000 government publications, 245,000 maps, 60 CD-ROM data files, and subscriptions to some 37,000 periodicals and magazines. The University Libraries have as many periodical subscriptions as all of the public libraries in the state combined. These and other collections are available to anyone who needs access to them.

The particular strengths of the Libraries' collections reflect the industries important to Minnesota, including food and agriculture, biotechnology, health care, mining, and engineering. The Libraries are also strong in information that supports these industries, such as management, finance, information processing, and computer science.

Specialized collections within the Libraries provide unique resources used by businesses and researchers both within and beyond the University. For example, the plat maps, fire insurance maps and aerial photographs in the John R. Borchert Map Library are used by engineering firms and businesses to trace the economic and environmental history of business sites across the state. The Charles Babbage Institute Collection supports research in the history of information processing, an important part of Minnesota's economy. This information is used by law firms, publishers and individual researchers. The engineering standards collections in the Science and Engineering Library are essential for product development. Information contained in the BioMedical Library is made available to hospitals and physicians throughout the Midwest. It should also be noted that the 3 million government documents in the Libraries include the only complete collection of U.S. government publications in the state, and the only comprehensive collections of United Nations and European Community publications. Major collections of intergovernmental and foreign documents are also unique in the state.

Because of the Libraries' long traditions of access and service, they serve as the state's major research library, a library of record for research information. Consequently, they

occupy a central position in the state's information-sharing networks. Document delivery for small business is a special focus. The Libraries serve as the first source for materials provided to businesses through Minnesota Project Outreach.

The MINITEX Library Network, which makes its home in the University's Wilson Library, supplies books, documents and photocopies of articles to Minnesotans through their local libraries. In 1990-91, MINITEX supplied 135,569 loans and photocopies from the University Libraries collections, comprising 92% of all requests filled by MINITEX staff. No other library in the U.S. loans more material to other libraries for their patrons' use. More than 400 loan requests are filled each day.

Three research and document delivery services are operated by the libraries. These services provide literature searches and document delivery to individuals and businesses throughout the state on a cost-recovery basis. Some businesses depend upon these services to meet their primary information needs; larger firms use the University's extensive collections and subject experts as backup. Hundreds of firms are served each year, with the majority coming from engineering, biotechnology, law, food, fertilizer, and chemical industries, and private research and information services. Minnesota Project Outreach uses the Libraries as its primary source for publications provided to small businesses. The MINITEX reference service uses both the collections and staff expertise to answer information requests which come through public libraries across the state.

Computerized information is an important component of much of the Libraries' service. Specialized data processing is provided by the Machine Readable Data Center, which serves state researchers, businesses, governments and non-profits by providing tailored reports on demographics, socioeconomic characteristics, and economic statistics from computer tapes of the Bureau of the Census, Bureau of Labor Statistics, and Bureau of Economic Analysis. The Libraries also serve as the coordinator for the Legi-Slate on-line service that assists University offices in identifying opportunities for research grants.

The University Libraries are a major component in the state's on-going effort to develop statewide "information highways" that will connect institutions and individuals through improved telecommunication networks. The Libraries' on-line catalog, LUMINA, is the major gateway to the Libraries' collections and can be accessed through direct dial-up from any computer. LUMINA terminals will soon provide campus users with access to the statewide PALS system, just as PALS terminals throughout the state can provide access to LUMINA. As national plans for a computerized network are implemented, the Libraries will become a central point for state access to national research and government information.

The Inventor Mentor

Professor Raymond M. Warner, Jr., first noticed Roger Gravrok in his junior-year course on device electronics: "At that time the class has about 200 students in it, and Roger was one of the few who had enough gumption to stand up and ask questions whenever something wasn't clear to him."

Gravrok's memory of Warner is equally vivid: "He was the first person to really describe clearly to me how a bipolar junction transistor works. I was working myself through college repairing consumer electronic products, but I never really understood the basic concept until Professor Warner explained it in class."

The respect Gravrok felt for Warner's teaching abilities grew into a desire to work with him as a graduate student. Said Gravrok, "I never really thought I would go to graduate school, and I probably wouldn't have, if not for Ray. When I told him I was thinking about applying to the graduate school and asked him if he would be my advisor, he just beamed and said 'sure.' Then he said, 'It will probably help your chances of being accepted if you write on your application that you intend to accept the research appointment Dr. Warner has offered you.'"

