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Sustainable Collaboration:
A Study of the Dynamics of Consortia

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Abstract

This report highlights enabling factors that promote research and development consortium longevity and effectiveness. Our work draws on an extensive case study of one consortium, the Abnormal Situation Management Consortium, and anchors these findings with a comparison of practices with three additional consortia – the McMaster Advanced Control Consortium, the Microelectronics and Computer Technology Corporation, and SEMATECH. All four consortia were created to develop methods, hardware and/or software. Consortia represent a unique organizational form that is ideally suited for flexibility in approach and fluidity in membership compared with other forms of collaborative arrangements. Findings suggest that the ability to recognize and respond to changing needs over time is what characterizes a successful R&D consortium. The structure and membership of the consortium must match the needs of each stage of the R&D process, from discovery through reduction to practice and into commercialization and deployment. A charismatic leader is an important contributor to consortium success, but the charisma must go beyond personality and into relationship building and networking. Individuals who take initiatives to span boundaries help broker relationships that support collaborative development. Interestingly the personal commitment of individual members can be a double-edged sword. On the one hand, individual member personal commitment helps build a shared sense of vision and encourages an action-oriented focus. As the R&D consortium's mission evolves from a research and development focus to a more commercialization focus, early member goals and personal commitment may not match the more pragmatic needs of the commercialization and deployment. Our work points to the critical importance of individual member capabilities, interests, and expertise – and the matching of these member characteristics with the phase of the consortium's R&D activities. A stable membership does not necessarily promote sustainability over time, and R&D consortia are encouraged to periodically evaluate their strategic intent and to consider organizational renewal through both new members and new company representatives. The report begins with an introduction to the study's objectives, and is followed by the in-depth case study, a review of consortia as an organizational form and comparative analysis of the four consortia. We conclude with a set of lessons learned that highlight structural, personal, financial and decision-making issues that appear to promote sustainability.

Key Words: Key words: Advanced Technology Program; case study; industrial process control; collaborative R&D; industrial collaboration; public-private partnerships

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Executive Summary

This study traces the evolution of the Abnormal Situation Management Consortium (ASMC) which developed from a research program funded by the Advanced Technology Program (ATP) between 1994 and 1998. More than a decade later, the consortium has transitioned to complete private funding, continues to function, and experienced recent growth in membership. This study explores factors that enabled the ASMC to maintain viability over time (to 2005), including the pivotal role of ATP funding in creating the momentum needed to tackle the very difficult problem of abnormal situation management. It further explores the subsequent organizational changes needed to maintain its relevance to member companies as the consortium evolved.

The ASMC presents an opportunity to study the life of a consortium over the course of more than a decade and to explore the transition from government to independent funding. The ASMC came to life in a time of rapidly advancing digital technology that, though it extended the possibility of plant operational control through the deployment of sophisticated sensors, was creating a significant management challenge in the form of alarm floods. Alarm floods were a serious problem for control room operators who were monitoring plant operations to identify operating conditions that were approaching some critical threshold. Such abnormal situations, if not corrected, could escalate to out-of-control operating conditions and lead to small-scale accidents or full-scale disasters. Early visionaries believed that a new way of handling abnormal situation management was essential to improving safety and increasing the efficiency of plant operations. The ATP project and subsequent research activities focused on cutting-edge research in plant operations control and alarm management aimed at changing the way that data were analyzed and presented to human operators for action. More than a decade later, ASMC continues its focus on alarm management but has transitioned from basic research to a product development and deployment focus.

As part of this study, the team also studied three other consortia, to a limited degree, to help anchor findings derived from extensive interviews with ASMC participants. The three are the McMaster Advanced Control Consortium (MACC), the Microelectronics and Computer Technology Corporation (MCC), and SEMATECH.

Key Findings

Our work suggests that consortia represent a unique organizational form that is ideally suited for flexibility in approach and fluidity in membership compared with other forms of collaborative arrangements. In seeking to identify factors that lead to success in consortia, we began with the mindset that a long-lived consortium is a successful one. We continue to espouse this view, but we would further qualify it with the recommendation that consortia regularly review goals, objectives, and progress to date. Based on our findings, we believe that longevity by itself is overrated as a criterion for success, and we instead suggest that a truly successful consortium is one that has a clear understanding of the value it provides and can recognize when it should either change its goals and objectives, reinvent itself or disband. A truly successful consortium lasts as long as it is needed and has an exit strategy to redeploy scarce resources.

With regard to factors that appear to promote consortium success, we immediately encountered what several other researchers have found, namely that counting patents, articles, or technology that specifically evolves out of consortium activities has only limited value in determining the benefits derived from the consortium. Placing specific value on transferred technology is likewise a challenge, particularly when consortium members would have to divulge what they consider highly proprietary information to construct a cost benefit analysis.

We distinguish between technology transfer to a product and the deployment of that product as a measure of success. With this yardstick, ASMC is less successful to date than members would like, since widespread adoption of products and techniques that have arisen from ASMC research has yet to be achieved in the petrochemical industry. This has resulted in a conscious change in emphasis toward product commercialization and implementation. It is also changing ASMC's outreach activities to include more users of the technology.

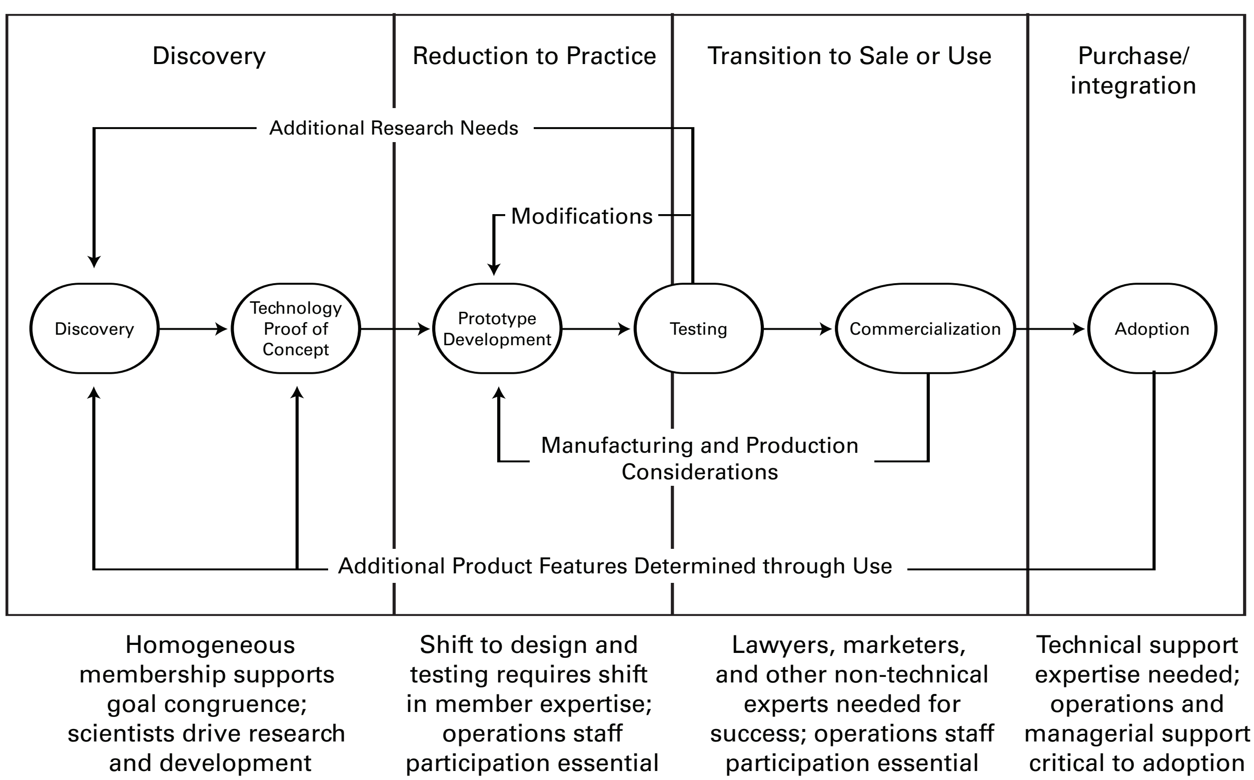
Our work highlights the importance of intangible benefits that result from participation in a consortium. Unfortunately, traditional return on investment (ROI) measures ignore intangible benefits and undervalue the knowledge gained through failure. To improve recognition and usefulness of intangible benefits, robust knowledge sharing mechanisms must be in place and an open exchange of information is essential. Organizational practices that promote information sharing – and the trust that members must develop to bring information to the table – help establish a positive environment for collaboration.

In creating an environment of trust and momentum, a charismatic leader is an important contributor to consortium success. We note, however, that this charisma must extend beyond personality and into relationship-building and networking. Individuals who take initiatives to span boundaries help broker relationships that support collaborative development.

Equally important to momentum is the value of early committed funding in an amount large enough to tackle multiple research streams. Such funding enables planning for higher risk projects, and the stability of multi-year commitment encourages both continuity of personnel and continuing strength of purpose, even in light of what appear to be very difficult and complex problems. Such was certainly the case with ASMC, where members maintain a staunch belief that ATP funding prompted them to set higher goals. This funding also encouraged industry participants to bring a level of commitment to the table that exceeded the dollars of cost sharing. Continuing member commitment to ASMC and its focus on improving abnormal situation management has kept many of the early members active in research and development. Early members continue to attend quarterly meetings and to participate in projects. Though ASMC membership has not grown dramatically, neither has it shrunk.

Membership longevity provides both benefits and constraints to sustainability. A homogeneous set of members promotes early dialog and goal formation; it further offers a stable environment in which to conduct high-risk research. Coupled with a knowledgeable membership, such homogeneity is the bedrock of discovery. As the consortium matures, however, longstanding experts with similar backgrounds and from similar companies encourage groupthink (Janis, 1972; Moorehead and Montanari, 1986) and often act as a barrier to entry.

Figure ES1. From concept to innovation: The structure and membership of the consortium should match the needs of each stage. This requires the consortium to evolve as it matures to be sustainable.



Cohesiveness and creativity are often a delicate balance, and new membership forces a consortium to rethink assumptions that otherwise would go unquestioned. Moreover, as the ASMC has discovered, the best experts to lead research and development efforts are not necessarily the ones to lead commercialization or adoption into practice.

Stability is further promoted by an organizational champion – a company or entity that holds a high and direct stake in the results of the consortium. For ASMC, Honeywell has been the organizational champion. The consortium's governance and decision-making practices must balance this champion's interest with those of the membership at large, however.

Finally, we believe that the organizational structure and membership must match the goals of the consortium and that formal mechanisms to review these should be adopted. Change management practices help balance the passion of research with the realities of development and deployment. Likewise, membership should be reviewed to ensure that membership evolves as the consortium evolves. Formal organizational practices that offer opportunity for periodic review and changes to strategic direction appear to enhance sustainability.

Part I

Introduction

1.1 Background

The Penn State study was formulated to identify those factors that appear to support the longevity and success of a research and development consortium. The focus of this study is the Abnormal Situation Management Consortium (ASMC) whose organizational leader, Honeywell, received funding from the NIST/ATP (National Institute of Standards and Technology/Advanced Technology Program) Program in 1994. ASMC is still operating today. The ASMC was chosen for this research study for the following reasons:

- Emerging in 1992, ASMC offers the opportunity to study consortium activities over more than a decade;
- ASMC has made the transition from government sponsorship to independent funding;
- ASMC has retained a majority of its early members; and
- Early founders and participants are still available for interview.

The ASMC grew out of a grassroots effort begun in 1989 by Honeywell, the Alarm Management Task Force, whose members were concerned about the alarms that were flooding control rooms with the advent of digital process monitoring, which offered limitless "free" alarms on computer screens instead of a wall panel of annunciators and gauges. As alarm floods intensified, the usefulness of the information declined, and the petrochemical industry was concerned about operators missing critical alarms that were being crowded out by non-critical ones. The principal goal of the early participants was to develop the ability to identify processing plant situations approaching an undesired and potentially dangerous regime of operation with sufficient lead time to reestablish normal operating conditions.

The ASMC was intended to support research and development to define the next generation of plant control system solutions that could dramatically improve the ability of process control operators to prevent or respond to abnormal operations and thereby avoid escalation to catastrophic events. This grassroots effort by individual petrochemical company staff was coordinated by researchers at Honeywell, which remains the primary leadership and coordinating entity.

The ASMC began with a research focus to expand basic alarm management into a more comprehensive abnormal situation management focus. Its efforts included the development of

Figure 1. Early control rooms of 1940s vintage based on analog technology gave way to more advanced digital control rooms in the 1970s and beyond, but still struggled with abnormal situation detection and management.

1940–1980 **1970–1990**

tools to promote abnormal situation management and metrics to assess success in this area. The focus embraced normal plant operations, shut-down and start-up activities, and human interactions with the process controls.

At the time the task force was formed, and later when ASMC was created, control rooms had seen little improvement from their typical layout of the 1940s. Even into the 1970s and 1980s, operators faced myriad gauges and still grappled with how to improve their monitoring of critical plant operational status. While digital technology offered a cost-effective way to track critical process variables, it offered little in the way of predictive ability. Operators' instruments and the control room layout had improved, but the operators' ability to assess abnormal situations and to manage them in a real-time way was still lacking.

The ultimate aim of the ASMC was to transition research results into Honeywell control system software and products. The Consortium has been run on sequential three year plans that over the past decade have transitioned from being primarily research-based to being more development- and deployment-based.

The Penn State study traces the evolution of the ASMC from a consortium focused mainly on research to one that emphasizes development and deployment. In tracing this evolution, we explored the role that ATP played not only in seeding this activity, but in laying the groundwork for over a decade of work, fostering a commitment by companies and other members well beyond the original ATP funding. Over the two-year study period, the Penn State team has conducted over 25 interviews and has participated in more than 150 hours of direct contact through meetings and conversations regarding the ASMC. Details of the study approach are presented in Appendix A.

1.2 Project objectives

The Penn State study began with three primary objectives:

1. Tell a practical story of a successful, sustainable collaboration;
2. Draw on interdisciplinary perspectives to explore factors that contributed to that success; and
3. Identify the role that ATP played in launching the consortium.

We have maintained these originally proposed objectives. We explore the organizational structure and its impact on the sustainability of a consortium. Additionally, in our interviews we were able to include significant participant comments on the role ATP played and the way the Consortium has changed since ATP sponsorship ended.

1.3 Report format

The remainder of this report begins with an in-depth case study of the development and conduct of the Abnormal Situation Management Consortium. Our detailed analysis includes a general history to the time period ending in 2005, social network analysis that helps us trace member influence by analyzing patterns of interactions between members, and an analysis of member and company representative commitment to the ASMC and its activities. We then build on this deep understanding of a single consortium with a review of the organizational aspects of consortia in general and continue with a comparative analysis of practices of the ASMC with three other consortia, which were studied in much less depth: The McMaster Advanced Control Consortium, the Microelectronics and Computer Technology Corporation, and SEMATECH. The final section of this report emphasizes lessons learned, organized around our initial research questions:

- Why are so few R&D consortia sustainable over time?
- How do members of consortia perceive their benefits from and contributions to collaboration-focused organizations?
- How do members of consortia leverage the collective resources for individual company gain?
- How do consortia create opportunities not available to individual companies?
- How do decisions made early in a consortium's life influence its stability over time?

In the body of the report, we focus on key findings and themes. Additional details of analysis and supporting data are provided in the Appendices.

Part II

ASMC Case Study

> *"The largest economic disaster in U.S. history (not due to natural causes) was a $1.6 billion explosion at a petrochemical plant in 1989. This accident represents an extreme case in a gamut of minor to major process disruptions, collectively referred to as abnormal situations…Most abnormal situations do not result in explosions or fires but are costly nevertheless, resulting in poor product quality, schedule delays, equipment damage, and other significant costs. The inability of the automated control system and plant operations personnel to control abnormal situations has an economic impact of at least $20 billion annually in the petrochemical industry alone."*

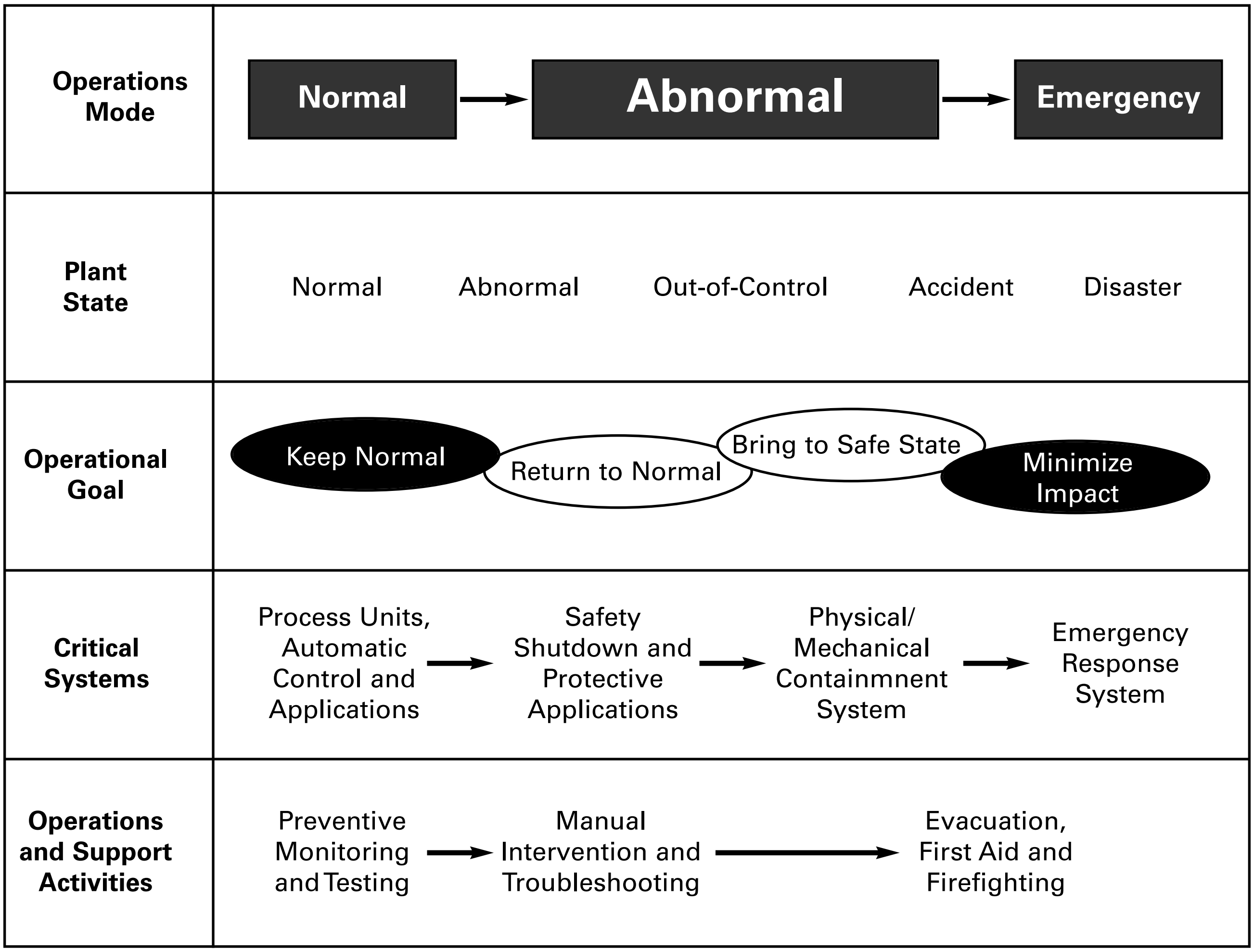
So began a 1994 proposal to the National Institute of Standards and Technology, Advanced Technology Program. This proposal, spearheaded by Honeywell, Inc., sought to address the challenging problem of abnormal situation management. In preparing for this proposal effort, Honeywell and its collaborators created the Abnormal Situation Management (ASM) Joint Research and Development Consortium (referred to as ASMC) under the U.S. Cooperative Research and Development Act. The ASMC linked Honeywell with seven U.S. petrochemical companies (Amoco, British Petroleum, Chevron, Exxon, Mobil, Texaco and Shell) as well as a specialty chemical company (Novacor).

In November 1994, the ASM research joint venture received $16.6 million in funding, including $8.1 million from ATP and industry cost-sharing of $8.5 million. Today, the ASMC is still operating, and several of its original members (albeit with several member company mergers along the way) remain active participants. This study traces the history of the Consortium and highlights its genesis, organizational structure, evolution from a research focus to its current development and deployment focus, and potential for future activities.

2.1 What is an abnormal situation?

Today, most oil refineries and petrochemical plants are operated using distributed control systems (DCS). In a DCS, modularity is used to help reduce complexity; the process often involves the use of individual control modules for each physical aspect of the system that is to be controlled. Before the 1980s, individual control modules were associated with analog

Figure 2. Anatomy of a disaster from normal operations to the critical or emergency state (Nimmo, 1995).



monitors that required hard-wiring into a central control room. The cost of installing such analog-based alarms was about $10,000 per alarm. However, in the 1980s, when many of these plants went from analog to digital systems, it became possible to monitor and control thousands of variables associated with plant operations, including temperatures, pressures, feed rates, and other production variables. In principle, more alarms should result in a better understanding of the status of each important piece of equipment throughout the process. This, in turn, should help increase plants' operational up-time. With the low margins associated with petrochemical production, particularly crude oil refining, plant managers have an incentive to focus on efficiency and throughput.

Plants can function effectively through a range of settings for each processing variable. Ideally, operators would be able to identify when a variable was beginning to go out of its desired range well before it actually exceeded the operating targets, and certainly well before it exceeded some critical level. As digital systems replaced analog, however, a rise in the number of variables tracked during production often resulted in a flood of alarms to the operator. Some of these alarms were the result of faulty sensors, while others were justified. Moreover, not all alarms had the same importance level, but with the high frequency of alarms it was often difficult for operators to differentiate among those alarms that needed to be dealt with immediately and those that did not require follow-up.

Industrial plants typically have well-defined operating conditions under which the plant is considered to be operating safely. These conditions may be a target value or a range of target values within which the equipment can safely function. Industrial plants also have basic guidelines for abnormal procedures such as plant shutdown, equipment shutdown, or emergency response planning. Between normal operating conditions and shutdown or emergency conditions lies an area of high uncertainty known as abnormal situations. Figure 2 depicts the anatomy of a disaster from a normal operating stage through an abnormal stage and into a critical or emergency stage (Nimmo, 1995).

At the time the proposal to ATP was being developed, there was little or no technology existing to cope with situations between normal and out-of-control operations (Nimmo, 1995). This made diagnosis very difficult and hindered recovery. Operators running plants at this time believed that control systems and procedures were inadequate to handle the increasing complexity of industrial plant operations.

2.2 Alarm management & abnormal situations

In the mid-1980s and beyond, petrochemical accidents increasingly were traced to the way abnormal situations were handled, including how alarms were tracked and managed, operational procedures and communication patterns, and roles and responsibilities of various plant personnel. Whenever plant control systems were upgraded, the number of features within the plant that could be evaluated increased dramatically due to lower cost digital alarm technology. Product engineers could put alarms on nearly every possible problem area.

According to one of the Consortium founders, alarms could be set if a particular value was too low or too high, or alternatively, alarms could be set if a particular value deviated beyond a certain point or approached a threshold. Because the alarms were easy to create, engineers began to develop very sophisticated sets of alarm combinations. Typically engineers created lots of alarms – perhaps thousands of possible alarms per control room operator, compared with dozens previously. This resulted in what are known as “alarm floods” and often severely stressed the plant operator’s capacity to separate critical alarms from non-critical alarms. Additionally, a flood of alarms encouraged control room operators to unilaterally determine which alarms were “real” and which were nuisance. False alarms create intense irritation. Moreover, frequent false alarms decreased the trust that operators had in the control system warnings (Reason, 2000).

