Case study of R&D efficiency in an ATP joint venture

By: Albert N. Link

Link, A.N. "Case Study of R&D Efficiency in ATP Joint Ventures," *Journal of Technology Transfer*, 1998, 23: 43-51. https://doi.org/10.1007/BF02509891

Abstract:

This paper summarizes the technical accomplishments and presents selected measures of research efficiencies and early stage economic impacts of the Printed Wiring Board (PWB) Research Joint Venture Project. The project was cost-shared by the Advanced Technology Program and carried out by a group of seven companies, with participation by Sandia National Laboratories. The period considerred in this case study is from mid-1991 through mid-1996, the time during which the research was conducted.

ATP's funding of the PWB Research Joint Venture has thus far had a number of direct and indirect economic impacts. Of the direct impacts, the largest to date has been the increase in R&D efficiency. The project achieved at least a 53 percent reduction in overall research costs. The increase in research efficiency has in turn led to reduced cycle times for both new project development and new process development. Collectively, the result has meant productivity improvements for member companies and improved competitive positions in the world market.

Keywords: joint venture | printed wiring board | steering committee | member company

Article:

Introduction

The ATP Award to the Printed Wiring Board Research Joint Venture

In April 1991, ATP announced that one of its initial eleven awards was to a joint venture led by the National Center for Manufacturing Sciences (NCMS). The objective of the project was to research aspects of printed wiring board (PWB) interconnect systems. A printed wiring board (PWB) or printed circuit board (PCB) is a device that provides electrical interconnections and a surface for mounting electrical components. The project was completed in April 1996. Actual ATP costs (pre-audited) amounted to $12.866 million over the five-year (statutory limit) funding period. Actual industry costs amounted to $13.693 million. During the project the U.S. Department of Energy added an additional $5.2 million. Thus, total project costs were $31.759 million. As part of its evaluation effort, the ATP wanted to understand better the working of the joint ventures it funded. It commissioned two studies of the Printed Wiring Board (PWB) Joint

Venture, the first in 1993, two years after the joint venture began; and a second in 199, soon after the project ended. This paper reports the results of those studies (Link 1993, 1997).

Trends in the Competitiveness of the PWB Industry

The United States dominated the world PWB market in the early 1980s. However, Japan steadily gained market share from the United States. By 1985, the U.S. share of the world market was, for the first time, less than that of the rest of the world excluding Japan; and by 1987 Japan's world market share surpassed that of the United States and continued to grow until 1990. By 1994, the U.S. share of the world market was approximately equal to that of Japan, but considerably below the share of the rest of the world, which was nearly as large as the two combined. While there is no single event that explains the decline in U.S. market share, one very important factor, at least according to a member of the PWB Project team, has been "budget cut backs for R&D by original equipment manufacturers (OEMs) because owners demanded higher short-term profits," which led to deterioration of the industry's technology base.

In 1991, the Council on Competitiveness issued a report on American technological leadership (Council on Competitiveness, 1991). Motivated by evidence that technology has been the driving force for economic growth throughout American history, the report documented that as a result of intense international competition, America's technological leadership had eroded. In the report, U.S. technologies were characterized in one of four ways: *Strong:* meaning that U.S. industry is in a leading world position and is not in danger of losing that lead over the next five years. *Competitive:* meaning that U.S. industry is leading, but this position is not likely to be sustained over the next five years. *Weak:* meaning that U.S. industry is behind or likely to fall behind over the next five years. *Losing Badly or Lost:* meaning that U.S. industry is no longer a factor or is unlikely to have a presence in the world market over the next five years. The 1991 Council on Competitiveness report characterized the U.S. PWB industry as "Losing Badly or Lost."

In 1994, the Council updated its report and upgraded its assessment of the domestic industry to "Weak" due in large part to renewed R&D efforts by the industry (Council of Competitiveness 1994). Recently, industry spokespersons have heralded signs of an industry turnaround in the industry.

Roles and Relationships among Members of the Joint Venture

Membership of the PWB Joint Venture, in addition to NCMS, and changes in the membership over the course of the project are summarized in Table 1. Although Digital Equipment (DEC) was one of the companies involved in the original NCMS proposal to ATP, it participated in the project for only 18 months. Its decision to withdraw was, according to NCMS, due strictly to financial conditions at the corporation at that time. DEC's financial condition did not improve—leading to the closing and sale of its PWB facilities.

