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THE EVOLVING NATURE OF GM R&D'S COLLABORATIVE RESEARCH LABS: LEARNING FROM STAGES AND ROLES

ROBERT T. TROTTER, II
Northern Arizona University

ELIZABETH K. BRIODY
Vehicle Development Research Lab

LINDA B. CATLIN
Claymore Associates

TRACY L. MEERWARTH
Vehicle Development Research Lab

GÜLCIN H. SENGIR
Manufacturing Systems Research Lab

Approved by Jan H. Aase
Vehicle Development Research Lab

Approved by Steven Holland
Manufacturing Systems Research Lab

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ABSTRACT

GM has initiated collaborative partnerships with prestigious research institutions, private-sector firms, and other partners at an increasingly rapid pace over the last decade. This paper, based on ethnographic interviews, observations, and social-network data, focuses on three dimensions of GM R&D's university collaborations. First, we profile the key historical trends in GM's first four university partnerships known as Collaborative Research Laboratories (CRLs). In these profiles, we note some of the decisions faced, issues confronted, and techniques employed to create the partnerships and achieve their joint work goals. Second, we focus on the combined experiences of the CRLs to describe the stages and transitions found in the partnership cycle. This allows us to document the role of participants central to the network, examine their impact on the partnership, and identify structural changes over time. Third, we focus on the evolutionary changes in CRLs as a partnership type. Symbolic, structural, and work practice changes indicate that CRLs are fundamentally different today than they were at their inception in 1998. Together, insights from the individual and combined CRL experiences, along with the evolution in this organizational form, shed light on how CRL partnerships can be strengthened and new ones cultivated.

INTRODUCTION

As market competition intensifies, firms around the world seek to expand their potential for growth while mitigating their risks. Mergers, acquisitions, joint ventures, strategic alliances, and partnerships are some of the ways in which firms have sought to gain a competitive advantage. An increasingly-popular trend among industrial firms involves leveraging university knowledge and expertise through formal organizational arrangements such as partnerships (Barringer and Harrison 2000; Neill et al. 2001; Sanjeev and Moraga-Gonzalez; 2001). Creating bridges between firms and universities is one mechanism to spur diffusion of innovation (Harkola and Greve 1995) and keep up with rapidly moving industry needs (Lewis 2000).

Both partners in these firm-university arrangements identify significant mutual benefits or complementary advantages. Research collaborations can offer direct benefits for university and company participants. Even when potential partners have the resources and knowledge to accomplish individual goals, working with outside experts can greatly improve the quality and comprehensiveness of the research and can help reduce its costs. Furthermore, many scientific advances are now occurring at the intersection of traditional fields (American Council on Education 2001:11)

In the late 1990s, GM R&D embarked on an innovative strategy involving universities that came to be known as the Collaborative Research Laboratories (CRLs). Until then, the connections between R&D and universities had been based largely on pre-existing relationships between individual researchers, and/or the availability of R&D contracts or consulting work with particular professors. One of the innovations making the CRL strategy unique was the creation of a formal partnership linking specific R&D researchers with a set of interested university professors and others who agreed to work in selected technical areas. With the attention of both industrial and academic researchers directed towards specific projects, the hope was that knowledge could be shared, expertise tapped, and outcomes realized that would be satisfying for both partners.

R&D management asked us to examine the structure and functioning of these CRL relationships to identify ways to improve their effectiveness. In general, we understood that these partnerships had gotten off to a good start and were working towards and accomplishing the goals they had created. We used a variety of methods to explore partnership activity between R&D and four U.S. universities. In the course of our study, it became clear that an evolutionary perspective would enable us to highlight the patterns related to size, structure, and dynamics as these partnerships aged. With a deeper understanding of these and other patterns over the course of the partnership relationship, we believed we would be able to offer stage-specific recommendations to address partnership issues, thereby enhancing partnership effectiveness.