At the time of the ATP proposal, the Honeywell team estimated that there was a cost of approximately $20 billion per year to the U.S. economy resulting from abnormal situations, an amount nearly equal to the total profits from the petrochemical industry. The estimate was derived from several factors, including:

- Plant surveys that showed incidents were frequent, with typical costs ranging from $100,000 to in excess of $1 million per year. One plant surveyed had 240 shutdowns per year at a total of $8 million.
- Refineries, on average, suffered a major incident once every three years with an estimated average cost of $80 million per incident.
- One insurance company's statistics showed that the industry was claiming on average more than $2.2 billion per year due to equipment damage, with estimated total losses expected to be significantly higher (but unclaimed). (Engineering Equipment and Materials Users Association, p. 109).

But the cost of abnormal situations is only one aspect of their impact. One of the most famous accidents, the accident at the Three Mile Island (TMI) nuclear power plant in 1979, caused major damage to the plant and resulted in permanent shutdown. The TMI incident did not harm any of the population near the reactor, but it did lead to a serious lack of trust in the nuclear power industry – so much so that after TMI, no nuclear power plants were ordered. This single serious abnormal situation incident destroyed an entire industry because of this loss of public trust.

The TMI accident highlighted yet another aspect of plant control problems: the presentation of data to plant control operators was inadequate to fully assess operating conditions (Rubinstein and Mason, 1979). Confusing interfaces, coupled with excessive alarm floods, created serious problems for plant operators across multiple industries. It was of particular concern to the petrochemical industry not only as an operations problem but also as a critical safety issue.

Today, the problem of abnormal situations that transition to critical situations continues to exist. On March 23, 2005, in what was widely considered to be the worst U.S. refinery accident in more than a decade, an explosion at BP's Texas City refinery killed 15 workers and injured more than 170 others (See Figure 3). According to Don Holmstrom, lead investigator of the U.S. Chemical Safety Board's inquiry into the disaster, "…at approximately 1:20 pm on March 23, there was a sudden, geyser-like release of flammable hydrocarbon liquid and vapor from an atmospheric vent stack at the BP refinery's isomerization unit. This release created a flammable vapor cloud, which ignited, causing as many as five explosions" (Houston Chronicle, June 29, 2005).

Figure 3. BP Texas City Refinery Fire

The U.S. Chemical Safety Board's investigations point to failures of sensors within the plant, inconsistent adherence to procedures, miscommunication, and a poor level of hazard awareness and subsequent safety practices. "Key alarms and instruments that would have warned operators of an emergency at the BP Texas City refinery were not working in the critical hours and minutes before [the explosion]. … Alarms that should have warned opera-tors of abnormal conditions…did not go off" (Belli, 2005).

The coordinated response of the operations team to abnormal situations begins with the DCS display screen. By design, a DCS provides the operator with warning messages and alarms for each individual deviant process value. The sophistication of the user support technologies has not kept pace with the task demands imposed by abnormal situations. In the worst cases, abnormal situations result in process shutdown, extensive loss of production, equipment damage, release of undesirable materials into the environment, death, and injury. Unfortunately, as processes and process control systems have become more sophisticated, the opportunities for abnormal situations have multiplied, and the complexity of modern plants has begun to surpass the ability of plant operations staff to deal effectively with situations as they arise. The actual annual cost of abnormal situations is difficult to quantify at an individual plant or for the industry in general. Abnormal events not only create equipment downtime, they also frequently damage equipment. One ASMC member noted that abnormal situations were costing his company between \$100–\$500 million annually in equipment damage alone. This does not include the larger cost of business interruption, a dollar figure that varies based on market condition.

Today, cost savings from a reduction in abnormal situations are estimated based on a comprehensive set of factors, including:

- Fewer unplanned outages and increased productivity,
- Fewer minor disturbances that result in sub-optimal production and energy use,
- Extending equipment and infrastructure life,
- Improved safety and reliability of equipment and processes,
- A reduction in the number of operators, each of whom can assume a wider scope of responsibility, be more empowered, and be better educated/trained, and
- Reduced impact of loss of expertise and knowledge as experienced maintenance staff, operators and engineers leave the work place.

2.3 Emergence of the ASMC

The key goal of the proposed work on abnormal situation management was to reduce the $20 billion impact of preventable abnormal situations through better decision support for the operations staff. The fundamental goal in developing the proposed system known as AEGIS (Abnormal Event Guidance and Information System) was to improve abnormal situation management by enhancing the accuracy, completeness, and speed of the human activities. At the time, analysis of abnormal industrial operations found that human error was the root cause for nearly 40% of occurrences (Nimmo, 1995). Abnormal situations are generally defined as the development of non-optimal conditions that cannot be handled automatically by the control equipment and thus require human intervention. The goal of the proposed program was to demonstrate the technical feasibility of collaborative decision support technologies. The project hoped to generate the underlying knowledge that could then be adapted to computer technology to automatically process inputs from multiple systems, identify out-of-target or out-of-range data, and based on known operating procedures, perform state estimation. Prediction of possible abnormal situations and their likelihood of reaching emergency or critical dimensions was also a project goal. Ultimately, the computer technology solution had to accommodate the human in the loop, presenting information in a way that was both easily understandable and actionable.

2.3.1 The early days before ATP funding

The precursor to the ASMC activities was the Alarm Management Task Force (AMTF), composed of key Honeywell customers who wanted changes to the flagship Honeywell Distributed Control System called TDC3000 (Total Digital Control 3000), which was released around 1984. By late 1989, there were enough systems in operation for customers to begin seeing problems with the way the control system handled alarms. Product engineers were increasing the load on control room operators from monitoring dozens of alarms to

Chronology of the ASMC

1992 Beginning. The Alarm Management Task Force was informally established in 1992 as an outgrowth of an effort to define improvements to current DCS alarm system technologies. Realizing that the alarm system was but a part of the larger issue of the management of unexpected process upsets, four companies (Amoco, Chevron, Exxon and Shell) teamed with Honeywell to develop a problem statement and a vision for the solution.

1994 Formation. The ASM Joint R&D Consortium (referred to as the ASMC) was formally established with the original five companies plus four others (BP, Mobil, NOVA Chemicals, and Texaco). The ASMC received matching funding from the National Institute of Standards and Technology's Advanced Technology Program for a 3.5-year, $16.6M research and technology development effort to develop collaborative decision support technologies.

1994–1998. The ATP research program focused on the development of a proof of concept system called AEGIS (Abnormal Event Guidance and Information System). The program successfully demonstrated the feasibility of the collaborative decision support technologies in the lab test environment.

1999-2001. The ATP program provided a critical mass of funding and focused effort for the development of a significant new technology-based solution concept. In 1998, the Consortium decided to embark on a three-year plan (1999–2001), using internal member funds, to prove the feasibility of the collaborative decision support technologies in the industrial plant environment. Under this new program plan, the ASMC focused on abnormality diagnosis, early warning, and assessing and learning from experiences.

2002–2004. In 2001, the ASMC assessed the progress and accomplishments of the past seven years of research, and members decided to renew their commitment to continue their collaboration and the pursuit of "best practice" solutions to the ASM problem broadly defined. During this time, ASMC emphasized the development of products and services to support these practices. Honeywell committed part of its product development docket to Consortium control to further this objective.

2005–2008. The solution development focus continues with deployment as a major thrust. Inclusion of operations staff from user member companies is expected to facilitate deployment.

monitoring potentially thousands of alarms with the newer digital technology. Among these thousands of alarms could be both unique alarms and repeat alarms, which further reduced situation awareness.

The charter of the AMTF was to "Define the next generation of plant control system solutions that [would] dramatically improve the ability of process control operators to prevent and respond to abnormal operations, thereby avoiding escalation to catastrophic event(s)." Task force members believed that process control plant operators had to deal with too much data at too low a level, thereby making it difficult to quickly grasp information about causes, symptoms, consequences, problems, and corrections.

There were about a dozen representatives from Honeywell's customer base, including: Mike Clark (Amoco), Ken Emingholz (Exxon) and Doug Rothenberg (British Petroleum). The task force determined that there was more to the problem of alarm system function than what was addressed in Honeywell products at the time. It decided that although alarm floods were an obvious problem, abnormal situation management was really the issue that needed addressing. The group met between late 1989 and 1992 and produced a needs assessment and recommendations to Honeywell architects to add new functionality to TDC3000. The assess-ment and recommendations were made available to all Honeywell customers. The customers involved in the activity concluded that this was a very productive exercise and the industry received direct benefit by this cooperative approach to defining requirements and focusing on common problems and leveraging resources.

In response to the desire for more than an an alarm management focus, the Abnormal Situation Management Solution Concept Team was established to identify current limitations facing industrial plant operations during abnormal conditions. Ted Cochran (Honeywell-Minneapolis) believed that his R&D group would be a good place to develop such a product, since its members focused more on longer term technical development and less on incremental product improvements. The team aimed to: 1) identify problems by monitoring conditions on customer sites over a six- to nine-month period and considering feedback on current or earlier events, 2) recommend changes in methodologies, practices, and operations, 3) devise technical solutions to achieve best practices, and 4) identify solutions in the form of prioritized products, applications, and services that could be implemented over a three- to five- year period, with intermediate results as appropriate.

Ted Cochran was the project manager for the Solution Concept Team. The team had a minimum budget of $200K from Honeywell for Phase I (1993 funds) and each customer was supposed to contribute a minimum of one person month (up to three person months) and $30K of additional travel and related expenses.

The ASM-Honeywell Solution Concept Team was to complete five major audits of customer sites, provide the customer site with feedback, provide a sanitized report to be shared with the core team, and identify enhancements to existing and future Honeywell products, applications, and services to improve efficiency in the identification and response to abnormal situations. In 1993, Peter Bullemer began doing interviews with plants from companies in the task force to try to dig deeper into the problem of control room alarms and their control and use. Bullemer and Ian Nimmo collaborated to complete plant interviews, and the two aggregated their findings into a report on needs in an abnormal situation control environment. The Solution Concept Team reported its findings to the Task Force, which then focused on the top

20 items from the list. The AMTF sent the top 20 back to Honeywell and asked the company to develop projects/products to address them. At this point the group decided more funding was needed to really address the R&D needs. Honeywell engineers, however, were skeptical, since the problem appeared to be more than a case of product upgrade; instead, it was a completely new set of technologies and ways of doing things.

By 1994 a problem statement emerged from the site visits that had been conducted over the past 12 months. During that time, it became clear that there was a critical need for operations and engineering teams within plants to work more closely together to help the plant operations processes run more consistently and to identify cause-and-effect relation-ships (root cause analysis) leading to abnormal situations. Site visits also identified several DCS human-machine interaction deficiencies, including:

- Inadequate precision of temporal information (true alarm order)
- Excessive nuisance alarms due to weak conditional alarming capabilities
- Inadequate system anticipation of process disturbances
- Lack of real-time root-cause analysis (symptom-based alarming)
- Lack of distinctions between instrument failures and true process deviations
- Poor integration of multiple information and control system components
- Limited capabilities to view interrelated process data
- Lack of adequate tools to measure, track and access records of abnormal situations
- Limited or time-consuming access to procedures or operating instructions
- Cumbersome and un-integrated communications among and within plants.

2.3.2 Formation of the Abnormal Situation Management Consortium

Around 1992, Honeywell locations in Minneapolis (R&D) and Phoenix (product development) were working with the AMTF. They realized that there needed to be structure to this activity to promote information sharing between Honeywell and its customers and among the customers themselves – many of whom were arch rivals. Ted Cochran began looking into what a joint venture might entail, including what the issues were, who cooperates and in what way, and how intellectual property (IP) would be shared. British Petroleum and Exxon, both participants in the Task Force, wanted to work together, but Ted Cochran was convinced that a formal structure was needed to really establish collaboration. This was a new approach for Honeywell, since in the past the company had waited until funding was in place before it estab-lished formal structures.

Early on there were tensions between Honeywell product and research engineers regarding how Task Force recommendations should be interpreted. Product engineers wanted to focus on how to translate recommendations into product feature up-grades; R&D engineers, on the other hand, believed that the problem required new solutions. This divergence of opinion followed Honeywell organizational lines, as well. Originally, product engineers out of Honeywell-Phoenix were responsible for the Task Force, but by 1993, responsibility was transferred to marketing, and progress toward a more formal abnor-mal situation management structure became more rapid. In October 1993, Ian Nimmo, who was in Honeywell's industrial automation business in Phoenix, took over responsibilities for the ASM and AMTF program activities.

In developing the joint venture documents for the ASMC, Ted Cochran focused on defining key concepts and organizational structures in conjunction with customers before getting lawyers involved. This early dialog helped to create a shared sense of purpose and put in place key champions for the ASMC within customer companies. While the documentation was evolving, the Task Force continued to meet regularly.

2.3.3 The ATP proposal

Honeywell struggled with whether to conduct a small self-funded program, working with a small number of customers, or to attempt the larger ATP proposal. A program the size of the ATP effort was unusual for Honeywell, and significant internal politicking was required to prepare and submit the proposal. The ATP proposal had a $16.6 million budget ($8.1 million from ATP and the remainder committed as industry cost sharing), which was very large compared with the more traditional $2–3 million typical project efforts at Honeywell.

Ted Cochran, Peter Bullemer and Ian Nimmo were the prime Honeywell personnel behind the strategy development. Ted Cochran and Peter Bullemer both hailed from Honeywell Labs in Minneapolis. At the time, their research group was considered one of the best in the country in human factors and display engineering. As the ASMC project was evolving to become a proposal to ATP, Ted Cochran ran management interference while Peter Bullemer was developing the problem statement. Ian Nimmo joined the planning effort from his position in product development at the Honeywell-Phoenix operations. Nimmo brought extensive experience in plant operations in the chemical industry to the planning and development team. Together Bullemer and Nimmo crafted a problem definition statement for the ATP proposal that was sensitive to the technical challenges and to the user environment.

In anticipation of a proposal, Ted Cochran believed the effort would be stronger if a legally formed consortium was already in place. The team spent more than a year working on the ASMC formation and strategy and about eight months working on the proposal. When it was time for a formal statement of commitment to the Consortium, there was still some hesitance among customer companies to join the ASMC. Amoco finally broke the logjam by writing a letter highlighting how important this effort was and explaining that only by doing this as a group could the refineries really make meaningful progress on the problem. This letter was eventually included with the ATP proposal. Exxon was the first company to formally join the Consortium, but the Amoco letter finally encouraged other companies to commit. Once Amoco, British Petroleum, Exxon and Shell joined, others in the industry saw the emerging critical mass. The Honeywell team had hoped to submit the ATP proposal with five committed members but ended up with eight committed members by the time the proposal was submitted in 1994.

The ATP proposal stressed a goal to "…demonstrate the technical feasibility of collaborative decision support technologies for improving the performance of operations personnel." The project would emphasize a system-level solution, AEGIS (Abnormal Event Guidance and Information System), which would be supported by precompetitive technological innovations and collaborative human-machine interaction. The system architecture that was proposed highlighted a modular structure with a customized toolkit for specific problem areas.

The goal was to create self-adaptive software that had a refined human-machine interface. To achieve this, three technical challenges had to be overcome as part of the project: (1) human-machine interactions that supported both individual console operators and collaborative work; (2) system architectures that combined multiple processing modules, databases and knowledge bases that could operate in real-time and that could be coordinated among themselves and between the software and the human operators; and (3) system customization challenges that would enable the system-level approach to be customized to the idiosyncratic and dynamic nature of individual plants and operations.

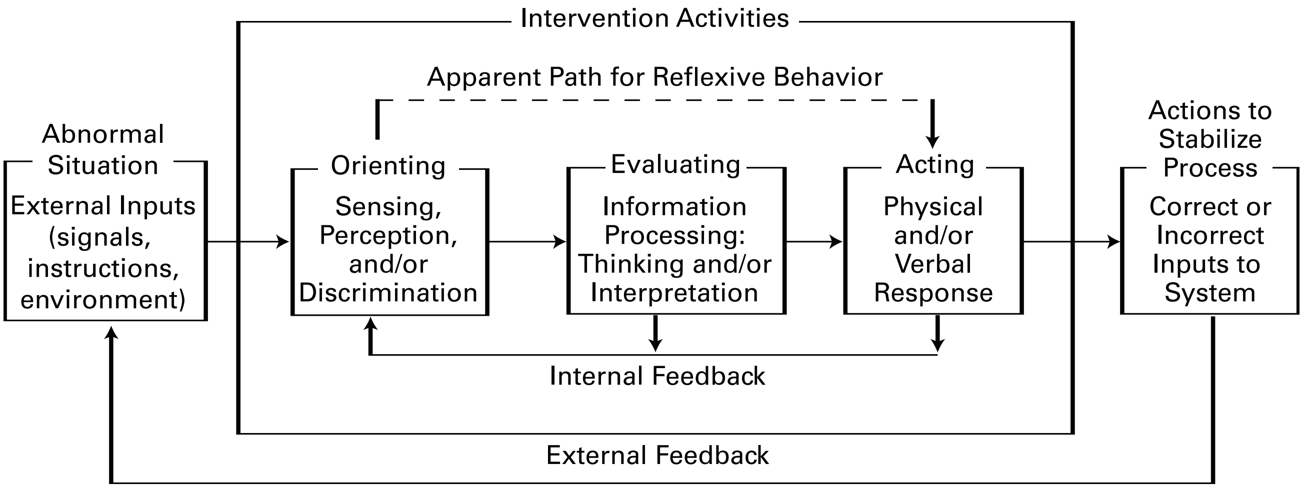
The project team proposed more than 30 technology development studies to address these issues, with rollout on a series of prototypes, and with the final prototype being tested at multiple sites to ensure flexibility and functionality. The team began with the presumption: "The major obstacle to improved abnormal situation management is that operations personnel need to have better decision support – in terms of problem identification, action alternatives, and consequence analysis – from the DCS, so that disturbances can be quickly managed" (ATP proposal, p. 3–2).

The team stressed a problem-solving approach of Orienting, Evaluating, and Acting (See Figure 4). Based on this, they created a decision-making model which was adapted from the Chemical Manufacturers Association.

In the first stage of the process, a disturbance is detected from some external input. Once an abnormal situation is perceived, hypotheses must be developed about what might be the root cause of the anomalous operating condition. Once hypotheses are formed and alternatives are identified, the operator must act. Additionally, this action must be in keeping with best practices to solve the particular anomalous operating condition.

The ATP team proposed to use statistical analysis to observe sensor readings, develop a set of "normal" operating conditions, predict future states based on current conditions and trends, and then to activate requests for updated information. All of this was to happen in the background to help minimize alarm floods. In a sense, the team hoped to create what we now call situation awareness. The term describes an operator's ability to understand the current

Figure 4. Decision-making model for operations intervention activities (ATP Proposal, 1994)



status of multiple inputs and the way that these inputs contribute to the overall situation's status. Such situational awareness helps the operator understand how the situation might change as the result of his or her actions.

AEGIS was intended to help reduce risks by predicting likely future out-of-control states, acting as an input to changes in control settings within plant systems, and alerting plant control operators of current and future states through a communications module.

2.4 The ATP project

Several past and current members of the Consortium indicated that this activity would have been neither possible nor sustainable without ATP support. They added that no other government agency had the vision to enable substantive company participation to leverage both government and customer resources toward a critical problem that was beyond the scope of any single industry concern. In fact, one member noted that the Consortium has been "riding on the momentum of the ATP funding ever since."

ATP funding brought momentum to the early Consortium activities. It brought together the best thinkers at Honeywell, petrochemical companies, universities, and smaller supporting companies. ATP funding created a collaborative environment in which petrochemical companies could come together to discuss practical aspects of plant control issues outside the confines of traditional antitrust issues.

2.4.1 ATP project activities

Honeywell received the award letter from ATP on November 21, 1994, for a 3.5 year, $8.1 million award to develop collaborative decision support technologies. The ATP funding was matched with $8.5 million of industry cost sharing. Ted Cochran was named Program Manager for the ATP-funded project. Ian Nimmo was named Program Director and Peter Bullemer was named Principal Investigator for the ATP project. Bullemer, was the technical lead for organizing Honeywell technical efforts between Honeywell-Minneapolis and Honeywell-Phoenix, representing Honeywell's R&D and business divisions, respectively. From December 1994 to March 1995, changes were made to the Consortium agreement; and work officially commenced on March 1, 1995.

The project was planned in three phases. The expected deliverables of Phase I included: site-specific close-out reports and site-specific response reports that addressed issues identified in the close-out reports (both of which were were intended for internal use by the company site visited); a summary report for the core research team's use that collated data from all of the site visits; and a Phase I Final Report that would identify the major issues that affect operations effectiveness during abnormal situations (owned by the core team). The new member site visits that are still conducted today are a legacy of the Phase I activities. Site visits remain a substantial up-front cost for any company considering membership in ASMC.

Members have discussed reducing or eliminating this initial assessment, but to date these discussions have not resulted in a policy change. Site visits can produce value for companies in terms of recommendations for improvements, but at least one member noted that this value can be captured by the company only if it has the expertise in place to truly understand the magnitude and nuances of the recommendations.

Phase II was intended to develop concepts, approaches, and test scenarios, as well as to provide more detailed research into the enabling technologies. Phase III was intended to develop functional and architectural designs from the second phase into field prototypes which could be applied to an actual process in a customer plant.

More than two dozen collateral studies were conducted to support the development of AEGIS and related technologies. In 1998, the Consortium unanimously agreed on the need to continue their collaboration and the pursuit of solutions to the ASM problem, even though the funding from ATP was ending.

As of 1998, when ATP funding ended, the ASMC activities had yielded only marginal impact on direct product features. This was primarily due to the research emphasis, and members were not surprised by this. At least one member noted that the early ASMC research focus did not have a product development strategy. Going so far as to describe this as a "fatal flaw," the member indicated that Honeywell had focused on computer architec-tures while members were interested in ideas concerning process state estimation and detection. As the Consortium moved forward after ATP funding, members would become more concerned about the lack of transition of ideas to products. In fact, subsequent three year plans for the ASMC increasingly emphasized the productization of ASMC findings.

During ATP funding and shortly thereafter, the ASMC focused on identifying best practices, and several members noted that the best practice findings compiled into reports yielded individual company benefits (see, for example, Crowe, 1999). In addition, projects undertaken at specific company sites offered insight into operations and potential improvements. Members have commented that sharing these insights with the Consortium for improved overall plant operations has been inconsistent among members; some have been very open about lessons learned and others have been more reticent. The Phase I practice of limiting the use of site specific data and providing Consortium members with summary reports encouraged individual site participation but entailed a trade-off with more detailed sharing of information.

2.4.2 ASMC organizational structure under the ATP project

The ASMC structure forced companies to collaborate in meaningful ways. Participation could not be in name only, and members were forced to contribute resources and to commit to attending quarterly meetings and sharing information. In fact, members understood that if they did not actively engage in Consortium activities, they would be asked to leave the Consortium. In point of fact, no member has ever been asked to leave, and several of the early members remain active in the ASMC today.

The ASMC had an explicit Participant's Handbook and a list of expectations. Some of these expectations included the notion that "no-one is ever wrong" and that disagreements are often the result of perceptional differences or experience differences. Discussions about divergent views were to be focused on trying to understand the underlying cause of the difference, without criticism.

Meetings were held quarterly, with members expected to share hosting duties so that the ASMC meetings rotated among member locations. At Quarterly Review Meetings (called QRMs), members were each required to present their progress on the issues the ASMC was trying to solve. This developed into almost a case of "one-upmanship" among member companies to do the best presentation.

Within the QRMs, members were expected to facilitate discussions and to manage the schedule. This forced members to be attuned to critical discussion points and to eliminate non-value adding conversations. The group used a standard format for Powerpoint slides to capture key features of projects, and these standard slides had the added benefit of creating consistency between presentations and clarity over time. Remote participation was and continues to be allowed, but members were encouraged (actually required) to attend several meetings per year in person.

Communication strategies for the Consortium have been noted as one of the strengths of its early organization. At the time it was formed, many members did not have access to e-mail, and so the ASMC decided to try to bridge the technology gap using Lotus Notes, a database that could be accessed by multiple systems (both PCs and Macs). Later, the Consortium would transition this entire system to the Internet on a members-only portion of the ASMC website.

The website (www.asmconsortium.com) had both publicly available information and private space for member companies and sensitive information, and this part of the website is password protected. The combined website and Lotus Notes information has gone through several transitions throughout the life of the Consortium, though not always successfully. Documents are often incomplete, relocated, or otherwise unavailable. Members have encountered difficulties with this website, and Honeywell maintenance of the site has not always been adequately staffed. This has frustrated administrators in the ASMC as well as members.