Three companies joined the joint venture to assume DECs research responsibilities: AlliedSignal in 1993, and Hughes Electronics and IBM in 1994. Also, Sandia National Laboratories became involved in the joint venture during 1992, as anticipated when NCMS submitted its proposal to

ATP for funding. Sandia subsequently obtained an additional $5.2 million from the Department of Energy to support the research effort of the joint venture.

Table 1. Membership changes in the PWB research joint venture

Original Members, April 1991	**1992**	**1993**	**1994**	**April 1996**
AT&T	AT&T	AT&T	AT&T	AT&T
Digital Equipment	—	—	—	—
Hamilton Standard	Hamilton Standard	Hamilton Standard	Hamilton Standard	Hamilton Standard
Texas Instruments	Texas Instruments	Texas Instruments	Texas Instruments	Texas Instruments
—	—	AlliedSignal	AlliedSignal	AlliedSignal
—	Sandia	Sandia	Sandia	Sandia
—	—	—	Hughes Electronics	Hughes Electronics
—	—	—	IBM	IBM

Note: Funding under the ATP award to the PWB research joint venture commenced in April 1991. The ATP funding period ended in April 1996.

The PWB research joint venture can be described in economic terminology as a horizontal collaborative research arrangement. Economic theory and empirical studies suggest that research efficiencies will be realized when horizontally related companies form a joint venture, due to the reduction of duplicative research and the sharing of research results (Link & Bauer 1989). This conclusion is supported in the case study here, as evidenced by the quantitative estimates of cost savings reported by the members, and by the specific case examples cited in support of the cost-savings estimates.

Table 2. Characteristics of members of the joint venture

Member Company	**Type of Producer**	**Primary Market Niche**
AT&T	Captive	telecommunications
Hamilton Standard	n.p.	aerospace
Texas Instruments	Captive	computers
AlliedSignal	Captive	defense
Sandia	n.p.	n.p.
Hughes Electronics	Captive	Computers
IBM	Captive	Computers

Note: PWB producers are divided into two general groups: manufacturers that produce PWB's for their own end-product use and manufacturers that produce boards for sale to others. Those in the first group are referred to as original equipment manufacturers (OEMs) or captives, and those in the second group are referred to as independents or merchants.

Characteristics of the joint venture member companies are summarized in Table 2. AT&T, Hughes, IBM, and Texas Instruments were four of the leading domestic captive producers of PWBs when the project began; they were also members of NCMS, the joint venture administrator. Although in the same broadly-defined industry (i.e., they are horizontally related), two of these companies, AT&T and IBM, were not direct competitors in PWBs because their PWBs were produced for internal use in different applications. AT&T produced PWBs primarily for telecommunications applications while IBM's application areas ranged from laptop to mainframe computers. Although Hughes and Texas Instruments produced for different niche markets, they did compete with each other in some Department of Defense areas. Hamilton Standard, no longer a producer, purchases boards to use in its production of engines and flight control electronics. AT&T and Texas Instruments are not involved in these latter two product areas. In contrast to all of the other companies, AlliedSignal is a major supplier of materials (e.g., glass cloth, laminates, resins, copper foil) to the PWB industry. In addition, it is a small-scale captive producer of multilayered PWBs.

Organizational Structure of the Joint Venture

A Steering Committee, with a senior technical representative from each of the participating organizations worked collectively to direct and control the four research teams to ensure that each was meeting the technical goals of the project. NCMS provided the program management, coordination, facilitation, and interface with ATP for the PWB project. NCMS coordinated and scheduled activities and provided the interface between the administrative functions of accounting, contracts, and legal functions related to intellectual property agreements.

The joint venture was organized to "mimic a company with a chain of command," according to one member of the Steering Committee. According to this member:

> If it was not organized this way then no one would be accountable. Most of the people had this project built into their performance review. If they failed on the project then they failed at work. The structure also allowed ease of reporting. The information flowed up to the team leader as the focal point for information distribution. The team leader would then report to the Steering Committee of senior managers who were paying the bills.

The joint venture's research activities were divided into four components:

- Materials
- Surface Finishes
- Imaging
- Product (research; not product development).

Prior to proposing to ATP's 1990 General Competition, the members of the research joint venture conducted a systems analysis of the PWB manufacturing process and concluded that fundamental generic technology development was needed in these four components of the PWB business. Each component consisted of a combination of research areas which (1) provided significant improvements to existing processes; and (2) explored new technology to develop breakthrough advances in process capabilities.