While some attention in the literature has been directed towards general organizational evolution (Laszlo 2001, Learned 1992), the bulk of attention has been directed at partnership structure and inter-organizational theory and practices (Anderson et al.1994, Prescott et al. 1998). However, the need to explore the overall evolutionary processes of collaborative partnerships has been clearly identified and initiated (Ring and Van de Ven

1994, Doz 1996), and there are a growing number of social network studies that have begun to explore the evolution of partnerships from various perspectives. Some of the most recent inter-organizational network evolution studies are focused on durability of networks (Kogut and Walker 2001), longitudinal analysis of alliance formation (Gulati (1995), transitional networks (Madhavan et al. 1998), the network basis for collaboration (Stuart 1998), the concept of social capital and the formation of industry networks (Walker et al. 1997), and on collaboration networks in general (Ahuja 2000).

In our review of the literature, we found that the majority of partnership case studies largely assume that a partnership life cycle is relatively homogeneous from start to finish. One of the directions on which we have embarked involves the development and testing of a partnership dynamics model to be used as a diagnostic tool for industry-university collaborations (Sengir et al. 2004). Both our model and our qualitative data suggest that partnerships are dynamic, change in size and complexity over time, and follow a stage-based life cycle. This conceptualization of partnership activity can provide important milestones for both maintaining and improving partnership quality.

Our paper begins with a description of the first four collaborative relationships in which GM was involved. We emphasize some of the similarities and differences among these CRLs in terms of participant demographics, technical areas of focus, work practices, and administrative policies. We draw on evidence from the profiles to make a case for the evolution of individual CRLs. We then develop a series of hypotheses to test some of the patterns that we observed in the profiles. Our survey data confirms the increasing size and complexity of CRLs over the course of the partnership cycle.

Next, we examine perceptions gathered from interviews and focus group discussions, and reported partnership interactions from the survey data. The data reveals the presence of partnership stages as the CRLs age. We document the pattern of the typical CRL structure as it progresses from a very simple start up involving a small number of people, through intermediate conditions in which people begin to connect and work more closely with one another, to a later point when complex subgroups of people jointly working on a common task emerge. We also draw attention to the importance of key players – particularly those from the university side – during the partnership cycle. These individuals keep communication lines open, solve problems, and help the partnering relationships develop.

Finally, we explore how CRLs have evolved as an organizational form since their creation. We identify the key attributes that have changed as the partnership type itself has changed. In general we find that these changes seem to have strengthened the CRL partnership program as a whole, while also strengthening the individual collaborative relationships.

DATA AND METHODS

We conducted our research in three phases. During the qualitative phase, we focused on partnership expectations and activities, and the development of the key variables for the social network survey. In the survey phase, we investigated partnership structure, dynamics, and roles.[1] Both phases followed a comparative empirical-analysis strategy focusing on themes and patterns (Bernard 1998, Schensul and La Compte 1999, Trotter and Schensul 1998), informed by prior ethnographic research on partnerships (Meerwarth, Briody and Kulkarni 2002, Meerwarth 2004). The third phase of our research involved the validation of our findings and recommendations.[2]

Qualitative Phase

The collection of interview, focus group, observational and documentary data comprised the qualitative phase. We collected this data on site at Eastern, Mid-Atlantic, Western, and Mid-Western Universities[3] and at GM R&D. We interviewed 65 individuals, 38 from GM and 27 from the partnering institutions; the interviews lasted one hour on average. Our interview questions focused on the nature of the participants' past and current relationships with their counterparts, perceived success factors for and obstacles confronting the partnership, institutional/organizational cultures of the partners, and expectations about the future of the partnership. Our eight focus groups, which lasted one and one half hours on average, explored partnership goals and expectations, the participants' current assessment of the partnership, recipes for an ideal partnership, and ideas for strengthening these long-term relationships. We conducted observations that generated field notes on interactions, key collaborative processes, and meetings both at GM and at the partnership institutions. Finally, we collected CRL documents to gain insight into the formally-stated goals and activities of these partnerships (e.g., CRL Agreements, agendas from CRL reviews).