The ASMC has used a planning cycle in which activities for the upcoming three year period are proposed and agreed to; then company commitments of in-kind participation are determined based on availability and interest. This has produced a sustained member company sponsorship of individual projects with an accountable in-kind commitment matched to specific projects.

In addition, just as the three year plan included new projects, it also provided an expected mechanism to introduce change. At the end of each three year period, new projects are expected and members participate in the selection process.

The ASMC was structured so that Honeywell would own all intellectual property that arose from the ATP research. This structure helped ensure continued Honeywell investment and helped create a critical mass of researchers aiming at product development. However, ASMC intellectual property policies, especially restrictions on publication of research results, have become a hurdle to university participation in the ASMC, as university intellectual property norms have changed in recent years. Enouraged to own patents for research funded under federal government programs under the Bayh-Dole Act of 1980 and its amendments in 1984, universities have come to expect to hold a patent position or at the very least, a shared patent position when research conducted by faculty, regardless of the source of funding, produces patentable IP.

There is only one university currently participating in the ASMC. Potential university members see the intellectual property issue as the single biggest hurdle to membership, and the most recent foray into a university member collaboration ended when intellectual property issues could not be resolved.

From the standpoint of member company sensitive information, the Consortium has maintained the practice of "scrubbing" the data presented. Often data from three or four company sites was combined and presented as a block so that results and lessons learned could be presented without singling out individual companies or their specific sites. Honeywell researchers and staff also collected information about plant shutdowns due to abnormal situations and the costs associated with these shutdowns, but the results were not reported in outside presentations.

Intellectual property issues have also arisen among members, particularly the large petrochemical members. Some members consider their operating procedures to be part of their competitive advantage. This has encouraged individual company funding of projects outside the purview of the ASMC for issues related to abnormal situation management. There have been at least two large-scale project efforts by individual companies working with Honeywell to create intellectual property that has no or only limited sharing with ASMC members.

Many of the organizational practices begun under ATP funding have continued, including the Quarterly Research Meetings (QRMs) and the development of three year plans. Only recently have members begun to question the need for quarterly meetings' lasting the traditional four days. The current three year plan will reduce the number of meetings, decrease the number of days for each meeting and increase reliance on web-based meetings.

In principal, each company representative carries equal weight. This was initiated to prevent undue influence by the larger players such as ExxonMobil. In reality, ExxonMobil continues to be perceived as a leader, partly due to Ken Emigholz's expertise and commitment to this issue, and partly due to the additional sums of research and development funds that ExxonMobil spends with Honeywell directly on situation awareness issues outside the context of the ASMC.

During discussions, particularly about membership, the one-company-one-vote rule has limited the Consortium's growth. Both ASMC petrochemical company members (called user members) and smaller supporting services company members (called associate members) acknowledge the need to increase ASMC membership. However, there is a difference of opinion with regard to how to expand. User members would like to see more associate members in the ASMC and would also like to see more university participation. Associate members would also like to expand membership among user members and universities, but they are committed to limiting membership among associate members to firms with non-competing skills. To date, associate members have effectively blocked adding members who are similar to themselves in service offering.

2.4.3 ASMC leadership

Administrative and technical leadership of ASMC activities has been provided primarily by Honeywell with advisory input from member companies. During the early AMTF days, leadership was seen by non-Honeywell participants as contentious and inconsistent. Several participants believed that the Honeywell staff members assigned to the AMTF were not sufficiently committed. Current members who were also present during those early days noted that leadership seemed to change from meeting to meeting, a fact that reinforced their belief that Honeywell was not as committed as it needed to be to abnormal situation management. A significant value of the ATP project funding was a formalization of organizational structure and leadership.

It is clear that having leaders who brought stability, enthusiasm, and consistency of purpose to the consortium has been a major factor in its success. Ted Cochran (Program Manager), Ian Nimmo (Program Director and chair of the Executive Steering Committee) and Peter Bullemer (Principal Investigator and chair of the Research Subcommittee) are frequently given much of the credit for forming the ASMC and securing ATP funding. Of course, other members contributed time, talent, and information to the effort, but the triumvirate of Cochran-Nimmo-Bullemer formed a core leadership group that successfully launched the ASMC and associated ATP project activities.

Program director responsibilities rested with Ian Nimmo during the ATP days, and later Peter Bullemer became program director. Nimmo and Bullemer eventually left Honeywell and formed small companies. Both remain fiercely committed to abnormal situation management, which is the focus of their individual companies. Both have wished to retain membership in the ASMC, but neither has wanted to compete within the confines of the ASMC. To date, their two companies have not held membership in ASMC concurrently. At present, Nimmo's company has left the Consortium and Bullemer's company has just joined in 2005. Ted Cochran remains a Honeywell employee, but with little or no contact with the ASMC for the past several years.

Kevin Harris became program director of the Consortium in 2001. After Peter Bullemer left, principal investigator duties were held by Dal Vernon Reising until July 2005, when he resigned his Honeywell position to join one of the ASMC associate member firms. At the present time, PI duties are being shared among Honeywell staff until a replacement is found.

The leadership styles of Nimmo, Bullemer, and Harris have differed dramatically. Nimmo was an organizer who was very passionate about the topic area. Bullemer continued this attention to detail, perhaps extending it even further, but brought a strong ability to build communication bridges between participants to the leadership role. Harris, on the other hand, brings an ability to administer with an eye toward flexibility. At the helm today, he is charged with maintaining company buy-in and keeping member companies satisfied with the slow-to-emerge product pace. The balancing act has been difficult at best, and Harris faces a particular challenge going forward with member companies divided on what the future Consor-tium should look like. On the one hand, some members would like to see membership expanded to include more companies and universities, though they have achieved little agreement on the kinds of companies to add. On the other hand, other members wish to retain the close-knit group in the interest of assuring that the knowledge generated by the ASMC remains closely held. This tension continues to play out during discussions at QRMs. Harris is pushing for an expanded membership, perhaps with reduced fees, but to date, members have been able to limit progress in this direction.

Kevin Harris sees his role as that of a coordinator who helps to create overall direction, interacts with Honeywell management in particular, and works with Honeywell's product marketing groups and development organization. Harris is working closely with Honeywell's marketing efforts to introduce the ASMC and its activities to the broader Honeywell Users Group, which includes a wide variety of companies using Honeywell products. Harris also acts as webmaster and has expressed interest in moving the Consortium information away from Lotus Notes, or at least to the current version of Notes, because of Honeywell IT's limited ability to support it.

During ATP funding, Ian Nimmo was the only person funded 100% by the Consortium. As the program director, this gave him the ability to focus on ASMC tasks and needs without needing to balance other Honeywell responsibilities or competing priorities. When ATP funding ended, full-time support for the program director transitioned to half-time. When Peter Bullemer held the program director position, he also participated in research projects, and so his involvement, though reduced on the administrative side, remained high due to the research participation. More recently leadership support has received as little as approxi-mately 30% funding for Kevin Harris and continues to fluctuate. Harris does not participate directly in research projects.

While he was PI, Dal Vernon Reising performed many of the tasks that would have fallen to Harris under previous regimes. Reising ran the research and development activities as chair of the Research Subcommittee but also tracked in-kind contributions and monitored other financials. He was also involved technically in some of the research projects. Harris, Reising and Doug Metzger, the main link to Honeywell product development efforts, talked weekly on conference calls and corresponded via e-mail; the three shared brainstorming and decision-making for many Consortium decisions, with input from the Consortium membership concerning project selection.

Kevin Harris and Dal Vernon Reising were a good fit for leadership roles as the Consortium transitioned from a research focus to a product development and deployment focus. Though research remains a priority, the emphasis is on getting the findings into products that can be adopted by industry operators. From a leadership perspective, both Harris and Reising were more tightly tied to product development and marketing, as evidenced by Harris' interactions with the Honeywell Users Group and with the joint discussions between Harris, Reising and Metzger to promote ASMC knowledge integration into Honeywell products and solutions. With Reising's departure in mid-2005, the impact of principal investigator duties shared among several Honeywell staff is yet to be determined.

Leadership has also come from member companies, albeit less formally. Company representatives to the ASMC have provided stability over time; several of the original company representatives still sit at the ASMC table. This consistency of both member companies and their representatives has helped the Consortium retain its collective history and has strengthened the Consortium's ability to continue post-ATP funding. Individual company representatives brought with them both a professional commitment as their company's representative and a personal commitment to the importance of managing and reducing abnormal situations. This has been particularly important in recent years as the churn-rate of company managers who make decisions about funding allocations, including fees to the Consortium, has increased.

2.4.4 Influence of Consortium members as assessed by social network analysis

There are many ways that Consortium members might exhibit influence or leadership within the various activities. The previous section discussed administrative leadership specifically. Another important aspect, however, is the ability of one or more participants to actively influence the interactions of other members. This influence might arise from access to unique information, the ability to create linkages between other members, or the ability to interact with a large number of members. Social network analysis (Scott, 2000) is one way to assess this influence, reflecting the relationship structure that various participants have with each other as evidenced by some output. Here we focus our attention on the publication history within the Consortium. Expanded data analysis is included in Appendix B.

Two limitations to using publication history must be noted. First, publication record has its own drawbacks as a measure of collaboration and influence since it doesn't reflect collaboration that occurred in other forms that were less visible or traceable, such as project participation. Detailed project participation was unavailable either as a permanent record or anecdotally as a historical description. Another difficulty with analysis of publication history is that not all companies equally support publication; some prefer to retain lessons learned for their own proprietary advantage. This may result in the under-representation of some ASMC members and participants compared to others.

To be able to have enough data to examine network structures over time, given the relatively small dataset of 40 authors who contributed to 29 articles posted on the website, we split the Consortium's history into two phases – the "Research Period" or time between ASMC founding and 1999, when research was more heavily emphasized, and the "Development Period" or time from 2000 and beyond, when product development and deployment were more heavily emphasized. Forty-percent of the authors (16 out of 40) published 21 articles during the "Research Period" and of these, plus some additional authors, 30 published 16 articles during the "Development Period." After creating an author-by-author matrix where the strength of each dyadic relationship (the value in each cell) was represented by the number of publications in which the dyad shared co-authorship, we evaluated the pattern of relationships using Ucinet software. Co-authorship has been studied recently (Borgatti, Everett and Freeman, 2002) as a way of examining, for example, the informal 'invisible colleges' that scholars create.

Our findings suggest that the Consortium's "Research Period" was structured by almost twice the level of organizational centrality as its "Development Period" (~19% compared to ~10%). Organizational centrality is a measure that reflects the density of relationship patterns. Statistics also illustrate that the "Research Period" was far less diverse than the "Development Period" by a factor of almost 1 to 4, respectively.

The ASMC relationship between the structure of its co-authorship and the type of work emphasized is consistent with prior research (Echols and Tsai, 2005). We focus on two specific findings.

1. The Consortium's network structure was more hierarchical and dense when basic knowledge was being created that required depth, triangulation, and shared norms to facilitate enrichment. During this basic knowledge creation period, leadership to create shared goals and objectives was particularly important.
2. The Consortium's network structure was flatter and more sparse when applied knowledge was being created that required sharing across different boundaries, where brokering, referrals and control played a greater role in outcomes. Here, as transition to products required more intraorganizational contact within Honeywell, and more interorganizational contact between Honeywell and ASMC member companies, a focused leadership effort was less evident. In this period, extensive prototype and company site testing broadened the network of participants involved in ASMC activities.

As far as specific actors are concerned, we found that the majority of control, access to others and information was held by Cochran, Bullemer, and Nimmo (respectively) during the "Research Period," and held by Bullemer and Aradhye (respectively) during the "Development Period." Milner was also a significant actor during the "Research Period" in terms of having unique access to information, control and/or referrals, but his publication activity was not significant enough for him to be considered a key member at that time. On the flip side, Guerlain was considered a part of the "Development Period's" key knowledge group, but because of her redundancy with Bullemer, she was not privy to unique information, control and/or referrals.

Of the six actors who published articles during both the "Research" and the "Development" periods (Emigholz, Nimmo, Miller, Guerlain, and Jamieson), only Bullemer brokered new relationships with co-authors. The other five remained inclusive in their networks of co-authors or published alone. Based on our analysis of publication history, Bullemer is the only person who served to connect or link the "Research Period" with the "Development Period" in the Consortium's history. His pivotal role deserves attention, yet is sensitive to the delineation between periods and our analytical focus on publication patterns.

In sum, network analysis enables us to better understand how the structure of relationships among people can help or hinder the organization's culture (namely through ways in which different network structures impact the type and depth of communication displayed, degree of efficiency sought, and/or level of status, hierarchy, and control for which members vie). We temper our claim concerning the apparent influence Bullemer exerted since it is based only on an analysis of publication history. However, anecdotal interview comments suggest that his influence did, in fact, reach beyond the publication record.

Based on publication history, multiple leadership roles, and anecdotal examples provided by ASMC members, it appears that Bullemer was a major linchpin and served as a consistent thread connecting ASMC over its history. Further insight is needed to determine whether his ability to take on this network position reflected his personal style (e.g., he sought certain networking roles and opportunities to publish with certain others to create a certain structure at a certain time), his job responsibility (e.g., his role in the consortium required that he behave the way he did), or some combination of the two. In terms of designing future consortia, we still must ask which matters most: To choose the right person who will naturally behave the right way under certain circumstances, or to develop the right job description?

2.5 Post ATP activities

2.5.1 Transition of research results to products

As the ATP funding concluded, the ASMC members unanimously agreed on the need to continue their collaboration and the pursuit of solutions to the abnormal situation management problem. Going forward, members intended to pursue approaches, technologies, and knowledge focused on three areas: abnormality diagnosis and warning, procedural operations, and assessing and learning from experiences. One of the early participants noted that the Consortium has not been able to repeat the rigor with which research was conducted under the ATP program. He noted that the ATP program forced the group to do research and helped it to define and carry out a carefully crafted work plan. The amount of planning that went into those early activities has diminished over time, as has the rigor of idea generation. This same person also noted that the three-year plan, though useful, is not as carefully put together as the early portfolio of projects. He indicated that the preparation for discussions of possible projects is limited. This may be due, in part, to the dramatic reduction in funding since the ASMC transitioned to all-private support. Although the three-year planning cycle and decision making practices remained consistent, the number of possible projects has declined and interest levels among some members seem to have taken a similar decline.

In 2001 the ASMC unanimously agreed to continue in the 2002–2005 program with increased emphasis on product development. To that end, Honeywell assigned control of part of its engineering development docket to the Consortium. Several products meeting the "Designed for ASM" criteria were released, and increasing emphasis was placed on open solutions using OPC (Object linking and embedding for Process Control). The OPC Foundation has established guidelines for data connectivity and sharing in automation and control that have become an industry standard for software development.

For the 2002–2005 program, the Consortium members wanted to achieve visible results each year of the program. Development was primarily centered on existing Honeywell products and their implementation and members wanted to further the mission of the Consortium by converting ASM knowledge into practice. Kevin Harris noted that Honeywell's own migration from the TDC/TPS flagship system to the newer Experion system during this same time period strained Honeywell's development resources. This meant that Honeywell development resources had to be stretched to continue reasonable improvement to the old system, while at the same time major missing features were added to the new system. This reduced the funding available for ASM other than the commitment to the ASMC. Without the system transition, Honeywell would have invested much more in this area, and progress would have been faster.

During the life of the Consortium, activities have transitioned from basic research to applied research, development, and most recently to existing and new Honeywell products. Consortium members have been increasingly vocal in their disappointment with the productivity of Consortium activities. Within the last year, members have begun to stress the need to see results and quantifiable benefits. One member, Nova Chemicals, declined to renew its membership in 2005 due to a lack of results. As the Consortium has transitioned to a deployment state, fewer resources are devoted to the early stage research that was the hallmark of the ATP-funded activities, though Honeywell does maintain two product developers targeted to ASM research needs.

Honeywell still views the Consortium as very important to getting ASM-related issues into products and into practice. Members, on the other hand, are beginning to see some of the activities supported by membership fees as tasks that Honeywell should increasingly do since the main benefit is related to Honeywell marketing and product development. At least for the current three-year cycle, the members appear willing to tolerate this tension and continue their collaboration.

The funding of projects within and outside the Consortium – between Honeywell and an individual member company – has been inconsistent across the life of the Consortium. For example, both ExxonMobil and Shell have undertaken projects outside the scope of the ASMC that are related to, but separate from, ASMC activities. Such pursuit of company-specific product development has created some distrust within the Consortium. Company-sponsored projects leading to products have yet to be shared with the Consortium at large. At present, there is a perception among several members that at least one of the projects being funded separately by an individual company has put that company ahead of the rest of the Consortium members by almost five years. As noted earlier, the equitable sharing of results and knowledge within the Consortium continues to be a bone of contention.

This has led more than one ASMC member to grumble about the importance of sharing and the apparent decline of open sharing since ATP funding ended. However, the view of declining information sharing has been explained by another member as the result not so much of a reduction in sharing as of a more project-centric approach. ASMC projects tend to be tightly aligned to individual member interests in the post-ATP years.

Products that come from ASMC are small relative to the overall cost of a Honeywell control system solution. A customer who is concerned about abnormal situation management might be more likely to buy Honeywell products since the tools are integrated into it. However, these tools can also increasingly sit atop or within other vendor systems with the wider adoption of the industry standard OPC interface, which promotes interoperability across systems. In addition, other vendor tools can be integrated into the Honeywell product solution. This mix and match approach to control system creation blurs the boundaries between knowledge that is unique to ASMC members and knowledge that non-ASMC members can purchase through products.

Products resulting from the ASMC range from alarm and event analysis tools to alarm configuration tools, procedural operations, and automation, executing, and tracking tools. The original approach proposed to ATP was to create unique modules targeted to specific purposes or tasks; that has continued forward. Based on ASMC activities, there are several products that can be traced in whole, or in part, back to the Consortium:

- GUS Pro
- Pro Trends
- User Alert
- Event Analyst
- Alarm & Event Analysis (AEA)
- Alarm Configuration Manager (ACM)
- Asset Manager
- Procedural Operations
- Intela Trac

- Early Event Detection (EED)
- ShadowPlant
- Alarm Management Services
- ASM Graphics Building Services

The product applications of ASMC-generated knowledge are difficult to identify, however, since product names and/or packaging has changed over time, and many of the tools have been deployed on both the older Honeywell TDC/TPS system as well as on the newer Experion system (sometimes under different names). Also, there have been significant enhancements to some of these tools without name changes, further distorting the product application of ASMC knowledge.

It should be noted that ASMC was (and continues to be) intended to generate both knowledge and tools. To date, transition to tools has been inconsistent. While members disagree with the pace of adoptable product outputs, all agree that the knowledge generated has been worthwhile. As previously noted, however, the ability of a company to gain competitive advantage from the knowledge generated by ASMC requires a strategic implementation of this knowledge across sites, with sites having the requisite in-house expertise to fully translate that knowledge into routine practices.

At the time of this writing, there are about 120 operating plant systems that are equipped with Alarm Configuration Management (ACM), one of the products arising from ASMC activities. The purchasing companies reflect a mix of the petrochemical industry and include both Consortium and non-Consortium companies. ACM enables the operator to suppress alarms and then to easily reenable them when the equipment comes back on line. It also knows the intended operational state and will check to see if the alarms are set in something other than their normal state. This latter capability is very powerful, especially at shift handover. It prevents alarms from being accidentally disabled and helps the next shift receive crucial operations information. ExxonMobil has purchased more than double the number of ACM products purchased by anyone else in the Consortium.

2.5.2 Post ATP project funding

Currently, projects funded as research (and communications) are funded approximately two-thirds by Honeywell and one-third by membership fees. The deliverables of these projects are available to all members to use directly. For example, a member company could apply a display design guidelines document to one or more of its console upgrade projects. Honeywell is contractually obligated to commit two full-time equivalents (FTEs) to ASMC related research and one FTE to Consortium management, about half of which is centered around managing the research itself.

Activities funded as development are financed entirely by Honeywell Process Solutions internal development (i.e., product developer labor hours). The intellectual property developed from these projects resides completely within Honeywell. The company is contractually committed to at least four FTEs of product developer hours above and beyond any ASM developments that Honeywell might choose to pursue on its own.

The process for selecting R&D activities is improving, with greater emphasis on development and deployment in later years. The Consortium has continued a numerical prioritization of projects by which member companies vote high, medium and low scores for individual projects, with higher scoring projects ranked higher than lower scoring projects. This process serves the Consortium well but is limited in that it is not more closely aligned, time-wise, to the member company budgeting calendar. This makes leveraging member company internal docketing of resources difficult for the Consortium. To address this, more emphasis has been placed on preliminary prioritization at the summer QRM.

The current timetable for selecting both research and development projects begins at the Summer QRM (June-July) when ASMC takes input from members and people in the Consortium about possible interests. The input is summarized and Honeywell staff (and others) develop proposals to meet these project requests. These proposals are sent to members prior to the October meeting. During the October QRM, decisions are made about the specific allocations. Projects cannot be listed for October decision-making without a member company sponsor. This ensures that there will be a company champion, a particularly important point when company site participation is required to complete the project.

Prior to the October meeting, Honeywell has done some assessment of those projects that are aligned with its own corporate strategy and interests. During the October meeting everyone participates in the discussion of proposed projects, but only user members vote for specific projects.

2.5.3 Marketing the ASMC

Several attempts were made to market ASMC activities over its history. For example, at one point the Consortium had a commitment from a publisher to produce a book from Consortium activities, with Ian Nimmo as the main editor. The purpose of the book was to share ASM information with the outside world. Six chapters were completed, but the book languished after that and was never completed.

The Consortium also attempted a video, the original intent of which was to advertise the ASMC within member companies to better educate member company staff about abnormal situations and the role the ASMC had in addressing this critical operations issue. Educating member company employees about ASMC has been and continues to be a major hurdle for adoption of products and practices within member companies. Many of the member companies are so large that the single company representative is insufficient to "get the message out" within the entire company. The video was intended to be an effective way to better educate company staff. A professional film crew was supposed to interview each of the members and get testimonials for inclusion in the video. This never happened, in part due to internal politics within several companies. Members agree that getting ASMC information into practice within their companies is difficult, and several have noted that beyond a select few internal company staff, their company employees-at-large don't know about the ASMC. ExxonMobil seems to be the exception to this, however, as it has aggressively promoted the existence of ASMC and its purpose throughout its organization.

More recently, the ASMC Communications Subcommittee has started putting on Webinars as a way to spread knowledge more widely. Each webinar lasts one to two hours and is focused on very specific topics, such as best practices in alarm management, or design of control rooms. All employees throughout member companies may attend the webinar, see the slides, hear the speaker, and interact with the speaker verbally or by texting. The presentation material is available on the ASMC web site, as is an audio-visual recording of each entire webinar. This is particularly useful for those unable to attend live, or for those who wish to go back and review topics of interest.

The ASMC has had considerable exposure to the professional industry at large with five cover stories in Chemical Engineering Progress, for example. Kevin Harris has also achieved moderate success in having ASMC materials and information included in marketing efforts and other Honeywell user meeting forums, and has addressed the past three Honeywell Users Group Annual Meetings.

2.6 Membership & member commitment

The ASMC began with a core group of members. This core group believed in the urgency of the problem and contributed their time and company resources. Table C1 in the Appendix presents the members for the early ASMC activities at the ATP proposal stage, and contrasts them with the 2005 membership.

The notion of membership and member commitment is quite interesting and presents both one of the most positive factors in early success, and one of the most limiting factors in continued Consortium longevity going forward from today. Early members have invested time and resources into this activity, and several believe that they don't want to "give away their hard-won knowledge" to newer members who have not paid as much. Early commitment provided both financial and in-kind resources for the ASMC.

Intellectual property ownership policy discourages new researchers, particularly universities, from joining the Consortium. User members believe this is a critical limitation and that a lack of new ideas is a major detractor from current satisfaction levels. Without a new source of ideas, membership may be less inclined to continue participating at the same levels as in the past.

Historically, the Consortium has four classifications of members. Membership fees are established with each three year program. Table C2 in the Appendix summarizes the current membership structure and fees. It must be noted that the 2005–2008 plan includes increased flexibility in membership initiation fees and sliding scales based on revenues for user members have been discussed. Both are intended to encourage membership.