A multi-company team of researchers was assigned to each of the four research components. The four research teams were involved in 62 separate tasks.

Each team had specific research goals as noted in the following team descriptions.

Materials Team: The majority of PWBs used today is made of epoxy glass combinations. The goal of the Materials Team was to develop a more consistent epoxy glass material with improved properties. The team was also to develop non-reinforced materials that exceeded the performance of epoxy materials at lower costs. Better performance included improved mechanical, thermal, and electronic properties (e.g., higher frequency) to meet improved electrical performance standards.

Surface Finishes Team: Soldering defects that occur during assembly require repair. The goal of the Surface Finishes Team was to develop test methods to use during fabrication to determine the effectiveness of various materials used during the soldering process and to develop alternative surface finishes. These test methods can be applied during fabrication to ensure the PWB meets assembly quality requirements.

Imaging Team: The goal of the Imaging Team was to investigate and extend the limits of the imaging process to improve conductor yield, resolution, and dimensional uniformity.

Product Team: Originally, this team was known as the chemical processing team. Its goal was to investigate the feasibility of additive copper plating and adhesion of copper to polymer layers. Based on input from the industry which revealed that this was not the best research path to take, its focus changed as did its name. The revised goal of the Product Team, after studying roadmaps and specification predictions, was to develop high density interconnect structures. (The Product Team, like the other teams, carried out research.)

Given the generic research agenda of the joint venture at the beginning of the project, the organizational structure seemed conceptually appropriate for the successful completion of all research activities. At the close of the project, this continued to be the opinion of the members. As a member of the Steering Committee noted:

> There is better synergy when a management team directs the research rather than one company taking the lead. Members of the Steering Committee vote on membership changes, capital expenditures, licensing issues, patent disclosures and the like. As a result of this type of involvement, there are high-level champions in all member companies rather than in only one.

Technical Accomplishments

The PWB Research Joint Venture Project accomplished the originally proposed goals, and the project exceeded the original expectations of the members. The joint venture entailed 62 distinct research tasks carded out by the project's four research teams. Technical accomplishments included, among many other things, the following: (1) the Materials Team developed the technology for making single-ply laminates and a new, dimensionally stable thin film material that has superior properties to any other material used by the industry; (2) the Surface Finishes Team improved test methods that determine the effectiveness of various materials during the soldering process; (3) the Imaging Team developed and successfully demonstrated the process required to obtain a yield of greater than 98 percent for 3 mil line and space features; and (4) the Product Team (also a research team) developed a revolutionary new interconnect structure and demonstrated its feasibility in production.

Conceptual Approach to the Analysis of Research Cost Savings, Early Productivity Gains, and Other Effects

The conceptual approach to the assessment of early economic gains from this joint venture parallels the approach used by others in economic assessments of federally supported R&D projects (see Link 1996b). Specifically, a hypothetical counter-factual survey experiment was conducted. Participants in the joint venture were asked to quantify a number of related metrics that compared the current end-of-project technological state to the technological state that would have existed at this time in the absence of ATP's financial support of the joint venture. Additional questions were also posed to each team leader in an effort to obtain insights about the results of the joint venture affecting the industry as a whole.

In a 1993 study (Link 1993), it was determined that only 6.5 of the 29 then ongoing tasks in the PWB Joint Venture would have been started in the absence of the ATP award, At project end, there were 62 research tasks, and it was estimated that about half of these would not have been started in the absence of ATP funding. (The number of research areas increased from 29 to 62 as the companies worked together and identified new problems and tasks to solve them.)

A counter-factual survey was created to examine that subset of tasks that would have been started even in the absence of ATP support. Each of the project team leaders was briefed about this study at the April 1996, end-of-project Steering Committee meeting. It was decided that the survey would focus on only one limited dimension of economic impact--namely cost savings attributable to formation of the joint venture, in terms of only those projects that the member companies would have pursued individually anyway in the absence of the ATP supported joint venture.

The limited focus had both positive and negative aspects. On the positive side, it ensured participation in the economic analysis by all members of the joint venture. And, estimates of quantified impacts would represent a lower bound estimate of actual economic value of the joint venture. On the negative side, a number of technical accomplishments that would not have come about but for the joint venture have the potential in time to generate large economic benefits to the PWB industry and to consumers of PWB-based products. No aggregate estimate of the potential value of these impacts was attempted in this study due to its early nature, though examples of productivity impacts currently realized by several of the companies were documented. Looking at developments several years downstream should shed more light on diffusion of the technology developed in the project and their benefits in use.