We followed an empirical-analysis strategy that was both inductive and comparative. For the qualitative analyses, we focused on themes and patterns that emerged from the interview and focus group data (Bernard 1998, Schensul and LeCompte 1999, Trotter and Schensul 1998). These analyses entailed the

- Discovery of key content elements (e.g., the structure of partnerships, the collaboration process, relationships) found in the interviews and focus groups;
- Identification of key quotes or verbatim data illustrating important themes or content areas;
- Linkages pertaining to themes and patterns across all the interviews and focus groups.

The qualitative data analysis contributed greatly to the design of the social-network survey by allowing us to: 1) identify key relationship variables, concepts, or attributes, 2) recommend the inclusion of key themes and concepts in the survey, 3) suggest role and relationship linkages (i.e., how the individuals are connected within the partnership), and 4) identify distinct stages in the life cycle of partnerships.

Survey Phase

We designed and administered an email-based social network survey to all known participants in the four CRLs (See Appendix A). The survey began with a small set of

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[1] We used data from both phases to develop a partnership model of the ideal ways of initiating, maintaining, and exiting CRL partnerships (See Sengir et al. 2003). A patent is pending on this model.
[2] See Kirk and Miller (1986).
[3] These names are pseudonyms.

demographic questions (e.g., name, position, experience with collaborative relationships) followed by a "name generator" matrix that allowed each respondent to identify the complete list of individuals that they were in contact with as part of the CRL.[4] For each individual named, we asked a series of questions pertaining to communication, joint work, and other features of the partnering relationship.

We sent surveys to all 176 of the individuals identified by the GM and university administrators as active participants in each of the four CRLs; participants included administrators, researchers, technicians, and graduate students. Our response rate was excellent,[5] based on an expected response rate of approximately one third of those surveyed (Stork and Richards 1992). Of the 176 surveys, 110 were returned (62.5 percent); the active refusal rate was less than 1 percent (1 individual) of the total surveyed. Table 1 provides the response rates by partnering organization.

Table 1: Response Rates and Total Responses to CRL Network Survey by Partner

Partner	Eastern	GM-Eastern	Mid-Atlantic	GM-Mid Atlantic	Mid-Western	GM-Mid-Western	Western	GM-Western	Row Totals
Surveys Sent	15	7	34	14	39	20	32	15	176
Surveys Returned	10	7	15	7	22	16	22	11	110
Percent Returned	66.7	100.0	44.1	50.0	56.4	80.0	68.8	73.3	62.5

We analyzed the survey data using a variety of techniques including free listing analysis, egocentric network analysis, sociometric network analysis, and network visualization analysis (See Appendix B for description of analysis programs used). The egocentric analysis allowed us to compare individuals and groups in relation to a range of variables including communication, trust, conflict, and work importance, among others. The sociometric data[6] allowed us to pool the responses from all of the individuals in a collaborative partnership and to analyze the structure of the partnership (e.g., connections, distance, density), as well as individual roles, subgroups, and measures of association and communication. The network visualization process allowed us to

[4] This survey followed a standard social network format using a focused name generator to identify partnership relationships (Wasserman and Faust 1994).
[5] We utilized standard response rate enhancement techniques. Co-Directors introduced the survey to participants in an email letter. Next, each individual received an email invitation to participate, with a request to return the survey in electronic format. We re-contacted individuals who did not respond to the first solicitation at timed intervals; we sent one, or, if necessary, two reminder requests. Each individual also received follow-up reminders from the CRL leadership to increase the response rate. All of the data was kept confidential. The CRL leadership was not informed of the participation or non-participation of any individual.
[6] We employed several network programs, including ego network programs (MULTINET, FATCAT) network role programs (Key Player), and basic sociometric programs (UCINET X) to conduct our analyses. See Appendix B for descriptions, and bibliography for citations.

compare the structures of the various CRL networks. The visualization programs utilize both two and three-dimensional visualizations, in some cases using kinetic images, and in other cases attribute analysis based on colors and structural dimensions.