User members are the large petrochemical companies that are Honeywell customers. They join the Consortium to better understand problems and to get solutions. Associate members, on the other hand, are generally smaller companies that produce products and want to understand what they can market to fill user members' needs related to abnormal situation management. Based on the scale of revenue, the company size and the ASMC fees, associate members make a larger commitment to the ASMC in terms of fees and the time commitment of the company representative to attend meetings and participate in-kind.

Some within the Consortium have suggested that associate members fill a gap in user member companies. In the course of the past several years, many of the user member companies have downsized their engineering staffs, which has created a knowledge gap in the area of abnormal situation management. Associate members tend to focus on filling this gap and providing valuable consulting services. Linkages between user members and associate members are not only through the ASMC, however, as both associate and user members use a multi-company suite of products, some beyond the commercial interests of Honeywell.

Membership fees have been evolving but remain a barrier to new member entry. Existing members are divided on their willingness to open the ASMC to new members, particularly at reduced membership rates and initiation fees. Honeywell believes that in order to be sustainable into the future, ASMC must continue to incorporate new members.

2.7 Member opinions

In addition to individual interviews, the Penn State team developed several brief surveys to try to capture member opinions. These surveys included questions about goals and objectives of the members and their companies regarding ASMC participation, benefits to ASMC membership, networking activities among members, and assessment of personal commitment of the member company representatives. All surveys were completed during the quarterly review meetings since members hesitated to commit additional time to the current study beyond the review meetings that they already attend. The surveys are included in Appendix D. No single survey had more than 13 respondents, and several of the surveys had fewer than 10 respondents in total returned. It should also be noted that nearly half of all surveys returned came from Honeywell staff. This is consistent with the attendance at quarterly review meetings, which have been dominated by Honeywell staff at a ratio of nearly 2:1 compared with member attendance. Due to the low number of surveys returned, statistical analysis is not possible. Also due to low numbers, we chose to summarize the results in this section rather than present any raw data.

2.7.1 Goals & objectives

Results of questions relating to the goal congruence between the ASMC and individual member companies suggest that there is a relatively good perceived fit. The results suggest that ASMC safety goals align with individual company goals, that the ASMC and its member companies share the same philosophy regarding abnormal situation control, and that they share the same definition of what constitutes an abnormal situation. In addition, member companies are involved in and can influence the research strategy and agenda. Not all companies, however, focus on the same things as outputs from the Consortium. The petro-chemical companies appear nearly equally divided between their preferences for knowledge versus their preference for products. Although there is a good fit of goals, member companies are divided in their belief that their company's agenda influences the ASMC agenda.

Petrochemical companies joined ASMC to achieve a multi-company view of the problem and to combine their effort with others to leverage knowledge. They also hoped to influence Honeywell directions. Many of these same companies remain today for those same reasons.

2.7.2 Perceived company benefits

Members were asked to consider their benefits to company participation in the ASMC in terms of dollar gains, cost savings and qualitative gains. In general Honeywell perceives its benefits to be improved products and services through better customer input and communication. The large petrochemical companies believe they receive benefits in two primary ways: first, through direct influence in Honeywell product features, and second, through the sharing of guidelines and best practices among ASMC members. Associate members find benefits that are marketing-related, focusing on the ability to help sell services and to anticipate possible product needs. None of the company respondents were able (or willing) to put dollar values on their benefits. This is in keeping with our observations during meetings and during our interviews where members were hesitant to share specific competitive information.

2.7.3 Member networking

Members tend to network with one another actively during quarterly review meetings, but much less frequently in between meetings. Our results suggest that members do have contact with one another, but the contact is more likely to be between the petrochemical companies and the associate members rather than among petrochemical members. Contact between members is inconsistent, however, with some members working more closely together than others. Contact between members outside the ASMC is circumscribed to problem-solving and has no relationship to business decisions outside the scope of abnormal situation management. This is consistent with our observations during interviews, wherein user and associate members discussed interactions, but interactions among the petrochemical companies was rather limited.

2.7.4 Member company commitment & knowledge of ASMC activities

ASMC company representatives are not the only company members that participate in ASMC projects, and most member companies do not send the same representative to every meeting. Results also suggest that company representatives share meeting information with their immediate supervisors, but that distribution beyond that is limited. There is some concern among various members of the Consortium that the specific member representatives are inadequate for full product penetration into member companies across multiple sites. Recent discussions within the quarterly review meetings to include operations personnel from member companies point to the acknowledged need and desire to expand understanding of ASM practices to broader company activities.

Responses also suggest that companies assign consortium representatives based more on knowledge of and experience with abnormal situations than on time availability. This tends to favor member representatives who have the requisite knowledge to understand and participate in ASMC discussions, but who may also be very busy with other company-based responsibilities. This fits with our observation that during quarterly review meetings there have been multiple individuals representing some of the companies over the life of the Penn State study.

We note that only two member company representatives have participated in other consortia. This reflects a relatively parochial knowledge of external formal collaborative relationships. Studies have shown that member experience with successful external collaboration programs encourages them to pursue increasingly focused and beneficial future collaborations. The limited experience of members may encourage them to be more internally focused.

The responses suggests that company representatives believe their companies are almost as committed to the Consortium now as they were during the ATP funding period. Results also suggest that information gained through the Consortium has helped the member companies recognize critical situations faster, improved situation awareness and reduced the number of situations that turn critical. Our interviews also included anecdotal information that suggests that some member companies are better able to incorporate ASMC findings into their normal plant operations.

2.7.5 Company representative's personal commitment

The Penn State team also asked company representatives about their personal commitment to the ASMC. The results suggest that the ASMC representative's role in their organization is more important to them than their role in the Consortium. Not surprisingly, they are more committed to their role in their home organization than to the Consortium. It also appears that, in general, what goes on in the Consortium does not affect the representative's career within his or her own company. This generalization is not consistent across all members, however. At least one member representative noted that his career has been adversely affected by participating in the ASMC at the expense of other things he might have done. He maintains that his personal commitment to abnormal situation management was a more important motivating factor. Conversely, another member representative indicated that his career was greatly promoted by participating in the ASMC, since his company encourages its staff to become recognized experts in a particular field of interest to the company. With such a small sample, however, it is difficult to get beyond anecdotes.

It also appears user and associate members' commitment to the Consortium has waned since the start of the Consortium, whereas Honeywell's commitment has moderately increased over time. These member representatives still appear to be committed to the Consortium, but their commitment is not as strong as when they first joined. This may be the direct result of a shift from research to a development and deployment focus. During the research phase, the tight coupling of member representative interests (most are scientists rather than operations staff) with the project goals and objectives reinforced commitment. Elsewhere in our interviews, we found similar sentiments concerning the declining momentum and rigor since ATP funding ended.

Part III

Consortium Practices

3.1 Overview of consortium practices

Understanding the dynamics of the ASMC requires that we carefully articulate the various forms collaboration might take and that we place ASMC in the context of these various issues. Smilor and Gibson (1991) note, "While consortia vary in organizational structure, technological emphasis, funding mechanisms, and personal make-up, they all share one abiding purpose...the transferring of technology in an efficient and timely manner" (p.3). In this section we review consortium practices in general, and then offer a comparison of ASMC to three other consortia, two of which are still in operation.

3.1.1 Consortium characteristics

A consortium is defined as "two or more companies sharing resources to create a new legal entity in order to conduct cooperative research and development activities" (Olk and Young, 1997, p. 856). Research and development (R&D) consortia emphasize basic or applied research in the early phases of innovation. Advancement of the industry is often the primary goal of a consortium, as much progress can be made when competitors collaborate in the early stages of innovation (Rigatuso, Tachi, Sylvester and Soper, 1997). Two distinguishing features of consortia include members' not being completely detached from their parent companies and changing membership, as some organizations leave and others join (Evan and Olk, 1990).

In the U.S. and Europe, most consortia are funded by both member companies and government resources (Mothe and Quellin, 1999), and many consortia are non-profit organizations (Rigatuso et al., 1997). In a study of 137 U.S. consortia formed between 1984 and 1989, Evan and Olk (1990) reported that the average membership was 13, while the median was five. Specifically, 40 consortia had only two members; 90 had between three and 25 members; and seven had more than 25. The maximum size was 92. The attrition rate of members ranged from six to 24%. Although several consortia limited membership to U. S. citizens, at least 20 had foreign members.

3.1.2 Legal aspects of R&D consortia

In comparison with other collaborative forms, a special feature of R&D consortia is that they allow for competitors to collaborate (Evan and Olk, 1990). Such activity was illegal in the United States until fairly recently, as the legal environment has historically been riskier for firms participating in cooperative R&D agreements than in other countries (e.g., Canada, Japan). In order to promote competition among companies within the same industry, the Sherman Antitrust Act of 1890 made collaborations illegal among competitors. However, rapid technology changes in the 1980s made it unlikely that individual American firms could remain competitive in the semiconductor and electronics industries, causing them to fall behind their counterparts in Japan and Europe. Therefore, the National Cooperative Research Act (NCRA) was passed in 1984 to relax antitrust regulations and allow for the formation of research joint ventures (Brod and Shivakumanr, 1997). To prevent monopolies in the final product market, the NCRA encourages collaborative R&D activities at the pre-competitive level, leading to technology that will be used independently by firms that do not further coordinate production or pricing decisions (Cohen, 1994). Pre-competitive research constitutes experimentation, development or testing of techniques, development of prototypes, and the exchange of research information (Evan and Olk, 1990). Specifically, section 2.6 of the NCRA protects "theoretical analysis, experimentation, or systematic study of phenomena or observable facts, the development or testing of basic engineering techniques, the experimental production and testing of models, prototypes, equipment, materials, and processes, the collection, exchange, and analysis of research information." At the present time, anti-trust legislation has not been used to prosecute any U. S. consortium (Rigatuso et al., 1997). Since 1984, consortia have been formed in a wide variety of industries ranging from telecommunications, microelectronics, semiconductor manufacturing, biotechnology, software engineering, transportation, and petrochemicals, among others.

3.1.3 Consortia compared to joint ventures

There are many types of strategic relationships that can exist between independent firms striving for mutual benefits. A joint venture occurs when two or more legally separate entities invest and engage in various decision making activities to form a jointly owned entity. Joint ventures represent a more traditional form of inter-firm collaboration, while consortia represent newer forms. Consortia generally have more members than joint ventures, many of which only include two member companies. In terms of goals and inputs from members, R&D consortia tend to be more loosely organized than joint ventures. Specifically, joint ventures have more focused goals, whereas consortia have less focused goals. The loose organization of consortia allows for the flexibility to adjust to changes in an industry, whereas a joint venture may have more difficulties adapting (Rigatuso et al., 1997). However, the pre-competitive focus of consortia often makes potential outputs uncertain and increases the difficulty of getting members to agree on specific goals (Evan and Olk, 1990). In addition, because the total budget of a consortium is generally smaller (e.g., $1–2 million, on average), members tend to invest considerably less equity and other inputs as compared with joint ventures. Finally, whereas R&D consortia include direct competitors, most joint ventures do not.

3.1.4 U.S. consortia compared to Japanese consortia

While the U. S. was concerned with anti-trust prosecution during the second half of the twentieth century, Japan was concerned with supporting collaborative R&D; therefore, Japanese consortia have a longer history than do those in the U.S. (Rigatuso et al., 1997). A survey comparing U.S. and Japanese consortia found structural differences, with U.S. consortia being more active in information exchange and using a wider variety of structures and coordination mechanisms (Aldrich and Sasaki, 1994). In addition, U.S. efforts tend to be larger, have more open-ended goals, and conduct more research in a central location (Olk and Young, 1997). The percentage of funding received from the government is 53% in Japan, but only 17% in the U. S., resulting in a heavier reliance on member dues for income (Rigatuso et al., 1997). Because Japanese consortia comprise self-contained research projects, their life-span is shorter than that of their American counterparts, which tend to have ongoing research projects and indefinite time frames (Aldrich and Sasaki, 1995).

3.1.5 Factors affecting the formation of R&D consortia

Both industry and company factors affect the formation of R&D consortia. For example, the degree of competition in an industry will strongly and negatively influence consortia formation, and firms in oligopolistic industries tend to form consortia at a rate greater than those in more competitive industries (Sakakibara, 2002). In addition, firms with superior R&D capabilities and past participation in consortia were more likely to join a Japanese government R&D consortium (Sakakibara, 2002).

A study of 53 successful U.S. consortia found that consortia formed under either emergent or engineered processes (Doz, Olk and Ring, 2000). Under an emergent process, consortia form due to changes in the environment (e.g., new governmental regulations, foreign competition) or the presence of similar interests among potential members. In contrast, engineered processes capture the intervention of a triggering entity such as individual or firm champions that draw attention to the need for collaboration. Whereas emergent processes reflect a bottom-up orientation, engineered processes reflect a top-down orientation. According to Doz et al. (2000), over time consortia that are formed as an engineered process will lead to networks governed by emergent processes which stress common interest and perceived interdependence. They also note that survival of a consortium will depend upon the ability to manage both emergent and engineered formation processes.

In the case of the ASMC, both emergent and engineered formation processes are evident. Clearly, changes in technology that led to alarm management problems and the realization that this problem was industry-wide and not firm-specific (emergent processes) were key triggering factors in heightening awareness of the need for collaboration. However, the formation of the ASMC would not have been possible without the key founding members and Honeywell willing to champion the cause (engineered processes).

Trist (1983) identifies nine phases of R&D collaboration development, which are listed below:

1. Identifying interdependencies,
2. Developing shared norms of problem solving,
3. Triggering cooperation: the need for a focal entity,
4. Selecting participants,
5. Making the shadow of the future visible,
6. Securing the participants' sustained ability to contribute,
7. Designing cooperation,
8. Learning and adjusting over time, and
9. Expanding scope and deepening commitments.

Across these nine phases we find that consortia go through the same general pattern of forming, storming, norming and performing that teams go through (Tuckman, 1965). Namely, consortia must determine how they will work together to identify interdependencies and to address problem-solving practices. In Trist's view, this must happen before the appropriate participants can be brought to the consortium. Once participants are selected, they can collectively develop a vision that highlights their collective goals for the future and then can use these goals to develop sustained financial and in-kind commitments. As part of the consortium's activities, cooperation mechanisms must be established that will direct the actual task accomplishments. Finally, as tasks are completed, learning must be shared over time in both technical and organizational dimensions. Success in getting the right projects undertaken by the right participants should help to expand the commitment of existing participants and perhaps pave the way for new participants as the scope of the consortium expands.

It is interesting to note that the longer a consortium continues, the more likely that a repeat in Trist's cycle might be needed. As scope changes through knowledge creation, and as early problems are solved, the consortium might again revisit its initial assumptions. This, in turn, might alter the future goals and participants.

3.1.6 Consortia outcomes

According to Moethe and Quelin (1999), consortium results can be divided into three primary categories:

1. Visible final results (product and/or process improvement and/or development),
2. Intermediary results (prototypes, norms, licenses, publications), and
3. Indirect intangible results (know-how, technological competence).

In a study of 317 industrial partners of the European EUREKA (Europe-wide, inter-governmental initiative for industrially-oriented) Consortium, the creation of a new prototype was the most common tangible result, followed by improvement in existing products and production of new products. EUREKA was formed in 1985 to support R&D with a goal of increasing the competitiveness of European industries. One of the largest issues for R&D consortia is knowledge or technology transfer between companies (Rigatuso et al., 1997). In a study of 16 firms involved with the EUREKA Consortium, Moethe and Quelin (1999) found that companies with more in-house resources and already strong research activity were better able to exploit the results garnered through consortium R&D. This is very similar to our interview results in the ASMC.

3.2 Motives for participating in consortia

Motivations to join consortia include the following (Moethe and Quelin, 2001; Rigatuso et al., 1997; Sakakibara, 1997):

- Share complementary knowledge by creating working ties with other companies in the field,
- Gain access to new knowledge and know-how,
- Eliminate wasteful duplication of R&D efforts,
- Improve efficiency by coordinating individual projects and by disseminating knowledge,
- Shorten research time as compared with individual companies setting up their own research efforts from scratch,
- Share and reduce the costs, risks, and uncertainties of R&D among participants;
- Leverage research dollars, and
- Enhance innovative productivity.

Because it is difficult to determine the tangible direct outputs of R&D collaboration, significant advantages, rather than hard outcomes, are inherent in the cooperation (Rigatuso et al., 1997). For example, in the EUREKA Consortium study, the sharing of complementary knowledge and access to new knowledge was the most significant goal for partners. Similarly, whereas firms perceived gaining access to complementary knowledge as the most important and pervasive objective, sharing fixed costs was one of the least important objectives in a study of 237 Japanese government-sponsored R&D consortia in the early stages of R&D (Sakakibara, 1997). In contrasting two primary motivations for joining a consortium, Sakakibara (1997) found that the relative importance of a cost-sharing motive increases with homogeneous participant capabilities or projects that are large, while the relative importance of a skill-sharing motive increases with heterogeneous participant capabilities.

3.3 Intra-consortium conflict

A study of 137 consortia by Evan and Olk (1990) revealed seven managerial problems that require experienced and capable leadership to address. Given the generic nature of these issues, they predict that "each consortium will experience a range of intra-consortium conflicts because of equity problems" (p.44). Consistent with their expectations, the ASMC has grappled with all of these problems in one form or another throughout its tenure. Therefore, despite being 15 years old, the research by Evan and Olk (1990) is still relevant to the study of the ASMC today. Each concern is discussed in turn.

3.3.1 Recruiting personnel from member companies and outside sources

Boundary spanners between member companies and a consortium are critical for communicating the progress of the consortium and transferring technology. Indeed, consortium member representatives are responsible not only for representing their companies' interests in the consortium but also for informing their companies of progress in the consortium. In the ASMC, the size of member companies has created problems for both types of representation. For example, some user member companies are so large that the consortium representative reflects only a small part of the company. In addition, many parts of member companies are not familiar with the work of the ASMC. ExxonMobil provided a "best practice" model of how to market the ASMC widely throughout its entire operation, but most other members never achieved that level of exposure. Early on, a video project was started to advertise the ASMC within user companies and document collective achievements, but it was never completed due to politics.

A tool for recruiting outside sources has been publications in outlets such as Chemical Engineering Progress (five cover stories), which have provided good exposure to outside sources for the ASMC. While some members have bemoaned many lost opportunities over the years to market the consortium and to make information publicly available (e.g., operating display guidelines), others have held fast to the contention that consortium information is part of their competitive advantage that should not be released to the public domain.

3.3.2 Obtaining resources

One of the conclusions reached by Evan and Olk (1990) was that active involvement of members was crucial to consortium success because it maximized outcomes for both member companies and the consortium itself. Two types of involvement include financial investment in the consortium and participation in organizational roles (e.g., management, being in charge of development). The EUREKA Consortium study found that, with regard to the creation of resources, organizational involvement through being a project leader was as important as financial involvement (Moethe and Quelin, 1999). Apprehensions over contributing initiation fees, annual dues, and technical expertise may result from the risky nature of projects, the lack of company resources, or the fear of sharing information that will be beneficial to a competitor.

3.3.3 Recruiting new members

Future consortium growth is dependent upon maintaining current membership and recruiting new members. Within ASMC, membership and its possible direction of growth continue to face varying opinions. Honeywell would like to see expanded membership, as would some members. Others fear that new members will dilute the focus on abnormal situations in the petrochemical industry (if these new members come from other industry sectors) or might be in direct competition with some of the associate member company activities. Because members do not have a common vision about how the consortium might grow, there has been only limited recruiting success, and thus limited growth.

3.3.4 Decision making

While there is no agreed upon way to make decisions across consortia, inputs are encouraged from all members, but favor those that have a greater investment in the consortium or a direct interest in the decision. Decision making procedures that allow for member input but still permit quick consensus are ideal.

For most issues in the ASMC, each company representative carries equal weight in decision making and has a vote. This was initiated to eliminate undue influence by the larger players, although varying levels of influence can be seen in deliberations. In ASMC project funding decisions, all members participate in the discussion, but only user member companies (petrochemical companies) vote.

3.3.5 Legal issues

Consortia must constantly look into their activities to ensure compliance with the law. In the ASMC, legal issues have been periodically re-examined, and Honeywell's in-house legal counsel has been consulted to check into the potential for antitrust violations. ExxonMobil's, Chevron's and other members' legal counsels have been involved in ASMC policy making or review at times.

3.3.6 Membership turnover

Membership turnover represents a loss of resources for a consortium, especially if new members are slow to be added. Internal and external factors comprise two main categories of reasons explaining why companies leave consortia. Dissatisfaction with consortia direction, productivity, or the high price of membership are examples of internal factors, whereas a change in corporate strategy that affects the attractiveness of membership is an example of an external factor.

The ASMC has experienced remarkable stability in its membership over the years, with many early members and their representatives still active today. However, multiple company mergers (e.g., Exxon and Mobil; Chevron and Texaco) have reduced two sets of fees and two sets of work commitments to one. Consortium fees have been halved purely because of mergers.

3.4 Comparison of consortia

3.4.1 Comparison approach

Comparing ASMC with well-known high-technology consortia such as the McMaster Advanced Control Consortium (MACC), the Microelectronics and Computer Technology Corporation (MCC), and the Semiconductor Manufacturing Technology (SEMATECH) Consortium allows insights to emerge from relative judgments, points of reference, and contrasts that can illuminate organizational attributes that might otherwise go unnoticed.

In addition to extensive work with ASMC, we are fortunate to have been able to attend meetings of the McMaster Advanced Control Consortium. We have also read Gibson and Rogers' (1994) historical documentation of a groundbreaking consortium used as a model for newly emerging consortia: the Microelectronics and Computer Technology Corporation, and have read existing case studies and literature about SEMATECH. The three additional consortia provide anchors to explore:

1. A related industry consortium with similar longevity and focus (MACC continues to thrive);
2. An unrelated consortium from a topical perspective, but one that has had extensive examination regarding governance and other issues (MCC had a limited life from 1982 to 1993); and
3. A hybrid consortium that has both related and unrelated comparisons to ASMC (SEMATECH is still in existence).

3.4.2 McMaster University Advanced Control Consortium (MACC)

This consortium has a very diverse group of members, including petrochemical and chemical companies, pharmaceuticals, consumer products, and others. The unifying theme is that all are process intensive industries that rely on some form of automatic control, optimization, and statistical analysis to evaluate, monitor and control their plant operations. Companies include both batch and continuous processing. Unlike ASMC which focuses on an industry sector, MACC's process control focus crosses multiple industries. This increases sharing among members and heightens the information shared at meetings.

MACC has been in existence since 1988. Unlike ASMC, MACC is a university-based consortium, focused on research and proof-of-concept demonstrations, with only limited interest in subsequent commercialization. To achieve these goals in some projects, MACC develops software code that can be downloaded by members and installed in the context of whatever control system the member site is using. MACC also emphasizes state of the art computational and analytical techniques. As such MACC seeks to push the envelope of process control, with only limited attention to development and deployment as embedded products. Interestingly, MACC has been highly successful in deploying its solutions since the member companies integrate solutions within existing company operating frameworks.

Part of MACC research focuses on event detection and developing statistical projection methods to anticipate abnormal situations. In this, its focus is more proactive than reactive, a feature that distinguishes its activities from those of ASMC to date. Membership in MACC is encouraged for companies that possess the in-house capabilities to actually integrate MACC software and solutions into company operations. Most MACC company representatives have a strong statistical background. MACC has sought to focus on lead companies that can use its research outputs rather than companies that are not in a position to assimilate and deploy results. Thus, technology development is the emphasis, not product development.

Technology transfer to member companies occurs in several ways and is focused on getting the tools into the hands of users as quickly as possible. Because of this, MACC releases new and updated codes for particular applications and highlights methods to apply existing and emerging software. Its efforts also focus on extensive sharing at two member workshops that tend to focus more on process developments and applications presentations and less on the cost-sharing and business aspects when compared to the ASMC meetings. Administrative meetings are held annually in conjunction with one of the yearly workshops. Interestingly, MACC considers its students to be one of its major outputs and schedules time during the workshops for students to present posters of the research projects they have been working on as part of MACC activities. Finally, short courses are offered on topics of interest, and the consortium also conducts company-based problem-solving and consultation.