Methodology for Data Collection

The methodology used to collect information for this study was defined, in large part, by the members of the joint venture. In particular, members requested that the information collected first be screened by NCMS to ensure anonymity and confidentiality, and then only be provided for the study in aggregate form. Under this condition, all members of the PWB research joint venture were willing to participate in the study by completing a limited survey instrument and returning it directly to NCMS.

The survey instrument considered these related categories of direct impact:

- Scale, Scope, and Coordination Efficiencies: Estimated Workyears Saved by Carrying Out the Research as a Joint Venture
- Testing Materials and Machine Time Savings
- Other Research Cost Savings
- Cycle-Time Efficiencies: Shortened Time to Put into Practice New Procedures and Processes
- Productivity Increases in Production.

The survey also considered these two broad categories of indirect impact:

- Technology Transfer to Firms Outside the Joint Venture
- International Competitiveness Issues.

Focused survey findings were supplemented with selected open-ended comments offered by respondents; by personal discussions with team leaders and company representatives during the April 1996, Steering Committee meeting; and by follow-up telephone and electronic mail discussions with available members.

Survey Results: Two Snapshots in Time, 1993 and 1996

All members concurred that the joint venture would not have formed by them or by others in industry in the absence of ATP funds to leverage the overall research program. Each member of the PWB research joint venture was asked which research tasks in which they were involved would have been started by their company in the absence of the ATP, funded joint venture. Aggregate responses suggested that only one-half of the tasks would have begun in the absence of ATP funding. The other one-half would not have been started either because of the cost of such research or because of the related risk. Tasks that would not have been started without ATP funding include:

- Development of alternative surface finishes
- Projection imaging evaluations
- Revolutionary test vehicle designs
- Plasma process monitoring equipment
- PTH modeling software, and also
- Approximately 25 others.

Of those tasks that would have been started without ATP funding, qualitative responses indicated that the majority would have been delayed by at least one year for financial reasons.

Direct Impact on Member Companies

Regarding the five categories of direct impacts:

1. Scale, Scope. and Coordination Efficiencies: Estimated Workyears Saved By Carrying Out the Research as a Joint Venture

Two years into the project, the members estimated a total of 79 workyears had been saved from avoiding redundant research, valued at more than $10 million (Link, 1993). At the end of the project, the members estimated a total of 156 workyears had been saved. The total value of these workyears saved was estimated at $24.7 million. The estimated $24.7 million in savings was based on an estimate of additional labor costs member companies would have incurred if research tasks that they have been willing to conduct individually in the absence of the ATP joint venture were in fact actually carried out individually and without collaboration (see Link, Teece, & Finan 1996 for related examples of labor savings from joint venture research).

An example of workyears saved by avoiding redundant research was provided by a member of the Steering Committee:

> The universal test vehicle developed by the imaging team was the foundation for the co-development and sharing of research results. Two examples of this relate to the evaluation of etchers and the evaluation of photoresists. Regarding etchers, one of the member companies did the initial evaluation, Sandia did the validation, and other member companies implemented the findings. Similarly, individual companies evaluated selected photoresists and then shared their results with the others. All members benefited from this joint development and sharing by avoiding redundant research time and expenses.

2. Testing Materials and Machine Time Savings

Two years into the project, the members estimated cost savings to be over $2 million from saving in research testing materials and research machine time. At the end of the project, the members estimated the total value of savings in research testing materials and machine time to be over $3.3 million.

Relating to research testing materials savings, a member of the Steering Committee noted:

> Before the consortium, there was no central catalogue of all the base materials used to produce printed wiring boards. Now, the Materials Component of the PWB research joint venture has produced a complete database of PWB materials that includes data on composition, qualifications, properties, and processing information for the domestic rigid and microwave materials. The information in this catalogue has saved research testing materials and will make it easier for designers and fabricators to select materials without having to search through supplier literature.

This member went on to note:

Considerable problems were encountered in creating the database because (1) materials suppliers do not provide standardized property test data; (2) all of the data needed to process the material were not readily available; and (3) some of the test data appeared to be exaggerated. The database is presently available within the consortium and there are plans to make the database available to the entire industry over the Internet.