In Fall 2003, we administered a follow-up survey to the same set of CRLs. For the purpose of this paper, we use the numbers of all known participants associated with this follow-up survey to compare with the numbers of CRL participants in the Spring 2002 survey.[7]

Validation Phase

In Fall 2002, we conducted 10 validation sessions attended by approximately 145 individuals including study participants and other interested individuals. We presented our preliminary results and recommendations and gathered input from GM and its partners on the validity of our findings and any potential gaps in data collection. These sessions were an opportunity for us to test the soundness of our analyses and interpretations, integrate new insights into our work, and collect additional data. They also were a way for us to provide timely feedback to study participants and the project sponsor.

BACKGROUND: CRL PARTNERSHIP PROFILES

GM had established Collaborative Research Labs at four U.S. universities by 2002 when this research was initiated. During the first stage of our CRL partnership project, we conducted research on the CRLs at Mid-Western, Mid-Atlantic, Eastern, and Western universities. Each of these partnership laboratories brings an important set of talents, skills, knowledge and research foci to bear on cutting edge business and industrial issues. Each partnership was established to yield benefits to both the GM side and the university side, created with specific technical goals in mind, and organized and managed to maximize learning and research output. An example of the CRL vision is as follows:

> …it will operate as an extension of General Motors R&D and provide the focal point for joint research with [the University] in areas that are core and critical to GM's long-term competitiveness and commensurate with the scholarly expertise and intellectual pursuits of the University faculty. It will establish the framework to link faculty expertise already aligned with GM needs with important projects and research questions. It will also motivate, over time, the growth and strengthening of additional areas of excellence of importance to GM, thus ensuring continued integration and alignment of faculty expertise of GM research needs.

From our investigations, we have found that each CRL partnership has contributed to our understanding of partnership change through time – both in terms of partnership maturity and changing partnership dynamics. The four CRLs profiled below provide historical information on each partnership, positioning us to discuss the CRLs as an evolving organizational entity.

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[7] At a later date we will perform other analyses of the follow-up survey data.

GM-Mid-Western University

The first Lab[8] was established at Mid-Western University in 1998 for five years. At the time of our study (2002), the GM-Mid-Western Satellite Lab was nearing the end of its partnership cycle and was exploring options for renewal. This partnership provided us with important information about the key evolutionary stages that labs go through, and the partnership transitions that are necessary in the later part of the partnership cycles.

Establishing a Satellite Lab at Mid-Western was a logical extension of pre-existing relationships with faculty and researchers at Mid-Western's College of Engineering. The idea that GM could justifiably support a longer-term research relationship with Mid-Western, in contrast to short-term contracts with specific professors, came from three College of Engineering professors. These faculty members approached GM's Vice President of Research in 1997 with the suggestion that GM researchers could partner with Mid-Western's Engineering researchers to work on longer-term projects that had potential applications to GM. In return, the College of Engineering would have a source of ongoing funding[9] for faculty, research scientists, and graduate students.

Geographically, the university is close to GM's R&D center in Warren, MI. Moreover, individual GM researchers had worked with College of Engineering faculty and research scientists on a number of projects for many years. One faculty member, for example, told us that he had worked in all GM truck plants and the luxury car plants on a variety of projects over several years. This condition meshed with GM's interest in leveraging Mid-Western's expertise for three of GM's R&D departments. Thus, the impetus for this type of partnering originated with a university, though GM saw its potential and quickly adapted it for other university collaborations.

The original Mid-Western Satellite Lab was comprised of three technical areas:[10]

- Advanced Body Design and Manufacturing
- Advanced Powertrain
- Advanced Systems Engineering.

Initially, the GM-Mid-Western Lab included seven projects, three in Body Design and Manufacturing, three in Powertrain, and one in Systems Engineering.