There is a public website and a member website. On the members-only website, companies can download software code, papers, and other information. Members receive an annual report that summarizes every project. During the meeting, sharing is encouraged, but it must be noted that during actual meetings, very little is written down and powerpoint slides for presentations by member companies are not distributed to members during the meeting or posted to the website later on. Members commented that this lack of formal written capture of presentations and discussions facilitates discussion and reduces the hesitancy of member companies to discuss problems and solutions. In addition, member heterogeneity promotes member company sharing. For example, non-competing consortium members such as Kodak (a camera and imaging company), Tembec (an integrated forest products company), and Dofasco (a steel manufacturing company) often share experiences openly in presentations and discussions.

MACC membership is $21,000 (Canadian; $18,225 USD) per year for three year periods. Most members have been participating for many years, and three of the original five companies are still members.

3.4.3 Microelectronics and Computer Technology Corporation (MCC)

MCC was the first private-sector, for-profit high technology consortium in the U.S. Created from scratch with no organization of its type to benchmark, MCC's decision-makers considered it an experiment with the goal of promoting technological leadership in electronics. MCC was launched in February 1982 and legally incorporated 6 months later without any government funding assistance. During its existence, MCC generated over $500 million from member-company funds and achieved its mission: to keep the U.S computer industry from being overtaken by the Japanese (Gibson, Kehoe and Lee, 1994).

Over its history, MCC was awarded 117 patents and also made legislative achievements, such as encouraging the passage of the National Cooperative Research Act (NCRA) in 1984, under which more than 350 U.S.-based R&D consortia have registered, among which is ASMC. As MCC transformed over its life-span, it shifted from providing highly leveraged support to long-term, goal-directed research and then to shorter-term, company-directed projects with greater emphasis on entrepreneurial developments and fostering spin-outs. MCC's first decade of experience teaches us about the barriers and facilitators that exist in achieving successful commercial applications from R&D that is produced in a consortium.

3.4.4 SEMATECH

Like MCC, SEMATECH's impetus was the U.S. semiconductor industry's startling realization that the Japanese had surpassed the U.S. The Semiconductor Industry Association (SIA) heightened the sense of urgency in the microelectronics industry and recommended that the

U.S. response required the creation of a non-profit industrial consortium that concentrated on research as opposed to manufacturing. The SIA committee formed to create this new organization and soon became the consortium itself: the Semiconductor Manufacturing Technology Consortium, or SEMATECH. These 13 charter members accounted for approximately 80 percent of the total U.S. semiconductor industry in 1987 (Browning, Beyer and Shelter, 1995). Interestingly, SEMATECH formed and continues today in the context of a highly competitive industry. Its existence has encouraged cooperation throughout the semiconductor industy. The consortia pursued three strategies to help improve the competitiveness of the U.S. seminconductor industry: (1) improved industry infrastructure, particularly equipment and materials suppliers; (2) improved manufacturing processes; and (3) improved factory management (Browning, et al., 1995).

SEMATECH received both government and industry funds. Fifty percent of SEMATECH's $200 million annual budget for its initial five year period came from the federal government and the rest was matched by member firms with dues set at 1% of a company's semiconductor sales with a minimum of $1 million and a maximum of $15 million. This high dues threshold has resulted in SEMATECH's membership being the same today as it was when founded (Rigatuso, Tachi, Sylvester and Soper, 1997). Instead of conducting research at member firms, SEMATECH opted to follow what MCC did: it built facilities located in Austin, Texas.

In an effort to find a charismatic CEO who could champion the cause with industry-wide respect and a strong vision, SEMATECH searched an entire year for its first CEO, Bob Noyce, founder of Intel (Browning et al., 1995). Minimal hierarchical levels were instilled in SEMATECH's organizational structure, and SEMATECH was able to modify its goals and adapt over time to meet members' needs. SEMATECH has been considered successful by many (Rigatuso et al., 1997) as it advanced models and knowledge such as enabling one Equipment Improvement Project (EIP) to improve the mean operating time between break-down of a chemical vapor deposition (CVD) tool from 75 hours to several hundred hours. SEMATECH's applied research agenda complements MCC's mission as well as the Semi-conductor Research Corporation's (SRC) agenda, which focuses on very basic research and emphasizes industry-academic collaboration (Rigatuso et al., 1997). SEMATECH's history appears on its website: http://www.sematech.org/corporate/timeline.htm.

3.4.5 Implications of similarities and differences for the design of a consortium

Appendix E summarizes the four consortia using common criteria for understanding organizational design and structural issues germane to emerging consortia. Here we reflect on these similarities and differences and their implications for the design of consortia.

3.4.5.1 Organizational structure and impetus

With the exception of MACC, the other three consortia evaluated experienced early disorder and ambiguity. With the ASMC, order was instituted during the preparation of the ATP proposal and subsequent formalization under ATP funding. MACC, on the other hand, started with a small homogeneous group and built the consortium through member consensus.

As a result, for SEMATECH and MCC, mixed conceptions of the consortium's culture emerged, as members joined from myriad locations and backgrounds with the attitude, "Time is precious, and we've got to tackle this crisis now!" Such mindsets and time-pressures reduce incentives to spend time on "soft-stuff," like talking about and working together to create a satisfying organizational culture that will positively sustain motivation toward the end goal over the long-term.

Members who join a consortium under such ambiguity, although intellectually accepting the fact that continuous change is in process, often forget about what embracing such change means in terms of the behaviors exemplified in the newly created consortium – that is, the feelings that accompany frequent changes such as indirectedness and indecisiveness. Obfuscation and "speaking in questions" may occur frequently (Browning et al., 1995). However, in addition to learning how to communicate, think, and invent together, members must learn how to constructively deal with conflicts among themselves as well. Having strategies for members to engage in constructive feedback enables conflicts to be resolved versus pushed aside only to emerge again. Skills in conflict resolution must exist before members can cooperate at the highest level. Including members in the consortium's creation provides an opportunity for increasing member buy-in. Once member buy-in is high, increased clarity, redirected energy, and faith in the outcome(s) occurs.

Contingency theory suggests that the organizational structure should fit the environment (Lawrence and Lorsch, 1967). Our comparison of these consortia espouses similar views. Organic organizational structures are more fluid and nimble with respect to adjusting to turbulent environments, whereas mechanistic structures place emphasis on command and control that often makes the timeliness of a change slower (see Burns and Stalker, 1967 for a full discussion of these two types of organizational forms). In our observations, ASMC and MACC had a more organic structure, with ASMC actually having three year planning cycles to help introduce change. On the other hand, MCC and SEMATECH both had mechanistic structures that made on-going change more difficult to achieve.

MACC was the only consortium of the four that was not initiated as a response to a crisis. In the majority of cases, cooperative efforts that pool resources together are often started as a response to a threat and are of a magnitude that no one firm can do alone. However, the mindset required to cooperate is opposite that of the competitive nature and high emphasis on proprietary work germane to high-technology members. In general, a crisis may serve only as a short term motivator. MCC, for example, started to decline after the Japanese threat (crisis) dwindled. As a crisis subsides, members will ask, “Why am I here?” Sustaining collaboration amongst a large group of members over time is a major challenge. ASMC continues to exist even though the alarm management crisis has lessened with the introduction of new processes. However, members believe that work remains to be done to truly predict and thus reduce and/or eliminate abnormal situations transitioning to a disaster. Moreover, ASMC membership realizes that though improved technology solutions have been developed, their adoption and practice is still a challenge.

3.4.5.2 Leadership

Initial leadership plays a significant role in the image of the new organization and its ability to overcome a liability of newness. Leaders who are widely respected, well-known, admired and charismatic create valuable relationships and are able to attract top quality employees and researchers. In the cases of ASMC and MACC, the founders were the charismatic visionaries, and MCC and SEMATECH founders actively sought such a leader.

The greater the extent to which an organization is dependent upon its leader’s personality, relationships, and leadership style, the more that organization has to potentially lose when its leadership changes. ASMC and SEMATECH have had multiple periods (as determined by changing goals) but have had leadership overlap to help create continuity. MACC has had consistent leadership over its lifetime, with a similarly consistent goal. MCC, the only consortium to have gone out of existence, had three distinct periods determined by changing goals, and these three periods had no leadership overlap.

3.4.5.3 Goals and objectives

The initial direction and objectives of the consortia all had in common the act of converting research to use. SEMATECH and MACC placed the most emphasis on technology transfer to members. ASMC and MCC placed a higher value on commercialization, but neither admittedly nor directly incorporated into its culture the 15–20 year time span generally required to commercialize basic research from the time of its invention.

Communication about changes to goals and objectives is critical to consortium stability. Organizations need to be able to overcome structural inertia, competitive inertia, organizational momentum, and their current management logic to maintain internal consistency, especially when shifts become necessary (Lengnick-Hall and Wolff, 1999). Thus, as long as goal shifts are communicated effectively and are well-understood, they should improve the organization’s ability to adapt. As goals evolve, member expectations need to evolve, or perhaps membership itself needs to evolve.

3.4.5.4 Membership

In all of the consortia, members came together as collaborators wanting knowledge that if not gleaned would have hurt them economically. In the cases of ASMC and MACC, members also knew that there was no other outlet for information generated by the consortium, so they were more motivated to participate and to share.

A vastly diverse membership with high longevity should lead to better decisions than a homogeneous membership with high longevity, primarily because group-think can set in (Cauley, 1998). A vastly diverse membership without longevity experiences loss of effectiveness as the group continues to form and reform, thus taking time away from achieving expressed goals.

3.4.5.5 Criteria for success

Success is based on how the evaluator defines it. Intangible benefits are often as important as tangible results. Refining the process and ways of making a consortium work is one outcome that rarely gets adequate acknowledgment. For example, members of both ASMC and MCC benefitted greatly from the collaborative experience, even though tangible results from such collaborations were lower than expected. Both MACC and SEMATECH base success on member's perceptions — their mindset centered on the community, whereas ASMC and MCC had what appeared to be more arms-length definitions of success with a mindset centered on individual companies getting their own benefits from the consortium's efforts. Paradoxically, MACC and SEMATECH initiated goals to enable technology transfer more clearly than did ASMC or MCC.

3.4.6 Some paradoxes associated with consortia

Based on our observations, readings, and interviews, we make several broad statements about apparent paradoxes involving consortia structure, intent, and success. Here we focus on the MCC and the ASMC, the two consortia about which we have the deepest knowledge.

The initial impetus for MCC was the threat of Japanese technology, yet overall, MCC's researchers did not push to commercialize their research into technologies that could counter the Japanese. Likewise, the initial impetus for ASMC was a change in technology that had the potential to allow members to better understand and thus prevent abnormal situations from transitioning into disasters. Such a transition would reduce severe economic loss and liability, yet ASMC members have been unable to attain widespread deployment into practice despite a clear definition of the consortium's purpose and a centralized contribution and commitment from Honeywell. It should be noted that ATP-sponsored research done in the early years of ASMC resulted in ambitious visionary concepts, particularly the AEGIS model, which was planned as a modular suite of software that could be seamlessly integrated with future control systems to improve early event detection and manage abnormal situations. When ATP funding ended, members were unable to apply sufficient resources to quickly convert these concepts into deployable solutions, which led to some feeling of disappointment. Eventually, members settled on selecting the parts of AEGIS that could be implemented more easily, and products started to emerge.

Initially, MCC was championed by the upper echelons of executives, but in the end, it was pressure from mid-level executives that MCC had to respond to in order to continue. ASMC was championed by mid-level executives and in the end it needs the upper echelons of its member-corporations to legitimize its efforts if it is to survive.

MCC was designed to minimize bureaucracy, but in the end, it grew larger and more bureaucratic. ASMC began its tenure as a highly formal organization with clearly established meeting content and procedures, established policies for voting and project selection, and with formal cost-sharing and reporting requirements. Today, the ASMC has reduced its meeting length and content and is struggling with some of this formal structure. This struggle will be heightened as the ASMC attempts to grow its membership.

MCC initially pursued a centralized research program, but in the end, it became a project coordinator of distributed activities. Likewise, ASMC initially pursued a centralized research program under ATP funding, but has more recently reverted to more company-based distributed activities. Further fragmentation occurs as ASMC member companies choose to work individually with Honeywell, outside of the boundaries of the consortium framework.

Instead of transferring technology as it initially intended, MCC ended up commercializing most of its technology through entrepreneurs and spin-out companies. Technology transfer has presented difficulties to ASMC as well. Here ASMC intended that Honeywell would provide the commercial platform for emerging research results, but to date, this has been less successful than anticipated, in part due to a major change to the underlying Honeywell platform and also due to the reduction in funding that occurred after the ATP project ended.

Part IV

Lessons Learned

This study was motivated by the following questions:

- Why are so few R&D consortia sustainable over time?
- How do members perceive their benefits from and contributions to collaboration-focused organizations?
- How do members leverage the collective resources for individual company gain?
- How do consortia create opportunities that are not available to individual companies?
- How do decisions made early in the consortium's life influence its stability over time?

This section is organized around these questions, highlighting what we believe about consortia and their practices based on our research.

4.1 Why are so few R&D consortia sustainable over time?

4.1.1 Consortia that yield member benefit should be continued, but careful examination should foster the development of exit strategies

We began this study with the bias that a long-lived consortium was obviously one that was more successful than a shorter-lived one. What we have observed is that longevity, per se, is an inadequate indicator of success.

About 10% of registered consortia have been disbanded, mostly because of project failure rather than project completion (Rigatuso et al., 1997). According to Evan and Olk's study (1990) of 137 consortia,the fact that "some consortia have existed for more than five years suggests that managers are achieving some level of success" (p. 44). However, Rigatuso et al. (1997) raise questions about longevity as a criterion for consortium success:

> "[A] consortia (sic) that has outlived its usefulness but continues to exist will take funding away from other, more productive projects. Also, a consortia (sic) that is

unsuccessful due to poor technology transfer could be argued to hinder new technologies. Research performed at this sort of consortia (sic) may have conceivably led to new products or processes that would benefit companies and the public but ineffective technology transfer back to the member firms prevented the proper use of the research. A successful, or even moderately effective, consortium should not have these problems."

4.2 How do members perceive their benefits from and contributions to collaboration-focused organizations?

4.2.1 Intangible benefits are often undervalued in consortia since they cannot be directly and immediately quantified

Activities that cannot be associated with cost savings or increased revenue frequently are undervalued in any type of cost benefit analysis. Such is the case with ASMC, where the ability to communicate in an open forum is highly valued by members, but not quantifiable. This ability to share has prompted continuing membership of several companies beyond what might otherwise have occurred with a simple return on investment (ROI) calculation. As companies evaluate their benefits to participation, serious attention should be paid to intangible benefits. Interestingly, prior work suggests that knowledge sharing and access to unique knowledge are important motivations for members (Moethe and Quelin, 2001; Rigatuso et al., 1997; Sakakibara, 1997), and yet few consortia actually measure these in any meaningful way.

4.2.2 Robust knowledge sharing mechanisms must be in place for companies to gain value from intangible benefits

To translate intangible benefits into company benefits rather than individual representative benefits, the representative must have formal mechanisms to share what is learned within the consortium more broadly across the company. In lieu of formally transferable technology that is embedded into products or commercialized services, companies can accrue benefit only when knowledge is shared broadly. Within ASMC, we observe that member companies have inconsistent knowledge distribution mechanisms, with most relying on the personal networks of their company representative. This limited knowledge distribution may explain, in part, why only a limited number of company operations have adopted ASMC related products. Lotus Notes enabled within-membership sharing, but its incomplete and missing information, coupled with inconsistent website updates and maintenance, hinders the usefulness of this important information repository. The lack of ongoing investment in routine IT and maintenance reduces the value of this information to members. Recent use of the web to conduct webinars is a laudable activity, but the long term value of this will be possible only if the information is able to be accessed easily in the future.

4.2.3 Standard return on investment (ROI) assessments ignore the value of knowledge gained through failure

All too often, companies do not recognize failure as a positive result. Understanding that an approach is not going to work — and redeploying the resources to an alternative — can yield significant financial value over time, particularly as each member is leveraging its investment. The ability to stop a stream of funding to an area that is not promising creates opportunities to use this funding elsewhere. Within the consortium, valuing fast, intelligent failure is essential to assessing the value of the consortium membership.

4.3 How do members leverage the collective resources for individual company gain?

4.3.1 Expertise of company representatives should match the goals of the consortium

There has been a problem linking the developments in the ASMC to the petrochemical member companies at large. The technology representatives who were the best people to address the R&D questions early in the Consortium's life have had only limited overall success in having ASM products adopted in their individual companies. This may be the result of the company representatives' ability to convince senior management within their respective companies that there is strategic value in abnormal situation management. The ambiguity of costs and benefits to participation in the ASMC only confounds this important issue.

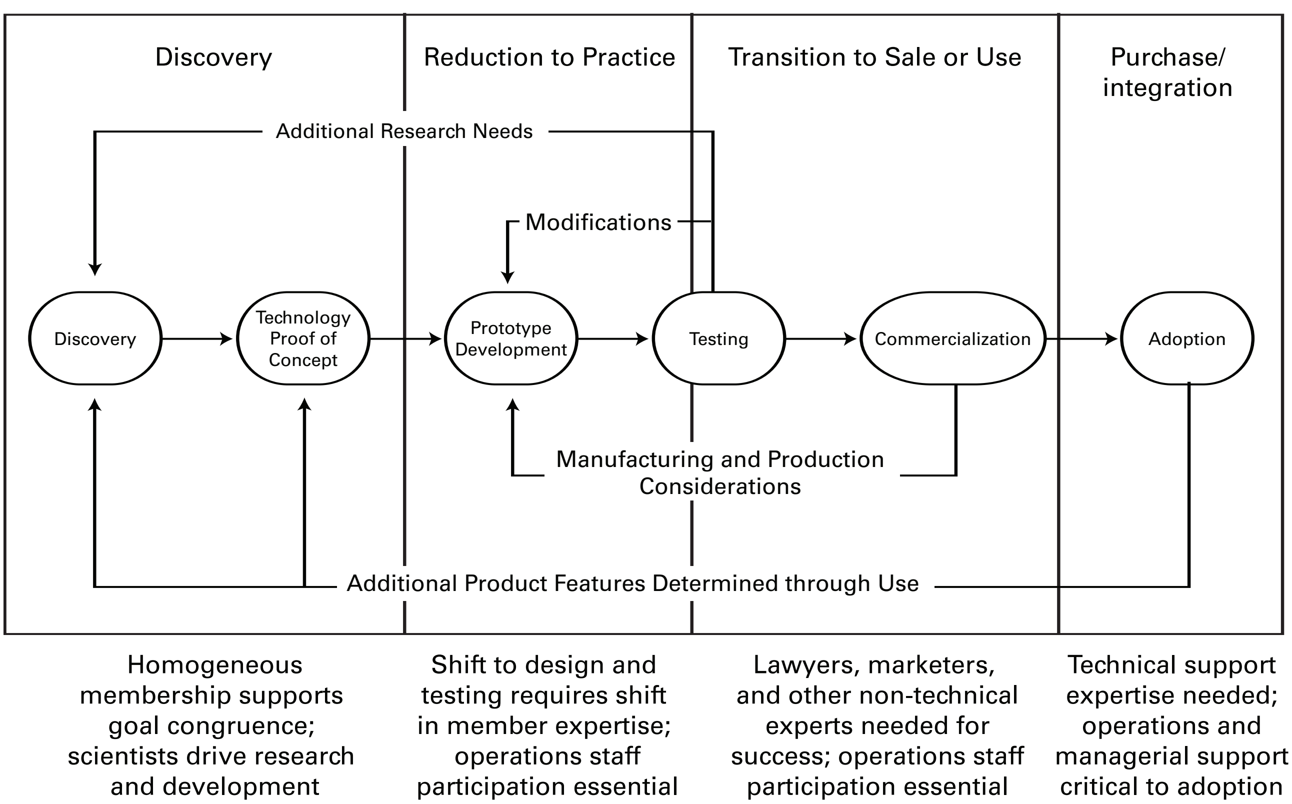
Successfully evolving ASMC's focus from R&D to product deployment may require an expanded membership for individual companies or different members entirely.

Figure 5 portrays the stages of technology discovery, development and deployment that are typical in R&D consortia. Here we emphasize the different needs for membership and expertise that must come together in the R&D consortium for success. We begin with discovery, where new ideas are created and/or combined to develop solutions to critical problems. Once proven, these ideas must be reduced to practice as either technology prototypes or methods that can then be tested. Once tested, technology inventions or methods may require modifications or may drive additional research questions prior to full-scale commercialization. Finally, the technology or method must be adopted, thus translating it into a benefit for the adopting organization.

We believe that these four stages require very different types of expertise to achieve success. In the early discovery and reduction to practice stages, homogeneous membership of companies and scientific expertise of member representatives helps insure goal congruity and minimizes the coordination required between members since all exhibit similar concerns. As a technology or method is reduced to practice, however, scientific expertise is no longer enough to capture the realities of the operating environment, and new member representatives from companies should be sought.

We also believe that this is a good opportunity for the consortium to begin adding company members, thus increasing heterogeneity. Such diversity of company members is even more important as the consortium seeks to transition the technology or method into sale or use. Multiple inputs as to operating environments are needed. In addition, the consortium should be adding non-technical expertise to help focus the product offering. Finally, at the adoption stage, the consortium must consider technical support. During this stage, the value of the scientific input is limited and instead, operations staff and member company management buy-in are critical to success.

Figure 5. From concept to innovation: The structure and membership of the consortium should match the needs of each stage. This requires the consortium to evolve as it matures to be sustainable



4.3.2 Open exchange of information must be detailed enough to yield actionable knowledge

The information that is shared must be in sufficient detail to enable the listener to determine its relevance to his or her own operating environment, as well as to determine what the information means in terms of the selection of the best alternatives. Unfortunately, since many consortia are composed of competitors banded together to collaborate on a critical issue, the actual knowledge sharing is often limited to superficial or high-level information. Such information may be interesting, and even useful in concept, but in practice may have only limited use in changing procedures or upgrading practices. It appears that knowledge sharing is more detailed when consortia have heterogeneous, non-competing members and when knowledge sharing is verbal and not written or otherwise captured formally. This is in direct conflict, however, with our earlier observations concerning robust knowledge sharing.

4.3.3 Leveraged facilities reduce individual company testing burdens

Pooled member commitment extends the test-bed opportunities for possible technology solutions and helps to spread the burden of such test-bed activities across member companies. Within ASMC the ability of individual companies to gain insights from applications at other companies results in a reduced need for individual company investment or commitment of facilities. This is an especially valuable membership benefit as individual companies are operating at or near capacity and thus might not be able to designate facilities for test-bed activities. According to the National Petrochemical & Refiners Association, many U.S. refineries are operating at up to 99% capacity. Such high utilization rates limit the ability of any one firm to conduct tests that require operating facilities (Lynch, 2005). It must be noted, however, that this benefit is not as important at the early research stage where only limited in situ testing might occur. For this reason, a consortium in its early stages of formation may undervalue this if it has a basic research focus. However, shared test-bed availability should be anticipated as a future benefit as consortium activities transition to development and deployment.

4.4 How do consortia create opportunities that are not available to individual companies?

4.4.1 Charismatic leadership helps garner resources and encourages sustainable activity

Leadership consistently emerges as an important issue. Yet we believe that a distinction must be made between personality and skill-set. Charisma as personality is not the same as charisma with respect to relationship building and networking (Weber, 1978). The former has less staying power than the latter. As such, a consortium is wise to find a leader who possesses relationship-charisma versus personality-charisma, and who is able to instill upon his or her successors, as well as embed within the consortium's culture, the requisite relationships and connections needed for seamless integration over time. Individuals who do take initiatives to span boundaries and cross borders need to be rewarded. People who facilitate putting diverse groups together — who have shared needs or wants — and who broker relationships between disconnected parties and look for ways to connect people have subtle but tremendous impact. Our work also suggests that carefully crafting the roles and responsibilities of the leadership, including the possible shared leadership among individuals, is a strategy that formalizes expectations and helps direct behaviors.

4.4.2 Pooled member commitment entices larger funding through government sources

Membership commitment to a consortium is a proxy for the importance of the goals of the consortium. Both the level of the commitment and the number of members establish the criticality of the consortium. Consortia with wide participation, a high degree of company financial and staff commitment, and a high degree of individual member commitment are more likely to garner government support.