3. Other Research Cost Savings

In the 1993 study, members were asked a catchall question relating to all other research cost savings associated with the research areas that would have been started in the absence of ATP funds, excluding labor and research testing material and machine time. In 1993, these other cost savings totaled $1.5 million. In the 1996 survey, the same catchall question was asked, and members' responses gave cost savings of over $7.5 million.

Therefore, quantifiable research cost savings attributable to ATP funds and the formation of the joint venture were $35.5 million at the end of the project--S24.7 million in workyears saved, $3.3 million in testing material and machine time saved, and $7.5 million in other research cost savings. In other words, members of the joint venture reported that they would have spent collectively an additional $35.5 million in research costs to complete the identified subset of research tasks that they would have conducted in the absence of the ATP-funded joint venture.

4. Cycle-Time Efficiencies: Shortened Time to Put into Practice New Procedures and Processes

Two years into the project, the members estimated that shortened time to put new procedures and processes into research practice was realized from about 30 percent of the tasks, and the average time saved per research task was nearly 13 months. At the end of the project, the members estimated that shortened time to practice was realized in about 80 percent of the research tasks that would have been started in the absence of ATP funds, and the average time saved per task was 11 months. Members did not quantify the research cost savings or the potential revenue gains associated with shortened time to practice.

As an example of shortened time to put into practice new procedures and processes, a member of the Steering Committee noted:

> The use of the AT&T image analysis tool and the improvements made in the tool during the contract has made a significant reduction in the evaluation time needed for photoresist process capability studies. This reduction has occurred due to the improved test methodology and the significant improvements in the speed and accuracy now available in making photoresist analysis.

5. Productivity Increase in Production

Two years into the project, members of the Steering Committee estimated that participants in the project had realized productivity gains in production which could be attributed to research developments in about 20 percent of the 29 research areas. The then-to-date production cost savings totaled about $1 million.

At the end of the project, the members estimated productivity gains in production which could be traced to research developments in about 40 percent of the 62 research areas. It was not possible to segment productivity improvements attributable to the group of research projects that would have been undertaken absent ATP funding from those that would not have been undertaken, due to the complimentary effects of research project results on production The teams estimated the value of these productivity gains in production, to date, to be just over $5 million. And, given that the PWB research joint venture's research has just completed, future productivity gains will, in the opinion of some team leaders, increase exponentially.

One example of productivity improvements in production relates to switching from two sheets of thin B-stage laminate to one sheet of thicker B-stage laminate. One member of the Steering Committee noted:

> For a business like ours, the cost saving potential was enormous, The problem was that reducing the ply count in a board carded risk: drill wander, reliability, thickness control, dimensional stability, and supply. The consortium provided the resources to attack and solve each of these problems. The result was that we were able to quickly convert all production to thicker B-stage, saving at least $3 million per year. Without the consortium this conversion might not have occurred at all.

A second example of productivity improvement relates to dimensional stability. In particular, another member of the Steering Committee noted:

> The inability to accurately predict inner layer shrinkage leads to a serious compromise with interconnection density and often leads to costly scrap. At the beginning of this program, our facility was in the 8 to 10 mil range and mis-registration scrap costs were in the range of $1.5 million per year. This problem was an area of special concern to the consortium members. As a result of this project, data exist that lead to an understanding of the problem, and a predictive model has been developed that is now being used to compensate for the art work associated with the circuit image on the boards. Our current capability is 5 to 6 mils and scrap is below $100,000 per year. The work of the consortium made these improvements possible.

A third member of the Steering Committee reported:

> Our company has reduced solderability defects by 50 percent due to the efforts of the surface finishes team on the PWB interconnect program. The defect levels decreased from 4 to 2 defects per 1,000 solder joints due to reduced variation in tin alloy and contamination at the solder reflow process (note that there are more than 1,000 solder joints per PWB.)

And a fourth member commented:

> The data collected from the NIST ATP program for improved registration and productivity gains were presented to the Defense Electronic Supply Center to convince them to allow single ply prepegs in construction of military PWBs. My company will obtain an ongoing benefit from this due to a 30 percent reduction in materials cost and improved registration of the PWBs which will improve yield.