Co-directors, one from the university and one from GM, were selected to manage the Satellite Lab. These co-directors were responsible for setting and maintaining strategic directions for the Satellite Lab, defining its business plan, overseeing proper functioning of all Laboratory activities, and maintaining links between university administration and GM R&D. Individuals on both sides of the partnership were appointed to head each of the three technical areas. While these named individuals played a key role in generating

[8] This Lab was originally referred to as a Satellite Lab; the term Satellite was changed later to Collaborative Research Lab.

[9] The funding was conditional.

[10] The terms used to designate research areas at the CRLs vary somewhat from site to site, but they include technical area, thrust area, and project area. Thrust area appears to be the most common term, and project is the term used for smaller programs in each thrust area.

the ideas and galvanizing interest in the partnership, the CRL organizational structure did not preclude other CRL participants from becoming highly-visible and valuable to the work of the CRL.

In addition to the annual funding level, GM donated the necessary equipment to Mid-Western for the agreed-upon research. GM furnished a university room converted into a dynamometer cell with engines, engine parts, support and control on how to run the engines, dilution tunnels, and emission benches. While the initial set-up took almost two and a half years to complete, far longer than anyone had anticipated, the dynamometer cell was ultimately up and running. Assistance from a GM technician and some of the equipment manufacturers was useful at the outset. In addition, GM researchers helped train graduate students and university researchers on how to use the equipment.

While Warren's proximity to the university was a benefit to the partners from an equipment standpoint, it also facilitated visits, reviews, internships, and other exchanges. The relatively short trip made it easy for either GM or university personnel to visit and/or work at each other's site. Some GM researchers, for example, actually worked 10-20 percent of their time at the Mid-Western over the course of their project. A monthly Friday review also has been useful in keeping project goals and objectives on track.

In 2002, GM determined that one technical area at the Satellite Lab, Advanced Systems Engineering, would not receive continued support at renewal; about 59 GM and Mid-Western participants were active in the CRL at this time. This decision was complicated by the fact that the CRL Co-Director was also the technical lead of the Advanced Systems Engineering area. Nevertheless, a CRL personnel change ensued as the Co-Director stepped down. Soon after, GM researchers and management decided instead to create two CRLs from the remaining two technical areas. Each had its own Co-Director and four technical or "project" areas. The decision to re-structure the CRL, and to eliminate one of its technical areas, forced GM to consider for the first time how to process a leadership change and terminate a CRL, key issues in the evolutionary lifecycle of these partnerships. Interestingly, at the time of our second social-network survey, the number of GM and Mid-Western participants had risen to 69, despite the termination of one of the key technical areas.

GM-Mid-Atlantic University

In 2000, GM established the second Satellite Lab in the College of Engineering at Mid-Atlantic University. GM conditionally pledged funding for three years to support the CRL at Mid-Atlantic.

GM R&D initiated the process for establishing this second Satellite Lab by sending out a letter to several universities, including Mid-Atlantic, where faculty were engaged in research projects that had potential applications for GM R&D. According to one of the faculty members at Mid-Atlantic,

> *The letter [from GM R&D] was photocopied and it went into various faculty mailboxes. It asked, 'Does anyone have an interest in this?' I read it and said, 'Well, I'd like to pursue this.' The dean said fine. He*

> *sent a letter to the same faculty members indicating that I would lead this effort with GM. He then sent a letter to GM telling GM that he had asked me to do it -- to coordinate this effort.*

After reviewing the invited proposals from several universities, GM selected Mid-Atlantic as the second satellite laboratory site. This action represented an innovation in establishing a procedure for selecting these research partnerships. The final decision to go with Mid-Atlantic was based on three considerations: previous experience researchers had in working with Mid-Atlantic faculty members on GM contract projects, Mid-Atlantic's expertise from working on industrial problems, and the types of research projects Mid-Atlantic proposed in four technical areas:

- Wireless and Wired Multimedia Networks
- Human Computer Interaction
- Dependable Embedded Systems
- Design Methodologies

According to one document, these four areas were to *…be aligned with areas of critical need for GM…* and were *…selected to be broad enough to allow flexibility in defining an evolving research agenda over a sustained period of several years.* Existing ties between GM researchers and some Mid-Atlantic faculty dating back more than 10 years, also contributed to the decision mix. There were six distinct projects in these four technical areas when the lab began in 2000; the number of projects has continued to increase.