Gravrok was accepted into graduate school and Dr. Warner included him on a large research project designing monocrystalline three-dimensional integrated circuits. Thus began a close personal and professional relationship between mentor and student.

Warner had spent the first half of his 40-year electrical engineering career in industry, working on transistor development at Bell Labs in the 1950s, as director of engineering at Motorola in Phoenix, then branch manager at Texas Instruments in Dallas, and finally, as U.S. technical director for the semiconductor operations of two large corporations.

"In my last two positions the companies looked on engineers as technicians, and I decided I had had enough of that," says Warner. "For a long time I had kept in the back of my mind the possibility of becoming a faculty member, so I went back and hit the books and then gave it a try." He joined the University's Department of Electrical Engineering in 1970.

For the next 19 years, until his retirement in 1989, Warner thrived in his three roles as teacher, researcher, and inventor. Gravrok, the last of his nine Ph.D. students, says Warner has an ability to see potential in people. "He gives you positive feedback, and gives you second and third chances to succeed," says Gravrok.

Warner credits his love of inventing to his father, a chemist in the rubber industry who invented the cold patch for inner tubes. His approach to inventing, however, came from an experience at Bell Labs. "My first bosses gave me the impression there were only a select few who were qualified to be inventors and that the process of inventing involved a sudden stroke of genius. But then I got a marvelous boss named Henry Stone, who taught me you could approach inventing in a systematic way. I continued to work that way through the rest of my industry and university careers and now have about 25 issued patents--most of them 'medicines for which there's no known disease,'" Warner jokes.

Warner sees no conflict between inventing and academic work, or between research and undergraduate teaching. "I think that by and large the best researchers make the best

teachers. Not every researcher will be intrigued by inventing, but I think it's a stimulating activity for faculty and students.

"Over the years I encouraged students to be constantly thinking of ways to improve what they were working on, and to write those ideas down in a bound notebook with numbered pages. I would frequently say to students, 'Write that down, write that down!' Not all, but many of my students were intrigued by the challenge of doing something that hadn't been done before. Roger's a prime example; he even logged the number of pages by month. So it's a student motivation tool; it gives them another dimension of the learning experience."

Gravrok truly did enter another dimension as his theoretical and bench research progressed. As he studied the constraints involved in integrated circuit design, he decided to challenge one of the dogmatic aspects of high-speed computing: the inevitability of electronic noise as a factor leading to random hardware errors. While playing with various aspects of circuit logic, he began to see a possible route to a circuit design that would be virtually immune to noise, making it possible to build faster, more reliable computers. "I took the idea to Ray, and he said 'Go with it.'"

Gravrok received his MSEE in 1986 and then spent the next three years investigating the noise-immunity concept for his doctoral research. There was really no "Eureka!" moment, he says, but rather the evolutionary process of inventing he learned from Warner. The result was the development, testing, prototype circuit fabrication, and patenting of Complementary Noise-Immune Logic (CNIL), which Gravrok describes as a "high-speed logic for reliable computing achieved through designable, near-ideal voltage-transfer characteristics."

CNIL was the subject of Gravrok's thesis in 1989; in the acknowledgments he writes: "Finally I express my gratitude to the CNIL concept itself; I am honored that it waited for me to stumble upon it." Also in 1989, Gravrok was issued a patent entitled "A Novel Family of Noise-Immune Logic Gates and Memory Cells," and, as co-inventor with Warner, a patent entitled "Complementary Noise-Immune Logic." Warner received two other patents in 1989, one for a "Channel Collector Transistor," and another for a "Monocrystalline Three-Dimensional Integrated Circuit."

In the fall of 1989, Cray Research, Inc., responded to informational materials and invited Warner and Gravrok to present the CNIL concept at the firm's product development center in Chippewa Falls, Wisconsin. The presentation went well, and even though Cray decided not to license the invention, it does have a new employee: Roger J. Gravrok, Ph.D., Senior Integrated Circuit Design Engineer.

Gravrok and Warner's invention has been licensed by the University to an entrepreneur in Northfield, who is starting a company to design custom computer circuits using the CNIL concept, as a contractor to corporations and others.