In the case of ASMC, high commitment of a homogeneous set of companies in the petrochemical industry prompted ATP to invest in R&D addressing a major problem of abnormal situation management. This focused industrial sector commitment heightened the attention to this problem. However, such focus is not without a cost.

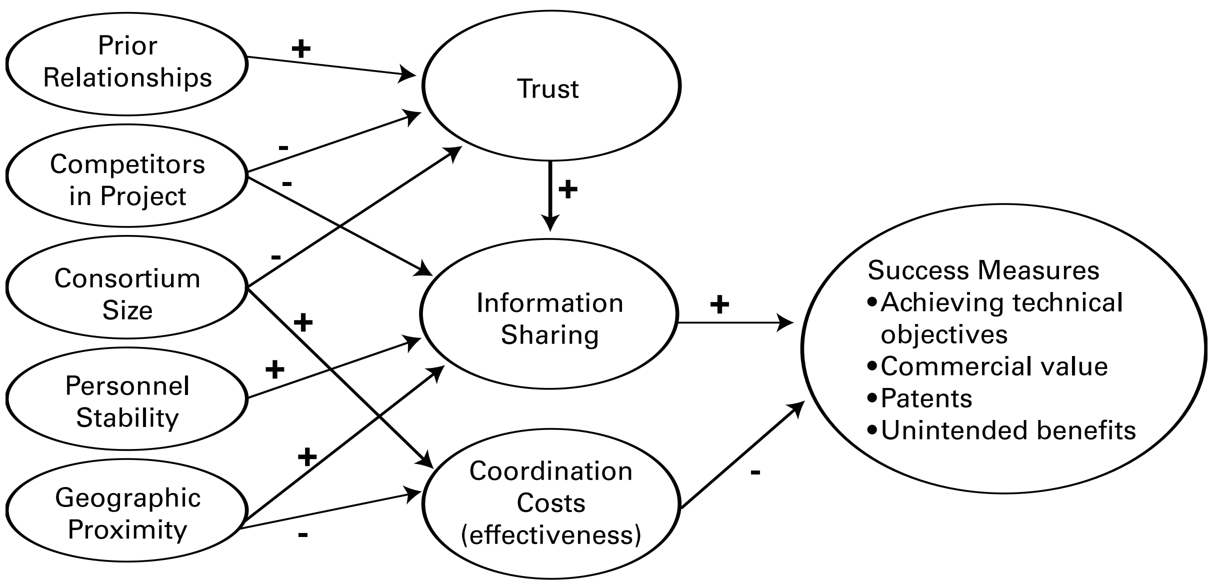
4.5 How do decisions made early in the consortium's life influence its stability over time?

4.5.1 A strong organizational structure can promote organizational trust and help establish the foundations for organizational collaboration

Dyer and Powell (2001) offer a model of the determinants of success in ATP sponsored joint ventures. This model stresses the importance of prior relationships, personnel stability, and geographic proximity as they, in turn, support trust and information sharing. Hindering factors were established to include consortium size, participation of competitors in the consortium and their impact on coordination costs. Success measures included achieving technical objectives, commercial value, patents, and unintended benefits. (See Figure 6).

Specifically, the authors point to more successful joint ventures being characterized by greater levels of knowledge sharing and by effective coordination mechanisms among participants. Interestingly, the ASMC appears to have dealt with inconsistent sharing levels among

Figure 6. Determinants of success in ATP-sponsored joint ventures (Dyer and Powell, 2001)



participants with a very robust set of coordination mechanisms that tended to reduce the negative impact. Here is an interesting example of the way in which a carefully crafted administrative structure, including formal communication mechanisms, regular face-to-face meetings and careful attention to financial and in-kind contributions, can mitigate member imbalances in knowledge sharing and openness. Such administrative policies may increase organizational trust and make up for (in whole or in part) a smaller level of personal trust among and between members. Though coordination costs within the ASMC are relatively high compared with overall resources (particularly post-ATP funding), these costs appear to be warranted as a way to maintain working relationships among a homogeneous group of competitors, namely the petrochemical company members.

4.5.2 An organizational champion facilitates sustainability

Sustainability is heightened when the consortium can identify a lead organization. This is especially true when competitors are members of the consortium. In the ASMC, Honeywell's ongoing commitment to the consortium is a key factor in its longevity. Honeywell provides the organizational and structural glue to the consortium, allowing members to focus on the R&D issues. Governance and decision-making practices that capture input from the membership at large are necessary precautions to balance the influence of the organizational champion.

4.5.3 Longevity of homogeneous members may limit growth opportunities

Within a consortium, a set of homogeneous members encourages goal congruity between individual members and helps to focus efforts on critical problems. This is very important with R&D activities. As problems become better understood or solutions mature, a focused homogeneous set of members may reduce the creativity of the consortium and may also reduce its ability to leverage resources. ASMC benefited early on from such a focus, winning ATP funding. More recently it has struggled with how to expand its coverage, impact, and resources. Since membership fees and Honeywell contributions are now the base of resources, the ability to grow this base is important.

A related issue involves the openness of the consortium to new members. Once again a set of member representatives who have strong contextual focus as well as strong relationships that have developed over time can be a detriment to consortium growth. Longevity breeds norms and customs, some of which may not be captured in any formal organizational mechanisms. This helps the consortium hang together over time but can also serve as a barrier to entry for potential members. When a consortium begins to exhibit fewer characteristics of collaborating companies and more characteristics of collaborating individuals, it runs the risk of alienating potential new members.

This issue is exacerbated within the ASMC since some of the same individuals have moved from one member company to another. When these individuals are the member companies' representatives, access to new ideas is limited. Such tightly coupled groups can be very cohesive but have been found to be less creative over time than more loosely coupled groups.

4.5.4 The formal structure that keeps a consortium running needs to be adjusted with time

A study of 25 R&D managers of 16 firms involved with the EUREKA Consortium found that whereas the beginning stages of R&D necessitate a high frequency of meetings to share information and arrive at consensus on obscure objectives, the product development stage reduces the need to meet as frequently (Mothe & Quelin, 1999). This pattern has been reflected in the ASMC, with the long-standing structure of four-day meetings held quarterly being recently reduced to three meetings of shorter duration held each year. Over the past year, the number of meetings has been viewed as excessive, given time and money considerations of member companies. To help offset the reduced face-to-face meeting structure, there has been increased usage of webinars.

4.5.5 Change management activities must balance the passion of research with the realities of development and deployment

Within the ASMC, the recent emphasis on product deployment has overtaken the passion for safety issues espoused by the founding members.

In the founding of the ASMC, the emphasis was on safety in the petrochemical industry. Interviews with many of the initial members revealed a great deal of passion associated with concerns about safety and how to improve practices that would reduce accidents and the occurrence of abnormal incidents. The sheer importance of this issue, along with strong individual commitment, led to the decision to not be protective of information on safety. Therefore, although concerns about intellectual property, competitive advantage, and legal obligations have always been present, members were personally invested in finding a way to overcome these barriers to consortium formation. Indeed, the crafting of a legal agreement that everyone would be able to abide with in terms of ownership of information and intellectual property was a huge accomplishment in the formation of the ASMC. Incidentally, the Honeywell lawyer who was charged with this responsibility received the “bulldozer award” for accomplishing what many thought was impossible.

In recent years, however, there has been less emphasis on safety and more emphasis on product deployment. The passion for increasing safety permitted an open environment that encouraged information sharing and the sacrificing of some proprietary rights for the common good. Now that the ASMC is focused less on safety than it was at the outset, concerns with legal issues and intellectual property have escalated. Quarterly meetings have more explicit discussion and debate about legalities than safety concerns. The initial passion of members for the safety issue seems to have been overtaken by a production focus.

4.5.6 Concluding remarks

Through over 150 hours of direct contact with consortium members, the Penn State team has been able to observe interactions between individuals across a wide spectrum of issues. Our observations lead us to conclude that the structure of a consortium is a contributing factor to its success over time. Centralized leadership balanced with distributed decision-making encourages company buy-in and individual member commitment. It should be noted that our findings are relevant to consortia whose goals include research and development through the collaboration of different companies. Our in-depth analysis points to the importance of vision and leadership. However, we have also found that consortium policies that promote periodic review provide the opportunity for the consortium to redefine itself, thus better matching activities with on-going and emerging needs. Without such periodic review, the consortium can sacrifice effectiveness in the name of longevity.

Part V

References

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Appendix A:

Penn State Team Methods and Approach

Over the two-year study period, the Penn State team has conducted more than 25 interviews and has participated in more than 150 hours of meetings and conversations regarding the ASMC.

We originally proposed five tasks over a 24-month period, beginning on October 1, 2003 and ending on September 19, 2005, and subsequently extended the study period to capture ASMC information through the end of 2005. Table A1 summarizes the Penn State approach. During this project the Penn State team collaborated using e-mails, phone calls and face-to-face meetings. As ASMC members were interviewed via phone or in person, the team prepared interview notes that were distributed via e-mail to the interviewee for comment and to the Penn State team after review. The Penn State team member attending the Quarterly Review Meeting (QRM) prepared comprehensive notes that included both a chronological description of the meeting's content and also interviews and summaries of conversations that occurred during the QRM. The team met at Penn State after the QRMs to discuss what we learned and how what we were hearing from ASMC members compared with our expectations given our understanding of the Consortium, other consortium practices, general management practices, and personal versus company commitment issues.

It must be noted that members gave freely of their time and input during quarterly meetings, and several have corresponded with the Penn State team via e-mail. None, however, was willing to go on record to discuss the costs associated with abnormal situations or critical incidents. This lack of data related to costs is not unique to the present effort, since many petrochemical companies view this as sensitive competitive information. In addition, members expressed concern about publicly admitting the extent of the problem due to potential legal liability.

Chronology of the Penn State study

In October 2003, Andrew Wang, our ATP study officer, and Irene Petrick, the study lead, attended the QRM in Richmond, CA. During this time, we presented our goals for the case study. During discussions, the members expressed their interest in metrics that might help them reflect the value of membership in the ASMC. Members were optimistic that their company upper management might be more inclined to be supportive of the membership fees and in-kind commitments if the value of membership could be calculated in quantitative terms. Members and Honeywell representatives all acknowledged that quantifying what are generally qualitatively expressed benefits had eluded them in their recent efforts, and all hoped that the Penn State team could aid in this effort. Progress on this quantitative effort was limited by data availability and member inability to put specific numbers to known, but not necessarily countable, benefits. In the cases where member companies were aware of the financial benefits as the result of decreased accidents, decreased critical situations, and the related plant shutdowns to reestablish equilibrium, company representatives were unwilling to disclose this information due to its proprietary nature.

During the October 2003 meeting, members asked what their time commitment would be to this study and expressed concern about overall time demands from the Consortium. The team prepared a memo on October 15, 2003, that established a one to one-and-one-half day commitment for each company representative for interviews and surveys, with potential additional time for review of materials, gathering of financial details, and establishing links with company managers and decision-makers related to ASMC membership. Members asked Kevin Harris of Honeywell to work with the Penn State team to identify alternative, less time intensive, data collection methods. Because of this, Kevin Harris has been a focal contact for the Penn State study.

Our objective was to pursue a case study analysis that would be acceptable to ASMC members who were concerned about the time commitment that might be required to meet our needs. Since ASMC member participation was critical to developing a comprehensive case study, the following compromises were made:

1. The PSU team would focus on the ASMC website and NIST/ATP files for all background information,
2. Interviews with ASMC user and associate members would be constrained to the quarterly review meetings which the members attended as part of their commitment to the ASMC,
3. There would be no or only limited contact with company executives other than the ASMC members and early principals,
4. Short surveys that could be completed during the quarterly meetings would be used to augment interviews and anecdotal information, and
5. Honeywell staff, particularly Kevin Harris and Dal Vernon Reising, would be primary sources of information in lieu of significant member contact beyond the quarterly meetings.

These compromises did not hamper data collection concerning how the consortium works on a day-to-day basis. As a result, the genesis and early years of the consortium are well understood. In addition, we have been able to trace activities of the consortium. Early principals and founders of ASMC have been particularly helpful and have participated in extensive interviews and follow-up e-mail discussions.

Table A1: Methods and Approach

Methods	Approach
Document review	A review of ATP documentation was completed at the Gaithersburg, MD location. Additional documents were gathered through web search and contact with study principals.
Social network analysis	Analysis of publication data was completed using UCINET software. Project data was incomplete and thus not suitable for analysis.
Personal interviews and site visits	Personal interviews were conducted during Quarterly Review Meetings. Only limited travel beyond this was made, including travel to McMaster Advanced Control Consortium. Phone interviews were also conducted. Interviews were Interviews were transcribed and the interviewee was asked to review, correct and comment.
Participant surveys	Brief paper-based surveys were distributed to attendees at Quarterly Review Meetings. ASMC members and Honeywell staff were included. Surveys were not distributed to anyone beyond the member representative for ASMC member companies.
Cost benefit analysis	Economic cost benefit analysis was not possible due to the proprietary nature of the data. Instead we included qualitative aspects of ASMC benefits in the participant surveys. We also included this topic in our interviews.
Observation	Quarterly Review Meetings were observed by the Penn State team. As part of this observation, we included topical analysis, analysis of participation, and meeting format.
Participant observation	The opportunity arose for Dr. Petrick and a graduate student to submit a proposal to the Research Subcommittee for a technical project in mobile device use in plant maintenance. The proposal was not funded, but the experience added deeper insight into the way that research projects are evaluated.
Comparative analysis	The ASMC was compared with three other consortia. For one of these, MACC, we were able to attend a member meeting at McMaster University and speak to members, administrators and students. Further e-mail follow-up with administrators helped to clarify our understanding of the consortium. We relied on secondary literature sources for our review of MCC and SEMATECH.

The compromises have limited our ability to conduct correlation analysis or other statistical and economic analysis due to a lack of data and due to its qualitative nature. In addition, though we are confident in our assessment of individual company participant motivations, we are less certain of the underlying company commitments and motivations regarding ASMC membership. For the petrochemical company members, we have had no contact beyond the company representative. For the smaller associate member companies, our interviews with the company representative were often sufficient to glean company motivation and commitment.

Within Honeywell, we have been able to interview several past and current staff involved in the ASMC, and have been able to include design engineers, marketing, product development managers and one executive. Our understanding of Honeywell's motivations and commitment is thus more fully formed.

Interviews with early principals, current members and others

The Penn State team interviewed all of the principal players in the early days of the ASMC, mostly by phone. In addition, most of these principals were willing to review interview notes for clarification and to respond to additional e-mail questions. We also had the opportunity to interview administrators and members of the McMaster Advanced Control Consortium.

As part of this study, we interviewed the following people, some more than once. It must be noted that interviews took several forms: formal interviews with written feedback provided to the interviewee for review (indicated below with an asterisk); informal discussions during the quarterly meeting breaks, meals and social events; and e-mail discussions and question/answer.

- Ian Nimmo (Honeywell, now with UCDS)*
- Ted Cochran (Honeywell)*
- Doug Rothenberg (BP Oil, now with D-RoTH, Inc.)*
- Ken Emigholz (ExxonMobil)*
- Bruce Colgate (ConocoPhillips)
- Peter Bullemer (Honeywell, UCDS, now with HCS)*
- Jack Pankoff (TTS Performance Systems)*
- Tim Montgomery (Chevron)
- Kevin Harris (Honeywell)*
- Dal Vernon Reising (Honeywell employee until 2005, now with HCS)*
- Michael Nevels (Celanese)
- Jim Davis (UCLA)*

- Rob Angerer (Shell)
- Bart Winters (Honeywell)
- Theodora (Dora) Kourti (McMaster University, home to another abnormal situation management consortium)
- John Hajdukiewicz (Honeywell)
- Paul Butler (Honeywell)
- John Moscatelli (UCDS)
- Thomas Marlin (McMaster University)

ASMC quarterly meeting attendance

Our primary interactions with ASMC petrochemical company user members and associate members were through attendance at the QRMs. The Penn State team has attended or participated in the following Quarterly Review Meetings:

Richmond, CA	October 13–15, 2003 (Petrick & Wang attending)
Phoenix, AZ	January 20–23, 2004 (Petrick remote presentation)
Bartlesville, OK	April 20–22, 2004 (Mohammed attending)
London, Ontario	July 20–23, 2004 (Petrick & Hedge attending)
Fairfax, VA	October 19–21, 2004 (Hedge attending; Ayoub remote presentation concerning possible research funding project)
Phoenix, AZ	January 25–27, 2005 (Hedge attending)
Houston, TX	October 11, 2005 (Petrick attending to provide final report summary)
Phoenix, AZ	January 25–27, 2006 (Petrick attending to provide focused feedback to ASMC members).

MACC meeting attendance

Irene Petrick also had the opportunity to attend one meeting of the McMaster Advanced Control Consortium during the study period. This was followed-up with e-mail questions, and then phone conversations. The information gathered from MACC and presented in this report has been reviewed by Thomas Marlin, MACC Director, and Theoradora Kourti, MACC Research Manager.

Final report review

This report has gone through extensive review. ASMC and MACC representatives reviewed early drafts and contributed clarifications and corrections. Kevin Harris reviewed this report extensively at various stages. At a final report-out to the ASMC at its January 2006 QRM, member companies were provided with a draft of this report for review and comment. In addition, ATP staff also reviewed its content.

With that said, any errors or misrepresentations are solely the responsibility of the study team.

Appendix B:

Social Network Analysis

Based on Articles Issued for Publication, 6/30/1995–2/21/2002
Compiled July 6, 2004

Appendix B Table of Contents:

References:

Borgatti, S.P., Everett, M.G. and Freeman, L.C. 2002. Ucinet for Windows: Software for Social Network Analysis. Harvard: Analytic Technologies.

B1. Data Used

Source: http://www.asmconsortium.com/

Click on 'publications' then Click on 'articles'

Data gathered December 5, 2002

Create symmetrical author x author network matrix where # co-authorships on 'issued articles' only = cell value, i.e., omit rough drafts, for review, for comment, etc. If status cell was blank, the article was assumed to have been issued.

Sole authored works are counted and appear along the diagonal

Cells without data are coded 0

Data used are as follows:

Title	ver	date	status	author
Improving the Operator's Capabilities	1.30	06/30/1995	Issued	Ken Emigholz
Human Supervisory Control and Decision Support State of the Art	1.00	07/31/1995	Issued	Ted Cochran
Refinery Implementation of an Operator Advisor System for Procedure Management		08/08/1995	Issued	David Beach Mike Knight
Abnormal Situation Management	0.10	08/25/1995	Rough Draft	Ian Nimmo
Plant Monitor: An On-line Advisory System for Monitoring Polyethylene Plants	1.00	09/18/1995	Issued	Tharuvai S Ramesh
Adequately Address Abnormal Operations	1.00	10/11/1995	Issued	Ian Nimmo
Operator Advisor System for Procedure Management		12/31/1995	Issued	David Beach
Abnormal Situation Management: NOT By NEW Technology ALONE...	1.01	01/24/1996	Issued	Ted Cochran
Best Practices for Information Presentation to Operators		01/31/1996		Neil Anderson Kris Vamsikrishna
A Training Perspective on Abnormal Situation Management: Establishing an Enhanced Learning Environment	1.00	02/12/1996	Issued	Peter Bullemer

Title	ver	date	status	author
Abnormal Situation Management in Petrochemical Plants	1.00	02/19/1996	Issued	Ted Cochran Chris Miller Peter Bullemer
User-Initiated Notifications: A Concept for Aiding the Monitoring Activities of Process Control Operators		04/12/1996	Issued	Stephanie Guerlain
Too Much of a Good Thing? : Alarm Management Experience in BP Oil	3.00	06/10/1997	Issued	Donald Campbell-Brown
Stemming the Alarm Flood: A Synopsis of the Colloquium	1.00	06/20/1997	Issued	Donald Campbell-Brown
New Training Strategy: Design the Work Environment for Continuous Leaning	1.00	10/24/1997	For Comment	Peter Bullemer Ian Nimmo
Managing Abnormal Situations in the Process Industries (Series of 3)	2.00	10/27/1997	Issued	Ted Cochran Peter Bullemer Ian Nimmo
Supporting Collaborative Field Operations With Personal Information Processing Systems		01/19/1998	For Review	Stephanie Guerlain
[Human] Supervisory Control and Decision Support: State of the Art [full text]		08/04/1998		Ted Cochran
Modeling Techniques to Support ASM in Process Industries		10/06/1998	Issued	Greg Jamieson Kim Vicente
The ASM Story		12/01/1998	Issued	Ian Nimmo
Central Control Rooms and Petrochemical Plants: Costs and Benefits		08/03/1999		Paul Milner Ted Cochran Peter Bullemer
The Alarm System from the Operator's Perspective		08/03/1999		CT Mattiasson Peter Bullemer
Collaborative Decision Support for Operations		11/03/1999		Peter Bullemer
Effective Control Center Design for a Better Operating Environment		11/03/1999		Ted Cochran Peter Bullemer Paul Milner
The Importance of Alarm Management Improvement Project		01/14/2000	Issued	Ian Nimmo
The Human Safety Factor in Control Room Design and Location		01/14/2000	Issued	Ian Nimmo

Title	ver	date	status	author
Operator Graphics Concepts	1.0	04/13/2000	Issued	Ian Nimmo
Visualizing Model-Based Predictive Controllers	1	08/09/2000	Issued	Stephanie Guerlain Greg Jamieson Peter Bullemer
Critiquing Team Procedure Execution	1	08/09/2000	Issued	Stephanie Guerlain Peter Bullemer
Ergonomic Design of Control Buildings		08/18/2000	For Review	Ian Nimmo
Hotel Fire Safety	1.00	08/28/2000	Issued	Michael J. Clark
Abnormal Situation Management in Asia Pacific	2	10/06/2000	Issued	Hiran Vedam Johannes Koene
Exploring the Culture of Procedures	1	10/06/2000	Issued	Greg Jamieson Chris Miller
Alarm Management and Rationalization		10/06/2000	Issued	Hiran Vedam Johannes Koene
Clustering in Wavelet Domain: A Multiresolution ART Network for Anomaly Detection		10/06/2000	Issued	Hrishikesh Aradhye Jim Davis
Fielding a Multiple State Estimator Platform		11/15/2000	Issued	Dinkar
Designing for Abnormal Situation	1.00	05/02/2001	Issued	Jamie Errington Peter Bullemer
Management. Proceedings of the Houston, TX. Mulitscale Anomaly Detection Using Principle Components Analysis and Adaptive Resonance Theory		05/29/2001	Issued	Aradhye H.B. Bakshi B.R. Davis J.R. Rathnasabapatry S Ahalt S.C.
Monitoring Transitions in Chemical Processes Using		05/30/2001	Issued	A. Sundarraman Raja Srinivasan
Intelligent Alarm Management through Suppressing Nuisance Alarms and Providing Operator Advice		05/30/2001	Issued	J. Liu Raja Srinivasan
Ecological Interface Design for Petrochemical Applications: Supporting Operator Adaptation, Continuous Learning, & Distributed, Collaborative Work		05/30/2001	Issue Pending	Greg Jamieson Kim Vicente
Alarm Performance Metrics		05/30/2001	Issue Pending	Ananth Nochur Hiran Vedam John Koene

Title	ver	date	status	author
Designing an Ethylene Plant Control Room and Operator User Interface Using Best Practices		05/30/2001	Issued	Jamie Errington Ian Nimmo
Recurring Causes of Recent Chemical Accidents		08/13/2001	For Comment	Tim Montgomery
Mandated Human Error Controls in the USA		09/19/2001	Rough Draft	Ian Nimmo
Cost-effective Human Factors Techniques for Process Safety New Response (Rosie Walters)		10/02/2001	Issued	Dennis Attwood David Fennel
Techniqes for Interacting with Large Information Spaces on Small Screens		10/21/2001	Issued	Michael Good Michael Dorneich John E. Deaton Floyd Glenn Joshua Downs
Technology Enables New Alarm Management Approaches		10/23/2001	Issued	Doug Metzger
Managing Transitions in Chemical Plants, Part 2: Identifying Modes and Transitions		02/21/2002	Issued	Rajagopalan Srinivasan Pradeep Viswanathan Hiranmayee Vedam Anathanarayanan Nochur