Indirect Impact on Member Companies and the PWB Industry

Two categories of indirect impact were identified which already are beginning to extend beyond the member companies to the entire industry: advanced scientific knowledge important to making PWBs, and improvements in international competitiveness. For these types of impact, descriptive information was collected to illustrate the breadth of the impact, but no effort was made to estimate aggregate dollar value or to segment them according to tasks that would or would not have been begun in the absence of ATP funding, This approach was based on advice of the Steering Committee which felt that attempting aggregate dollar valuations at this time would be extremely speculative in nature.

1. Technology Transfer to Firms Outside the Joint Venture

Two years into the project, the members estimated that 12 research papers had been presented to various industry groups; 40 professional conferences fundamental to the research of the joint venture had been attended; information from the research tasks was shared with about 30 percent of the industry supplying parts and materials to the PWB industry; and personal interactions had occurred between members of the Imaging Team and suppliers of resist materials to the industry.

At the end of the project, a total of 214 papers related to the research findings from the PWB project had been presented, 96 at professional conferences and 118 at informal gatherings of PWB suppliers and at other forums. Additional papers were scheduled for presentation at the time of this study.

Members of the joint venture offered the opinion that such transfers of scientific information benefited the PWB industry as a whole by informing other producers of new production processes. They also benefited the university research community as evidenced by the fact that these papers are being cited in academic manuscripts.

Members of the Materials Team attended 10 conferences at which they interacted with a significant portion of the supplying industry. Specifically, they estimated that they interfaced regarding the PWB Project with 100 per, cent of the glass/resin/copper suppliers, 100 percent of the flex laminators and microwave laminators, 90 percent of the rigid laminators, and 50 percent of the weavers.

Members of the Steering Committee were asked to comment on the usefulness, as of the end of the project, of these technology transfer efforts. While all thought that they were important to the industry, one member specifically commented:

> One indication of the successfulness of the technology transfer efforts can be reflected in the fact that two of the PWB program papers presented at the IPC conferences were selected as best papers at these conferences. The IPC conferences are recognized worldwide as the premier PWB industry conferences. I think this shows that the industry appreciated the depth of the technology effort. Another indication of the usefulness of the technology transfer process is the fact that new PWB manufacturers are exhibiting

interest in joining two proposed follow-on programs to continue certain areas of the current research.

Another member noted that his company relied on an independent PWB shop for dense boards. A measure of the success of the joint venture's technology transfer efforts is that this independent supplier, not a participant in the joint venture, has also increased its yield of these boards.

2. International Competitiveness Issues

The health of the domestic PWB industry is fundamental to these companies becoming more competitive in the world market. At a recent meeting, NCMS gave its collaborative project excellence award to the ATP-sponsored PWB project. At that meeting the NCMS president credited the project with saving the PWB industry in the U.S. with its approximately 200,000 jobs.

The members of the PWB Research Joint Venture perceived that as a result of their involvement in the joint venture, their companies have become more competitive in certain segments of the world market such as computing, the fastest growing market for PWBs. Although any one member company is involved in only one or two market segments, thus limiting the number of team members' responses relevant to each market segment, all members indicated that their companies' market share either stayed the same or increased as a result of being involved in the PWB project.

Likewise, members perceived that the domestic PWB industry as a whole has increased its competitive position in selected world markets as a result of the accomplishments of the joint venture.

Most respondents expressed an opinion on how the PWB Research Joint Venture has affected the industry share in the different segments of the word PWB market. The responses indicate that the PWB project has increased industry's share in every market segment, with the strongest positive responses in the computer and military segments. No member was of the opinion that they or other members of the joint venture had increased their share at the expense of nonmembers, and this can be attributed to fact that the results of the PWB project have been widely disseminated.

3. Other Company Impacts

Members of the Steering Committee were asked to complete the following statement: My company has benefited from its involvement in the PWB joint venture in such nontechnical ways as . . . . Representative responses were:

- We have learned to work and be much more open with other industry members. We have learned where other companies stand on technology. We have learned we in the industry all have the same problems and can work together to solve them. We have learned how to work with the Federal Labs, something we have never done before.

- We have an increased awareness of industry trends, needs, and approaches. We have learned that our company's intellectual property is not as proprietary as we initially believed--rarely can it be directly applied by our industry colleagues.
- We have gained prestige from being associated with the program. The joint NCMS/NIST/ATP research program has a national recognition. Suppliers that would not normally participate in collaborative projects will when a team like this is formed to become a joint customer.