The list of 40 authors issuing a total of 29 articles issued, in alphabetical order are:

Ahalt
Ananthanarayanan
Anderson
Aradhye
Attwood
Bakshi
Beach
Bullemer
Campbell-Brown
Clark
Cochran
Davis
Deaton
Dorneich
Downs
Emigholz
Errington
Fennel
Glenn
Good
Guerlain
Jamieson
Knight
Koene
Liu
Mattiasson
Metzger
Miller
Milner
Mylaraswamy
Nimmo
Rajagopalan
Ramesh
Rathnasabapatry
Srinivasan
Sundarraman
Vamsikrishna
Vedam
Vicente
Viswanathan

B2a. Statistics for 1999 and prior years

1999 and before

Starting fitness: 0.652
Final fitness: 0.652

Core/Periphery Class Memberships:

1: T.Cochran I.Nimmo P.Bullemer

2: K.Emigholz D.Beach M.Knight T.Ramesh N.Anderson K.Vamsikrishna C.Miller S.Guerlain D.Campbell-Brown G.Jamieson K.Vicente P.Milner C.Mattiasson M.Clark H.Vedam J.Koene H.Aradhye J.Davis D.Mylaraswamy J.Errington B.Bakshi S.Rathnasabapatry S.Ahalt A.Nochur A.Sundarraman R.Srinivasan Jliu T.Montgomery D.Attwood D.Fennel M.Good M.Dorneich J.Deaton F.Glenn J.Downs D.Metzger S.Rajagopalan P.Viswanathan N.Ananthanarayanan

Blocked Adjacency Matrix

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                                 1 1 1 1 1 1 1 1 1 1 2 2 2 2
2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 4 4 4
                   5 2 9   1 3 6 7 8 4 0 1 2 3 4 5 6 7 8 9 0 1 2 3
4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2
                   I T P   K D T N K M C S D G K P C M H J H J D J
B S S A A R J T D D M M J F J D S P N
                   ----------------------------------------------
```

FREEMAN'S DEGREE CENTRALITY MEASURES:

Diagonal valid? NO
Model: SYMMETRIC

		1 Degree	2 NrmDegree	3 Share
2	T.Cochran	8.000	19.512	0.333
9	P.Bullemer	5.000	12.195	0.208
15	P.Milner	2.000	4.878	0.083
16	C.Mattiasson	1.000	2.439	0.042
3	D.Beach	1.000	2.439	0.042
8	K.Vamsikrishna	1.000	2.439	0.042
7	N.Anderson	1.000	2.439	0.042
10	C.Miller	1.000	2.439	0.042
4	M.Knight	1.000	2.439	0.042
14	K.Vicente	1.000	2.439	0.042
13	G.Jamieson	1.000	2.439	0.042
5	I.Nimmo	1.000	2.439	0.042
1	K.Emigholz	0.000	0.000	0.000
12	D.Campbell-Brown	0.000	0.000	0.000
11	S.Guerlain	0.000	0.000	0.000
6	T.Ramesh	0.000	0.000	0.000
17	M.Clark	0.000	0.000	0.000
18	H.Vedam	0.000	0.000	0.000
19	J.Koene	0.000	0.000	0.000
20	H.Aradhye	0.000	0.000	0.000
21	J.Davis	0.000	0.000	0.000
22	D.Mylaraswamy	0.000	0.000	0.000
23	J.Errington	0.000	0.000	0.000
24	B.Bakshi	0.000	0.000	0.000
25	S.Rathnasabapatry	0.000	0.000	0.000
26	S.Ahalt	0.000	0.000	0.000
27	A.Nochur	0.000	0.000	0.000
28	A.Sundarraman	0.000	0.000	0.000
29	R.Srinivasan	0.000	0.000	0.000
30	Jliu	0.000	0.000	0.000
31	T.Montgomery	0.000	0.000	0.000
32	D.Attwood	0.000	0.000	0.000
33	D.Fennel	0.000	0.000	0.000

		1 Degree	2 NrmDegree	3 Share
34	M.Good	0.000	0.000	0.000
35	M.Dorneich	0.000	0.000	0.000
36	J.Deaton	0.000	0.000	0.000
37	F.Glenn	0.000	0.000	0.000
38	J.Downs	0.000	0.000	0.000
39	D.Metzger	0.000	0.000	0.000
40	S.Rajagopalan	0.000	0.000	0.000
41	P.Viswanathan	0.000	0.000	0.000
42	N.Ananthanarayanan	0.000	0.000	0.000

Descriptive Statistics

		1 Degree	2 NrmDegree	3 Share
1	Mean	0.571	1.394	0.000
2	Std Dev	1.450	3.536	0.000
3	Sum	24.000	58.537	0.000
4	Variance	2.102	12.505	0.000
5	SSQ	102.000	606.782	0.000
6	MCSSQ	88.286	525.198	0.000
7	Euc Norm	10.100	24.633	0.000
8	Minimum	0.000	0.000	0.000
9	Maximum	8.000	19.512	0.000

Network Centralization = 19.02%
Homogeneity = 17.71%

NOTE: For valued data, both the normalized centrality and the centralization index may be larger than 100%.

Actor-by-centrality matrix saved as dataset FreemanDegree

B2b. Interpretation of 1999 and prior years statistics

In 1999 and prior years, the knowledge network based on ASM articles issued was centralized (centralization score was ~19%) and homogenous (homogeneity score was ~18%). The centralization score, based on further analysis means that few people (3 out of 16, or ~19% of the group issuing articles), namely Cochran, Nimmo and Bullemer, occupied positions of information, access and control, and the other authors had to work through these 3 people to reach each other. The homogeneity score means that the group was not considered highly diverse.

Cochran held the most control, access to others and information, followed by Bullemer, and then by Nimmo. Although Milner shows to have held control, information and access to others twice that of Nimmo and one-fourth that of Cochran, Milner was not considered a member of the "upper echelon."

Note: The matrix consisted of 16 x 16 authors with cell-values computed based on 21 articles issued.

B3a. Statistics for 2000 and years after

2000 and after

SIMPLE CORE/PERIPHERY MODEL

Type of data: Positive
Fitness measure: CORR
Density of core-to-periphery ties:
Number of iterations: 50
Population size: 100

Starting fitness: 0.266
Final fitness: 0.266

Core/Periphery Class Memberships:

1: P.Bullemer S.Guerlain H.Aradhye

2: K.Emigholz T.Cochran D.Beach M.Knight I.Nimmo T.Ramesh N.Anderson K.Vamsikrishna C.Miller D.Campbell-Brown G.Jamieson K.Vicente P.Milner C.Mattiasson M.Clark H.Vedam J.Koene J.Davis D.Mylaraswamy J.Errington B.Bakshi S.Rathnasabapatry S.Ahalt A.Nochur A.Sundarraman R.Srinivasan Jliu T.Montgomery D.Attwood D.Fennel M.Good M.Dorneich J.Deaton F.Glenn J.Downs D.Metzger S.Rajagopalan P.Viswanathan N.Ananthanarayanan

Blocked Adjacency Matrix

1 2 1 1 1 1 1 1 1 1 1 2 2 2
2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 4 4 4
1 9 0 2 3 6 7 8 4 5 1 2 3 4 5 6 7 8 9 0 1 2 3
4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2
S P H T D T N K M I K D G K P C M H J C J D J
B S S A A R J T D D M M J F J D S P N

Density matrix

	1	2
	-----	-----
1	0.667	0.068
2	0.068	0.019

FREEMAN'S DEGREE CENTRALITY MEASURES:

Diagonal valid? NO
Model: SYMMETRIC

		1 **Degree**	2 **NrmDegree**	3 **Share**
20	H.Aradhye	5.000	12.195	0.104
9	P.Bullemer	5.000	12.195	0.104
34	M.Good	4.000	9.756	0.083
40	S.Rajagopalan	3.000	7.317	0.063
23	J.Errington	2.000	4.878	0.042
11	S.Guerlain	2.000	4.878	0.042
1	K.Emigholz	2.000	4.878	0.042
29	R.Srinivasan	2.000	4.878	0.042
21	J.Davis	2.000	4.878	0.042
13	G.Jamieson	2.000	4.878	0.042
18	H.Vedam	2.000	4.878	0.042
5	I.Nimmo	1.000	2.439	0.021
28	A.Sundarraman	1.000	2.439	0.021
33	D.Fennel	1.000	2.439	0.021
36	J.Deaton	1.000	2.439	0.021
37	F.Glenn	1.000	2.439	0.021
38	J.Downs	1.000	2.439	0.021
24	B.Bakshi	1.000	2.439	0.021
25	S.Rathnasabapatry	1.000	2.439	0.021
10	C.Miller	1.000	2.439	0.021
26	S.Ahalt	1.000	2.439	0.021
22	D.Mylaraswamy	1.000	2.439	0.021
30	Jliu	1.000	2.439	0.021
35	M.Dorneich	1.000	2.439	0.021
32	D.Attwood	1.000	2.439	0.021
41	P.Viswanathan	1.000	2.439	0.021
19	J.Koene	1.000	2.439	0.021
42	N.Ananthanarayanan	1.000	2.439	0.021
2	T.Cochran	0.000	0.000	0.000
8	K.Vamsikrishna	0.000	0.000	0.000
6	T.Ramesh	0.000	0.000	0.000
7	N.Anderson	0.000	0.000	0.000
12	D.Campbell-Brown	0.000	0.000	0.000

		1 Degree	2 NrmDegree	3 Share
3	D.Beach	0.000	0.000	0.000
4	M.Knight	0.000	0.000	0.000
15	P.Milner	0.000	0.000	0.000
27	A.Nochur	0.000	0.000	0.000
17	M.Clark	0.000	0.000	0.000
39	D.Metzger	0.000	0.000	0.000
14	K.Vicente	0.000	0.000	0.000
31	T.Montgomery	0.000	0.000	0.000
16	C.Mattiasson	0.000	0.000	0.000

DESCRIPTIVE STATISTICS

		1 Degree	2 NrmDegree	3 Share
1	Mean	1.143	2.787	0.000
2	Std Dev	1.245	3.038	0.000
3	Sum	48.000	117.073	0.000
4	Variance	1.551	9.227	0.000
5	SSQ	120.000	713.861	0.000
6	MCSSQ	65.143	387.524	0.000
7	Euc Norm	10.954	26.718	0.000
8	Minimum	0.000	0.000	0.000
9	Maximum	5.000	12.195	0.000

Network Centralization = 9.88%
Homogeneity = 5.21%

NOTE: For valued data, both the normalized centrality and the centralization index may be larger than 100%.

Actor-by-centrality matrix saved as dataset FreemanDegree

B3b. Interpretation of 2000+ years statistics

In the year 2000 and subsequent years, the knowledge network based on ASM articles issued was less centralized (centralization score was ~10%) and far less homogenous (homogeneity score was ~5%) compared to the previous period analyzed. The centralization score, based on further analysis, shows that the new 'upper echelon' consisted of Bullemer, Guerlain, and Aradhye (3 out of 30—24 new authors + 6 authors from the prior period—or 10% of the group issuing articles) who occupied the highest positions of access and control. The other authors were for the most part disconnected from direct access to each other. The homogeneity score means that the group was much more diverse than in the prior period.

Of the 6 authors who issued articles during the '1999 and before' period and who also issued articles this period (Emigholz, Bullemer, Nimmo, Miller, Guerlain and Jamieson), only Bullemer worked with authors 'new' to the '2000 and after' period. The other 5 authors remained inclusive or published alone. Thus, Bullemer was the sole connecting person between the 2 time periods.

During this '2000 and after' period, Bullemer held more connections to others than Guerlain (who published only with Bullemer), and Aradhye, but because of Guerlain's redundancy to Bullemer, Aradhye and Bullemer ranked highest for control, information and access; 2.5 times Guerlian's rank.

Further dissection of the reduced centralization score shows that although Bullemer and Aradhye held the most information control, and access to others (e.g., they could provide the best referrals and usually had privy to more knowledge of articles issued or in process than others), they were not far ahead of Good, Rajagopalan, Errington, Guerlain, Emigholz, Srinivasan, Davis, Jamieson, and Vedam. Cochran was absent from this period of data, indicating that what dominated the knowledge network in an 'authoritarian-sense' (based on article-linkages) was now gone. This drastic change (from having such a 'hierarchical, easily identified central player-type of network' to a 'flatter, more knowledge-egalitarian type of network') may be associated with a critical event or significant leadership change within the consortium. A caveat: sensitivity to other delineations between periods could also illuminate different structural changes in the network.

Note: The matrix consisted of 30 x 30 authors with cell-values computed based on 18 articles issued.

B4a. Statistics for all years

All years

FREEMAN'S DEGREE CENTRALITY MEASURES:

Diagonal valid? NO
Model: SYMMETRIC

		1 Degree	2 NrmDegree	3 Share
9	P.Bullemer	10.000	24.390	0.139
2	T.Cochran	8.000	19.512	0.111
20	H.Aradhye	5.000	12.195	0.069
34	M.Good	4.000	9.756	0.056
13	G.Jamieson	3.000	7.317	0.042
40	S.Rajagopalan	3.000	7.317	0.042
1	K.Emigholz	2.000	4.878	0.028
11	S.Guerlain	2.000	4.878	0.028
21	J.Davis	2.000	4.878	0.028
29	R.Srinivasan	2.000	4.878	0.028
23	J.Errington	2.000	4.878	0.028
5	I.Nimmo	2.000	4.878	0.028
15	P.Milner	2.000	4.878	0.028
18	H.Vedam	2.000	4.878	0.028
10	C.Miller	2.000	4.878	0.028
7	N.Anderson	1.000	2.439	0.014
38	J.Downs	1.000	2.439	0.014
33	D.Fennel	1.000	2.439	0.014
4	M.Knight	1.000	2.439	0.014
16	C.Mattiasson	1.000	2.439	0.014
26	S.Ahalt	1.000	2.439	0.014
22	D.Mylaraswamy	1.000	2.439	0.014
3	D.Beach	1.000	2.439	0.014
14	K.Vicente	1.000	2.439	0.014
25	S.Rathnasabapatry	1.000	2.439	0.014
36	J.Deaton	1.000	2.439	0.014
37	F.Glenn	1.000	2.439	0.014
28	A.Sundarraman	1.000	2.439	0.014

		1 **Degree**	2 **NrmDegree**	3 **Share**
8	K.Vamsikrishna	1.000	2.439	0.014
30	Jliu	1.000	2.439	0.014
41	P.Viswanathan	1.000	2.439	0.014
32	D.Attwood	1.000	2.439	0.014
35	M.Dorneich	1.000	2.439	0.014
24	B.Bakshi	1.000	2.439	0.014
42	N.Ananthanarayanan	1.000	2.439	0.014
19	J.Koene	1.000	2.439	0.014
12	D.Campbell-Brown	0.000	0.000	0.000
6	T.Ramesh	0.000	0.000	0.000
39	D.Metzger	0.000	0.000	0.000
17	M.Clark	0.000	0.000	0.000
31	T.Montgomery	0.000	0.000	0.000
27	A.Nochur	0.000	0.000	0.000

DESCRIPTIVE STATISTICS

		1 **Degree**	2 **NrmDegree**	3 **Share**
1	Mean	1.714	4.181	0.000
2	Std Dev	1.931	4.709	0.000
3	Sum	72.000	175.610	0.000
4	Variance	3.728	22.177	0.000
5	SSQ	280.000	1665.675	0.000
6	MCSSQ	156.571	931.418	0.000
7	Euc Norm	16.733	40.813	0.000
8	Minimum	0.000	0.000	0.000
9	Maximum	10.000	24.390	0.000

Network Centralization = 21.22%
Homogeneity = 5.40%

NOTE: For valued data, both the normalized centrality and the centralization index may be larger than 100%.

Actor-by-centrality matrix saved as dataset Freeman Degree

BONACICH CENTRALITY

WARNING: This version of the program cannot handle asymmetric data.
Matrix symmetrized by taking larger of Xij and Xji.

EIGENVALUES

FACTOR	VALUE	PERCENT	CUM %	RATIO
1:	7.690	21.7	21.7	1.533
2:	5.015	14.2	35.9	1.896
3:	2.646	7.5	43.4	1.201
4:	2.203	6.2	49.6	1.101
5:	2.000	5.7	55.3	1.000
6:	2.000	5.7	60.9	1.082
7:	1.848	5.2	66.2	1.142
8:	1.618	4.6	70.7	1.068
9:	1.515	4.3	75.0	1.071
10:	1.414	4.0	79.0	1.048
11:	1.350	3.8	82.8	1.350
12:	1.000	2.8	85.6	1.000
13:	1.000	2.8	88.5	1.000
14:	1.000	2.8	91.3	1.000
15:	1.000	2.8	94.1	1.000
16:	1.000	2.8	97.0	1.307
17:	0.765	2.2	99.1	2.452
18:	0.312	0.9	100.0	
	35.376	100.0		

Bonacich Eigenvector Centralities

		1 **Eigenvec**	2 **nEigenvec**
1	K.Emigholz	0.091	12.920
2	T.Cochran	0.669	94.551
3	D.Beach	0.000	0.000
4	M.Knight	0.000	0.000
5	I.Nimmo	0.292	41.240
6	T.Ramesh	-0.000	-0.000
7	N.Anderson	-0.000	-0.000
8	K.Vamsikrishna	-0.000	-0.000
9	P.Bullemer	0.599	84.757
10	C.Miller	0.099	13.994
11	S.Guerlain	0.179	25.338
12	D.Campbell-Brown	0.000	0.000
13	G.Jamieson	0.092	13.062
14	K.Vicente	0.012	1.699
15	P.Milner	0.174	24.590
16	C.Mattiasson	0.078	11.022
17	M.Clark	0.000	0.000
18	H.Vedam	0.000	0.000
19	J.Koene	0.000	0.000
20	H.Aradhye	0.000	0.000
21	J.Davis	-0.000	-0.000
22	D.Mylaraswamy	0.012	1.680
23	J.Errington	0.116	16.384
24	B.Bakshi	0.000	0.000
25	S.Rathnasabapatry	-0.000	-0.000
26	S.Ahalt	0.000	0.000
27	A.Nochur	0.000	0.000
28	A.Sundarraman	0.000	0.000
29	R.Srinivasan	0.000	0.000
30	Jliu	0.000	0.000
31	T.Montgomery	0.000	0.000
32	D.Attwood	0.000	0.000
33	D.Fennel	0.000	0.000
34	M.Good	0.000	0.000
35	M.Dorneich	-0.000	-0.000
36	J.Deaton	-0.000	-0.000
37	F.Glenn	0.000	0.000

		1	2
		Eigenvec	**nEigenvec**
38	J.Downs	0.000	0.000
39	D.Metzger	-0.000	-0.000
40	S.Rajagopalan	0.000	0.000
41	P.Viswanathan	0.000	0.000
42	N.Ananthanarayanan	0.000	0.000

Descriptive Statistics

12

		Eigenvec	**nEigenvec**
1	Mean	0.057	8.125
2	Std Dev	0.143	20.253
3	Sum	2.413	341.237
4	Variance	0.021	410.180
5	SSQ	1.000	20000.000
6	MCSSQ	0.861	17227.549
7	Euc Norm	1.000	141.421
8	Minimum	-0.000	-0.000
9	Maximum	0.669	94.551
10	N of Obs	42.000	42.000

Network centralization index = 104.92%
WARNING: Centralization index uninterpretable for disconnected graphs.
1=redundant; lower score — less constrained (brokers)

Structural Hole Measures

		1	2	3	4
		EffSize	**Efficie**	**Constra**	**Hierarc**
1	K.Emigholz	2.000	1.000	0.500	0.000
2	T.Cochran	4.000	1.000	0.344	0.407
3	D.Beach	1.000	1.000	1.000	1.000
4	M.Knight	1.000	1.000	1.000	1.000
5	I.Nimmo	2.000	1.000	0.500	0.000
6	T.Ramesh	0.000	0.000	0.000	
7	N.Anderson	1.000	1.000	1.000	1.000
8	K.Vamsikrishna	1.000	1.000	1.000	1.000
9	P.Bullemer	6.000	1.000	0.240	0.387
10	C.Miller	2.000	1.000	0.500	0.000
11	S.Guerlain	1.000	1.000	1.000	1.000
12	D.Campbell-Brown	0.000	0.000	0.000	
13	G.Jamieson	3.000	1.000	0.360	0.122
14	K.Vicente	1.000	1.000	1.000	1.000
15	P.Milner	1.000	1.000	1.000	1.000
16	C.Mattiasson	1.000	1.000	1.000	1.000
17	M.Clark	0.000	0.000	0.000	
18	H.Vedam	2.000	1.000	0.500	0.000
19	J.Koene	1.000	1.000	1.000	1.000
20	H.Aradhye	4.000	1.000	0.280	0.168
21	J.Davis	1.000	1.000	1.000	1.000
22	D.Mylaraswamy	1.000	1.000	1.000	1.000
23	J.Errington	2.000	1.000	0.500	0.000
24	B.Bakshi	1.000	1.000	1.000	1.000
25	S.Rathnasabapatry	1.000	1.000	1.000	1.000
26	S.Ahalt	1.000	1.000	1.000	1.000
27	A.Nochur	0.000	0.000	0.000	
28	A.Sundarraman	1.000	1.000	1.000	1.000
29	R.Srinivasan	2.000	1.000	0.500	0.000
30	Jliu	1.000	1.000	1.000	1.000
31	T.Montgomery	0.000	0.000	0.000	
32	D.Attwood	1.000	1.000	1.000	1.000
33	D.Fennel	1.000	1.000	1.000	1.000
34	M.Good	4.000	1.000	0.250	0.000
35	M.Dorneich	1.000	1.000	1.000	1.000
36	J.Deaton	1.000	1.000	1.000	1.000
37	F.Glenn	1.000	1.000	1.000	1.000

		1 EffSize	2 Efficie	3 Constra	4 Hierarc
38	J.Downs	1.000	1.000	1.000	1.000
39	D.Metzger	0.000	0.000	0.000	
40	S.Rajagopalan	3.000	1.000	0.333	0.000
41	P.Viswanathan	1.000	1.000	1.000	1.000
42	N.Ananthanarayanan	1.000	1.000	1.000	1.000

B4b. Interpretation of statistics for all years

Overall, Bullemer ranked highest in terms of article-based knowledge control and access among all authors who issued ASM articles between 6/30/1995 – 2/21/2002.

Cochran followed in second place, but was absent from work done in the year 2000 and beyond.

Aradhye claimed third place, but he was absent from work done in 1999 and prior years.

During all years analyzed, Nimmo issued the most sole-authored articles (5 out of 7 or ~71%). Bullemer issued the most articles (12), of which only 2 were sole authored (~17%). Cochran issued 11 articles, of which 3 (~27%) were sole authored. Aradhye issued 5 articles, none of which were sole-authored. The remaining numbers of articles issued was 4 (N=1); 3, 3, 3 (N=3); 2, 2, 2, 2, 2, 2, 2, 2, 2 (N=9); 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 (N=23), averaging 2.225 articles per person. Clearly, Bullemer, Cochran, Nimmo, Aradhye and Good (who worked on 4 articles), respectively, lead the knowledge-generation efforts at ASM.

Overall, in terms of influence, Cochran was identified by the normalized Eigenvalue Index to have been most influential, followed closely by Bullemer. Nimmo was in third place for 'influence', with a score about half that of Bullemer's influence score. Guerlain and Milner tied for 4th in terms of influence, with Errington coming in 5th place. The only other authors that had any influence at all were (in order of most to least): Miller, Jamieson, Emigholz, and Mattiasson.

Overall, Bullemer was the author who had the opportunity to broker the most knowledge in the network. Aradhye came in 2nd with Good following a close 3rd. Rajagopalan, Cochran and Jamieson came in 4th. Emigholz, Nimmo, Miller, Vedam, Errington, and Srinivasan had moderate knowledge-brokering opportunities, and no only else had any opportunity to broker knowledge in the complete network analyzed. (Note: a knowledge-brokering opportunity is defined as an opportunity to connect otherwise disparate knowledge; the opportunity to create new knowledge combinations if you will).

Overall, in terms of number of direct connections to others, Bullemer's direct network consisted of 6 colleagues, Cochran's, Aradhye's, and Good's consisted of 4 colleagues each, and Jamieson's and Rajagopalan's consisted of 3 colleagues each. Of course, the indirect connections (with whom did their direct contacts connect?) makes the difference in terms of whether these active authors got any benefits or not from their co-authors (e.g., the linchpin is: with whom did the co-author's have co-authoring relationships with, and were these people active or not?).

Note: The matrix consisted of 40 x 40 authors with cell-values computed based on 29 articles issued.

Appendix C:

Membership, fees and member commitment

Table C1: Membership Comparison from early ASMC to 2005

Early Members (1994 Legal Agreement)	Notes	2005 Members
Honeywell, Ian Nimmo, Ted Cochran and Peter Bullemer	Dal Vernon Reising, ASMC PI for Honeywell until 2005 has now joined an ASMC member company	Honeywell, Kevin Harris, ASMC Director; Doug Metzger, Development Manager; includes Honeywell Specialty Materials, essentially a user member, and UOP
SACDA, Inc., Paul Fish		
Shell Canada Limited, Ed Huestis Shell Oil Company, Tony Delyria (followed by George Paoli)	Only one company member currently	Shell Oil Company, Manish Bharati
British Petroleum, Doug Rothenberg Amoco Oil, Mike Clark	British Petroleum and Amoco merged and maintained membership after the merger, but are not members now.	
Exxon Research & Technology, Ken Emigholz Mobil Corporation, Din Attarwala	Exxon and Mobil merged	ExxonMobil, Ken Emigholz
Chevron Research & Technology, Roger Humphrey	Chevron and Texaco merged and the joint company maintains current membership	Chevron, Tim Montgomery
Novacor Chemicals, Jaime Errington	Nova Chemicals maintained membership until 2004; elected not to renew membership	

Early Members (1994 Legal Agreement)	**Notes**	**2005 Members**
Applied Training Resources, John Josserand		
Gensym Corporation, Paul Lindenfelzer		
		Celanese Chemicals, Darrell Bond
		ConocoPhillips, Bruce Colgate & Bob Zapata
		BAW, Karen Smith
	Associate member company formed by one of the early ASMC company representatives	TTS Peformance Systems, Jack Pankoff & Kevin Smith
	Associate member company, UCDS, formed by one of the early Honeywell ASMC founders, Ian Nimmo. UCDS held membership prior to 2005, but elected not to renew membership.	
	Associate member company formed by former Honeywell and ASMC company representatives	HCS, Peter Bullemer and Jaime Errington joined in 2005
		UCLA , Jim Davis
		NTU Singapore, Martin Helander

Table C2: Membership fee structure, 2005–2008 plan

Membership Class	Annual Membership Fee	Initiation Fee	Notes
Honeywell	Allocate the equivalent of at least four FTEs of product development resources each year for the Consortium-directed Development Program; allocate the equivalent of two FTEs of research personnel resources; allocate at least one FTE in professional support		This commitmnt was made with the 2001–04 program in response to ASMC members' desire to see more product deliverables that embody ASM knowledge
User Members (petro-chemical companies)	Annual membership fee to the ASMC Joint Fund based on the company's prior year annual gross revenue <$100M = $30K fee $100M -$1B = $40K fee >$1B = $50K fee Also contribute at least 1/4 FTE as an in-kind contribution	Initiation fee based on prior year annual gross revenue <$100M = $50K fee $100M - $1B = $75K fee >$1B = $100K fee	Sliding membership fee is a new feature. Previously, user members had a flat $50K fee. The sliding initiation fee and/or partial payment through in-kind contributions is also new. Previously $500K represented the initiation fee.
Associate Members (companies that provide unique knowledge or capabilities related to ASM)	Annual membership fee to the ASMC Joint Fund based on the company's prior year annual gross revenue <$50M = $10K fee $50M - $100M = $15K fee >$100K = $30K fee Also contribute at least 1/6 FTE as an in-kind contribution	Initiation fee based on prior year annual gross revenue <$50M = $10K fee $50M -$100M = $15K fee >$100K = $20K fee	Sliding scale for membership is consistent, but sliding scale for the initiation fee is new. Previously $25K represented the initiation fee.
University Members	$50K matching in-kind contribution	No initiation fee.	Stable fee structure over the life of the ASMC.

Table C3: Perceived company benefits

	Benefits	Financial Gains or Costs (in $)	Qualitative Gains or costs	Length of Participation	Have benefits changed over time?
Honeywell	Customer input Improved products & services influence	None	Improved products Better communication with customers	Since inception	Yes
User Members	Honeywell's products Guidelines and best practices from ASMC	None listed	None listed	Varies from inception to 2000	Yes
Associate Members	Marketing & Product development opportunities	None listed	Helps sell services	Varies from inception to late 1990s	No

Appendix D:

Survey Instruments

Abnormal Situation Management Organizational Questionnaire

All of your responses will be kept confidential and will not be attributed directly to you or to your company.

	This past year?	Over the past 5 years?
1. How many projects does your company do with Honeywell outside of ASM Consortium?		
2. How many projects does your company do with Honeywell within the ASM Consortium?		
3. How many projects do your per-sonally work on with Honeywell outside of the ASM Consortium?		
4. How many projects do you per sonally work on with Honeywell within the ASM Consortium?		
5. How many of your Alarm Manage-ment projects are done outside of the ASM Consortium?		
6. How many of your Alarm Management projects are done within the ASM Consortium?		

		Strongly Disagree	Somewhat Disagree	Disagree	Neutral	Agree	Somewhat Agree	Strongly Agree
1.	One of the major reasons my organization continues to be a part of this consortium is that leaving would require considerable sacrifice—another consortium may not match the overall benefits we have here.	1	2	3	4	5	6	7
2.	My organization's commitment to the ASM Consortium has increased over time.	1	2	3	4	5	6	7
3.	My organization's commitment to the ASM Consortium has decreased over time.	1	2	3	4	5	6	7
4.	My organization was more committed to the ASM Consortium when there was NIST funding.	1	2	3	4	5	6	7
5.	My organization is committed to being an active part of the ASM Consortium.	1	2	3	4	5	6	7
6.	The information gained through the ASM Consortium has allowed my organization to solve routine problems more quickly.	1	2	3	4	5	6	7
7.	The information gained through the ASM Consortium has helped my organization recognize critical situations faster.	1	2	3	4	5	6	7
8.	When workers participate in ASM research projects, their situation awareness improves.	1	2	3	4	5	6	7
9.	Fewer situations turn critical because of information developed in the ASM Consortium.	1	2	3	4	5	6	7

10. My organization has adopted software that emerged from the ASM Consortium.	1	2	3	4	5	6	7
	Strongly Disagree	**Somewhat Disagree**	**Disagree**	**Neutral**	**Agree**	**Somewhat Agree**	**Strongly Agree**
11. My organization has changed its standard operating procedures as a result of the ASM Consortium.	1	2	3	4	5	6	7
12. My organization modified its approach to Abnormal Situation Management as a result of information from the Consortium.	1	2	3	4	5	6	7

Company Name: ______________________ **Your Name:** ______________________

Abnormal Situation Management Networking with Members

This questionnaire attempts to identify patterns of interaction between members. Your answers will help the Penn State team understand communication between ASMC members. All of your responses will be kept confidential and will not be attributed directly to you or to your company.

Who do you most often collaborate with in the ASMC?

Name: **Type of collaboration** **Frequency**

1. ______________________
2. ______________________
3. ______________________
4. ______________________
5. ______________________

On a scale of 1 to 5, please rate the following statements.

	Strongly Disagree	Disagree	Indifferent	Agree	Strongly Agree
1. I am part of a smaller group of ASMC members that work more closely together than the consortium as a whole.	1	2	3	4	5
2. I routinely seek the advice of my ASMC colleagues.	1	2	3	4	5
3. My company leverages its ASMC membership through my contacts with other ASMC company representatives.	1	2	3	4	5
4. My company maintains projects outside of the scope of ASMC (separately funded) with other ASMC company members.	1	2	3	4	5
5. My company's only contact with ASMC members is related to ASMC activities.	1	2	3	4	5
6. During meetings I seek out specific colleagues to interact with.	1	2	3	4	5
7. During meetings I speak with all other participants at least once during each day.	1	2	3	4	5
8. Most of my conversations with other ASMC members concern abnormal situation management topics.	1	2	3	4	5
9. I have similar interests to most other ASMC members.	1	2	3	4	5
10. During the course of ASMC meetings, I feel I am able to influence the direction of conversations and discussions.	1	2	3	4	5

Company Name: ________________________ **Your Name:** ________________________

Abnormal Situation Management Personal and Professional Questionnaire

This questionnaire seeks to identify the commitment that your company has maintained to the ASMC over time. In addition, we hope to identify differences between your personal commitment to the ASMC and your professional commitment to ASMC as the result of your company's membership. All of your responses will be kept confidential and will not be attributed directly to you or to your company.

On a scale of 1 to 5, please rate the following statements.

	Strongly Disagree	Disagree	Indifferent	Agree	Strongly Agree
1. I actively sought to be my company's representative to the ASMC.	1	2	3	4	5
2. My company assigns its representative based on time availability.	1	2	3	4	5
3. My company assigns its representative based on knowledge and experience with abnormal situations.	1	2	3	4	5
4. I actively participate in research projects with other ASMC members.	1	2	3	4	5
5. Other members of my company participate in research projects with ASMC members.	1	2	3	4	5
6. I collaborate with other ASMC company representatives in non-ASMC activities.	1	2	3	4	5
7. I have published articles with other ASMC company representatives.	1	2	3	4	5
8. I only communicate with other ASMC company representatives at the quarterly meetings.	1	2	3	4	5
9. I attend at least two quarterly meetings every year.	1	2	3	4	5
10. I have been the only representative for my company at ASMC meetings.	1	2	3	4	5
11. Personnel in my company can describe the ASMC and its philosophy.	1	2	3	4	5
12. My immediate supervisor is familiar with my activities in ASMC.	1	2	3	4	5

	Strongly Disagree	Disagree	Indifferent	Agree	Strongly Agree
13. My company considers my participation in the ASMC during my performance evaluations.	1	2	3	4	5
14. I contact other ASMC company representatives to confer on common problems.	1	2	3	4	5
15. I have personal relationships with other company representatives outside of the scope of the ASMC activities.	1	2	3	4	5
16. I am (or have been) my company's representative in other consortiums.	1	2	3	4	5
17. The ASMC is my primary venue to maintain contact with other professionals outside of my company.	1	2	3	4	5
18. In describing my professional achievements, my direct association with the ASMC is important.	1	2	3	4	5

Company Name: ______________________________ **Your Name:** ______________________________

Abnormal Situation Management Goals and Objectives Questionnaire

This questionnaire focuses on the relationship between your company's goals and objectives surrounding abnormal situation management and the goals and objectives of the ASMC. As you consider your answers, please think about how closely aligned your company is to the ASMC's research and development agenda. Your answers will help the Penn State team refine its thinking about how consortium activities support individual company activities over time. All of your responses will be kept confidential and will not be attributed directly to you or to your company.

On a scale of 1 to 5, please rate the following statements.

	Strongly Disagree	**Disagree**	**Indifferent**	**Agree**	**Strongly Agree**
1. The ASMC goals are the same as my company's goals concerning safety.	1	2	3	4	5
2. My company shares the same philosophy as the ASCM regarding abnormal situation control.	1	2	3	4	5
3. My company and ASMC share the same definition of what constitutes an abnormal situation.	1	2	3	4	5
4. My company is more interested in the knowledge gained from ASMC membership than it is in the software products produced.	1	2	3	4	5
5. My company seeks to install all of the ASMC products for abnormal situation control across its plants.	1	2	3	4	5
6. My company's approach to plant maintenance is similar to the ASMC philosophy.	1	2	3	4	5
7. My company has been deeply involved in setting the research strategy for the ASMC.	1	2	3	4	5
8. My company has been able to influence ASMC research agendas to coincide with our control needs.	1	2	3	4	5
9. My company's influence has remained constant over the life of our membership in ASMC.	1	2	3	4	5

	Strongly Disagree	Disagree	Indifferent	Agree	Strongly Agree
10. My company is influential in establishing the ASMC research agenda.	1	2	3	4	5
11. My company was influential in establishing ASMC technology and solution development.	1	2	3	4	5
12. ASMC research and development activities directly impact my company's R&D investments.	1	2	3	4	5
13. ASMC research and development activities indirectly influence my company's R&D investments.	1	2	3	4	5
14. My company has partnered with other ASMC members to develop or implement technology solutions to situation management.	1	2	3	4	5
15. My company has partnered with non-ASMC members to develop or implement technology solutions to situation management.	1	2	3	4	5

Company Name: ______________________ **Your Name:** ______________________

Abnormal Situation Management Company Benefits Questionnaire

This questionnaire addresses the benefits that your company has derived from its membership in the ASM Consortium. As you reflect on your answers, keep in mind that your responses will not be attributed to you directly or to your company. Your responses will help the Penn State team explore ways to quantify what are more traditionally described as qualitative benefits.

Describe the top five benefits that your company has accrued from its membership in the ASMC.

Benefit	**Dollar gains or cost savings related to benefit**	**Qualitative gains or cost savings related to benefit**

How long has your company participated in the ASMC? ______________________________

____

Have the benefits that your company received through its membership in the ASMC changed over the life of your participation? ______________________________

____

Company Name: ____________________ **Your Name:** ____________________

Abnormal Situation Management Support Questionnaire

Please describe the top three reasons for each question

Questions	Reason 1	Reason 2	Reason 3
Why did your company choose to join the ASMC?			
Why does your company continue to support the ASMC?			
Why does your company contribute money to the ASMC?			

	I influence decision	I make decision	My boss makes decision	Another unit makes decision (please specify)
1. Who makes the decision to commit funds to the ASMC?				
2. Who in your organization has the power to purchase software developed in the ASMC?				

Please feel free to elaborate on the back of this page if you feel you need more room for your answers.

Company Name: ______________________ **Your Name:** ______________________

Appendix E:

Consortia Comparison Table

Criteria	ASMC	MACC	MCC	SEMATECH
Organization Type	Non-Profit Members are competitors outside of the consortium	University-based Non-Profit Some members are competitors, while other members are not competitors per se outside of the consortium; pre-competitive	For-profit Members are competitors outside of the consortium	Non-Profit Members are competitors outside of the consortium National Threat & Technology Crisis
Impetus for Starting and Initial Funding (AKA Business Model)	Alarm Management Crisis spawned by emerging digital technology Motivated by individuals and a core company – Honeywell –who was trying to figure out how to leverage their software. Privately pushed	Ongoing problems in process control Formation initiated by university with cooperation of 5 companies; funded solely by memberships and any additional small grants received (small, because MACC is project-based). Privately pushed	National Threat to Gross National Product Government-initiated but with 100% private funding. Government pulled	Government and Industry Trade Association jointly agreed that response was necessary; 50% gov't funding, 50% private funding.[i] Private & Government Sector Motivated

Reflections: MACC was the only consortium of the four that was not initiated as a response to a crisis. In the majority of cases, cooperative efforts that pool resources together are often started as a response to a threat[ii] and are of a magnitude that no one firm can do alone.[iii] However, the mindset required to cooperate is opposite the intense competitive nature and high emphasis on proprietary work germane to high-technology members.[iv] In general crises may only serve as short-term motivators.

MCC for example started to decline after the Japanese threat (crisis) dwindled. As a crisis subsides, members will ask: why am I here? Sustaining collaboration amongst a large group of members over time is a major challenge. ASMC continues to exist even though the alarm management crisis has lessened with the introduction of new processes. However, members believe that work remains to be done to truly predict and thus reduce/eliminate abnormal situations transitioning to a disaster.

continued

Criteria	**ASMC**	**MACC**	**MCC**	**SEMATECH**
Initial Leadership	Three founding individuals shared leadership ASMC was a group of concerned scientists and visionaries	Two founding individuals shared leadership; science-based, heavily aimed at research; initial leadership was visionary in terms of the problem they selected to work on (use statistical analyses to determine when process patterns begin to change; versus examining individual measurements).	MCC founders appointed a very charismatic leader; a visionary with limited term of office Choice of initial leader deemed very important to the consortium's success.	Semiconductor Industry Association formed a committee of 13 corporations. This committee became the consortium. No leader for first year; the consortium searched for a year to find the right leader Choice of initial leader deemed very important to the consortium's success; as learned from MCC
Reflections: Initial leadership plays a significant role in the image of the new organization and its ability to overcome a liability of newness. Leaders who are widely-respected and -known, admired and charismatic create valuable relationships are able to attract top quality employees and researchers. In addition, charismatic personalities are often associated with dynamic and volatile phenomena and with profound and sudden transformations. Thus, placing strong emphasis on an early leader's qualities is expected. All four consortia benefited from early charismatic leadership; In the cases of ASMC and MACC, the founders were the charismatic visionaries; with MCC and SEMATECH founders actively sought such a leader.				
Initial Direction and Objectives	Longer-term theoretical focus with the goal to transition to applied results into product solutions. Goal: To create applied research and move it to commercialization.	Short-term incremental applied solutions aimed at a long-term problem. Goal: To generate an ongoing plethora of newly developed concepts and hand them over for application after proof of concept (e.g., information artifacts, code); this is accomplished within the university goals of publishing and educating students.	Long-term theoretical focus; with the eventual goal to generate products (explicit intellectual property); only limited plans for transition to commercial use. Goal: Create Theoretical Research and move it to applied research then to commercialization.	Long-term focus to improve industry supply base of equipment and materials; to improve manufacturing processes; to improve the management of factories (Peterman, 1988).[v] Long-term expectations balanced against annual planning cycle. Goal: Applied Research with emphasis on technology transfer to members (not commercializa-tion per se); adjusted as needed to meet member's needs.

continued

Criteria	ASMC	MACC	MCC	SEMATECH
Reflections: The initial direction and objectives of the consortia all had in common the act of converting research to use. SEMATECH and MACC placed the most emphasis on technology transfer to members. ASMC and MCC placed high value on commercialization, but neither admittedly nor directly incorporated into its culture the 15 to 20 year time span generally required to commercialize basic research from the time of its invention (c.f., Browning, Beyer, & Shetler, 1995).[vi]				
Goal—Consistency over Time	Three year planning cycle. Goal has transitioned from theoretical development to product development to product deployment. Now ASMC's goals are being reconsidered. Members expected goals to stay consistent, but have realized that emphasis must change.	Goal has been consistent: To invent and apply. This goal has remained consistent over the consortium's life. Members expected goal to stay consistent.	Goal changed over time; different leaders put different goals into place. Members did not always expect goals to change the way they did.	Goals were fluid and expected to be so. Priority was placed on frequent adjustment and evolution of consortium goals to meet members' needs. Members defined what changes were needed, and goal-changes were well-communicated to all members.
Reflections: Organizations need to be able to overcome structural inertia, competitive inertia, organizational momentum, and their current management logic to maintain internal consistency, especially when shifts become necessary.[vii] Thus, as long as goal shifts are communicated effectively and are well-understood, they should improve the organization's ability to adapt. As goals evolve, member expectations need to evolve or, perhaps, membership needs to evolve.				
Organization Structure	Leverage members' knowledge — ASMC members meet at off-site locations and allow site-visits to each other's plants. Responsibility for technology transfer was centralized with Honeywell as expected product developer. Organic	The academicians and students are considered the experts, and the users/members are considered those in need who have data, resources, and facilities to share, serving as test beds. Responsibility for technology transfer was decentralized. Organic	Leverage members' resources — separate facility eventually built for members to work together. Responsibility for technology transfer was decentralized. Large size Mechanistic with highly developed hierarchy	Leverage members resources and knowledge — set up own facilities where members came to work together; Created "technical terms dictionary" to facilitate effective communication; Responsibility for technology transfer was fairly well centralized. Mechanistic with limited hierarchy

continued

Criteria	ASMC	MACC	MCC	SEMATECH
Reflections: Organic organizational structures are more fluid and nimble with respect to adjusting to turbulent environments, whereas mechanistic structures place emphasis on command and control that often makes the timeliness of a change slower.				
Membership	Small homogeneous set of members Membership declined in part due to consolidation	Small diverse set of members Stable target number of members	Large diverse set of members Fast growing membership to drive Consortium resources	Small homogeneous set of members Core members remain
Reflections: All consortiums' members came together as collaborators wanting knowledge that if not gleaned would have hurt them economically. In the cases ASMC and MACC, members also knew that no other outlet for information generated by the consortium existed, so they are motivated to participate and share. Differences in consortia occur in terms of diversity of membership, longevity of membership, and rate of membership growth. A highly diverse membership with high longevity should lead to better decisions than a homogenous membership with high longevity (e.g., because groupthink is likely to set in).[viii] A highly diverse membership without longevity experiences loss of effectiveness as the group continues to form and reform, thus taking time away from expressed goals. There is a fine line between the cost — the time, effort/energy, and money required to initiate and sustain diverse groups working together — and the benefits of such collaboration in terms of newness, innovativeness, and impact able to be generated.				
Leadership over the Continuum	2 periods (research and development phases) with distinctly different leadership; Bullemer provided leadership overlap.	1 period, consistent over time	3 periods with distinctly different leadership; no leadership overlap.	Multiple periods, but seamless; CEO and Chairman of the Board changed but appeared to seamlessly carry SEMATECH over its history without significant disruption between periods; structures of governance initially in place were durable and upheld by each successor (even when Noyce (initial leader) suddenly died 2 years after taking office).

continued

Criteria	ASMC	MACC	MCC	SEMATECH
Extent to which achieved success	Measure of success not well-defined. ASMC has been in existence for the last 13 years.	Measure of success: the extent of sharing across the membership (give and take); the extent to which the consortium identifies future collaboration opportunities; Another important measure was acceptance of results by others in academe and industry. One measure is invitations to present results at industrial, trade association and academic conferences. MACC has been performing for the last 17 years.	Success was measured as learning to collaborate.[ix] MCC's greatest challenge, like that of ASMC, was to get its technologies used or transferred in such ways as to please members in terms of identifiable, measured and tangible outcomes. MCC, like ASMC, was highly criticized for not having specific, measurable results. MCC lasted ~10 years.	Success measured many ways: ability to thwart Japanese threat; ability to invent semiconductor breakthroughs that significantly advanced the industry; ability to keep its members satisfied; and survivability. SEMATECH has been performing for the last 19 years.

Reflections: Success is based on how the evaluator defines it. Intangible benefits are often as important as tangible results. Refining the process and ways of making a consortiu, work is one outcome that rarely gets adequate acknowledgement. For example, members of both ASMC and MCC benefited greatly from the collaborative experience, even though tangible results from such collaborations were lower than expected. Both MACC and SEMATECH base success on member's perceptions—their mindset centered on the community; whereas ASMC and MCC had what appeared to be more arms-length definitions of success with a mindset centered on individual companies getting their own benefits from the consortium's efforts. Paradoxically, MACC and SEMATECH initiated goals to enable technology transfer more clearly than did ASMC or MCC.

i. New business model that positions the consortium to operate without federal funding was initiated in 1995 (http://www.sematech.org/corporate/timeline.htm).

ii. R. Axelrod. (1984). The Evolution of Cooperation. New York: Basic Books.

iii. J. J. Barron. (1990). Consortia: High•Tech co•ops. Byte, 15(June): 15 page 269.

iv. L. D. Browning, J. M. Beyer, and J. C. Shetler. (1995). Building cooperation in a competitive industry: SEMATECH and the semiconductor industry. Academy of Management Journal, vol. 38, iss. 1, 113•151.

v. J. Peterman. (1988). Address to the Industrial Research Institute at the meeting of the National Academy of Sciences, Washington, DC.

vi. Ibid.

vii. Cynthia A. Lengnick•Hall,JamesA.Wolff.(1999). Similaritiesandcontradictionsinthecore logic of three strategy research streams. Strategic Management Journal, vol. 20, iss. 12, pp. 11091132.

viii. See C. McCauley. (1998). Group Dynamics in Janis•s Theory of Groupthink: Backward and Forward. Organizational Behavior and Human Decision Processes, Vol. 73, Num. 23, pp. 142–162.

ix. David V. Gibson and Everett M. Rogers. (1994). R&D Collaboration on Trial: The Story of MCC—America's first major for•profit R&D consortium—and its quest to enhance the competitiveness of America's high•tech firms. Harvard Business School Press.

About the Authors

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