Lastly, the members were read the goals of the ATP as stated in its enabling legislation. Albeit qualitative information, the members of the Steering Committee of this joint venture generally agreed that the ATP had indeed fulfilled its stated goals in the case of the PWB Research Joint Venture.

Summary and Conclusion

ATPs funding of the PWB Research Joint Venture Project has thus far had a number of direct and indirect economic impacts. Of the direct impacts, the largest to date has been the increase in R&D efficiency. The project achieved at least a 53 percent reduction in overall research costs. The increase in research efficiency has in turn led to reduced cycle times for both new project development and new process development. Collectively, the result has meant productivity improvements for member companies and improved competitive positions in the world market. As a result of knowledge dissemination activities by members of the joint venture, capabilities across the entire industry are expanding. These technology advancements are thus improving the competitive outlook and world market share of the U.S. PWB industry.

The survey findings associated with the above direct and indirect economic benefits are summarized in Table 3. Therein, the categories of direct economic impacts to member companies are Separated into those for which dollar values were obtained and those for which dollar values were not obtained, so-called quantified and non-quantified economic impacts.

The survey results described in the previous sections and summarized in Table 3 should be interpreted as only partial and preliminary estimates of project impacts. First, although ATP funding of the joint venture has led directly to research cost savings and early production cost savings and quality improvements, the bulk of the production cost savings and performance gains will be realized in the future both in member companies and in other companies in the industry as the research results diffuse and are more widely implemented. As such, the valued economic impacts reported in Table 3 are a conservative lower-bound estimate of the long-run economic benefits associated with ATP's funding of the joint venture research.
In the methodology implemented thus far, data collection has focused on gathering from participants their best estimates of cost savings and economic benefits, relative to a counter-factual situation without the ATP. The participants in the PWB Research Joint Venture are obviously those in the most informed position to discuss research cost savings, potential applications, and economic consequences that they have realized from the results obtained. The methodology does not as yet include consideration of market-determined economic benefits deriving from the joint venture research. Full impacts across the marketplace cannot be observed

instantaneously at the end of the project, but only in the future as research results diffuse and become embodied in PWB products.

Table 3. Summary of survey findings on partial early-stage economic impacts

Categories of Partial Early-Stage Economic Impacts	After 2 Years	At End of Project
Direct Impacts to Member Companies		
*Quantified Economic Impacts**		
Research Cost Savings		
Workyears saved	$10.0 mil.	$24.7 mil.
Testing materials and machine time saved	$2.0 mil.	$3.3 mil.
Other research cost savings	$1.5 mil.	$7.5 mil.
Product Cost Savings		
Productivity improvements	$1.0 mil.	$5.0 mil.
*Non-Quantified Economic Impacts**		
Shortened Time to Practice		
Average time saved per research task	12.7 months	11.0 months
Indirect Impacts on Member Companies		
Competitive Position in World Markets	increased	increased
Spillover Impacts on PWB Industry		
Technology Transfer		
Research papers	12	214
Conferences attended	40	96
Competitive Position in World Markets	increased	increased

*These impacts are based only on those research tasks that the members thought they would eventually have done without the ATP, and not the cost and time savings associated with the new capabilities resulting from those tasks that they would not have done at all without the ATP.

References

Council on Competitiveness. *Critical Technologies Update 1994.* Washington, DC: 1994.

Council on Competitiveness. *Gaining New Ground: Technology Priorities for America's Future.* Washington, DC: 1991.

Link, Albert N. "Advanced Technology Program Case Study: Early Stage Impacts of the Printed Wiring Board Joint Venture. Assessed at Project End." Report prepared for the Advanced Technology Program, November 1997.

Link, Albert N. "Advanced Technology Program: Economic Study of the Printed Wiring Board Joint Venture After Two Years." Report prepared for the Advanced Technology Program, April 1993.

Link, Albert N. *Economic Impact Assessments: Guidelines for Conducting and Interpreting Assessment Studies.* NIST Planning Report 92-2, May 1996a.

Link, Albert N. *Evaluating Public Sector Research and Development.* Westport, CT: Praeger, 1996b.

Link, Albert N., and Laura L. Bauer. *Cooperative Research in U.S. Manufacturing: Assessing Policy Initiatives and Corporate Strategies.* Lexington, MA: D. C. Heath, 1989.

Link, Albert N., David J. Teece, and William F. Finan. "Estimating the Benefits from Collaboration: The Case of SEMATECH." *Review of Industrial Organization,* October 1996.