One advantage of developing an Agreement with Mid-Atlantic is that it had a history of working with industrial partners. For example, as a part of previous contracts between GM and individual Mid-Atlantic faculty members, Mid-Atlantic and GM had previously signed a "Master Agreement" that addressed intellectual property issues and set the precedent for many of the start-up issues for the collaborative laboratories as a whole. Thus they could devote their attention to concentrating on the technical work and the way in which they would organize their activities.

The organizational structure of the second GM satellite laboratory followed the pattern established at the Mid-Western. Two co-directors, one from GM and one from Mid-Atlantic, were responsible for setting and maintaining strategic directions for the Laboratory, assisted by a Satellite Laboratory Review Committee comprised of university faculty and GM researchers.

Mid-Atlantic immediately involved students – graduate and undergraduate – in lab-related activities. As one faculty member related, *The lab started in January and students weren't admitted until the fall. However, the spring class looked for industry projects and they began working [on the GM project] as soon as the lab started.* Mid-Atlantic faculty have continued to involve students from many classes and several disciplines in activities related to the lab's research every semester. As at Mid-Western, GM furnished equipment for the Mid-Atlantic lab; because much of the research related to the driver-vehicle interface, GM sent a van for the students to work on. When Mid-Atlantic faculty and students came to Warren at the end of the first year of collaboration, they brought the van to demonstrate the application of their year's activities.

The “retreats” are one aspect of the GM-Mid-Atlantic relationship that has kindled significant interest. Mid-Atlantic hosts reviews of the collaborative work every 6-8 weeks; typically, Mid-Atlantic participants present the work. GM researchers visit the campus to attend the formal presentations and interact informally with their counterparts either prior to or following these sessions.

In the GM-Mid-Atlantic relationship, we had the opportunity to investigate both the early stages and some of the transitions they faced. One issue for Mid-Atlantic, which surfaced in the third year of their Agreement, was the uncertainty of renewal; at this time, about 48 GM and Mid-Atlantic participants were involved in the CRL. Mid-Atlantic faculty were concerned about the continuation of current and new graduate student support. Without renewal, they would need to identify other sources of student funding. Not only did this issue raise our awareness of the importance universities attach to graduate student support, but also highlighted the budgeting difficulties inherent in two different fiscal cycles. GM’s budget year corresponds to the calendar year while the academic year runs from September through August. Faculty began voicing their concerns in 2002. In the end, GM re-funded the Mid-Atlantic lab for an additional five years (2003-2007). By Fall 2003, the number of GM-Mid-Atlantic participants had increased to 59.

Another issue surfacing in early Fall 2003 pertained to a change in the Mid-Atlantic Co-Director. The current Co-Director announced that he would step down in 2004. Since this individual had played such a significant role in the development and growth of the CRL, selecting a replacement who would be well connected on both the Mid-Atlantic and GM sides, knowledgeable about the overall CRL vision and its technical areas, and interested in the Co-Director position was a challenge. This leadership change underscored both the centrality of key CRL participants in the success of these partnerships, and the importance of a succession plan for CRL leaders.

GM-Western University

Western University became the third collaboration of this partnership type. It was announced early in 2001, and launched later in the year through a process similar to the one used to select Mid-Atlantic. GM invited several universities to submit proposals for the kinds of research they would be interested in collaborating on and sent researchers from R&D to the candidate universities to discuss the proposed projects. Here’s how one participant at Western described the selection process:

> *There were various questions that were asked back and forth between GM and Western. We made a proposal suggesting natural areas focused on our work covering all the things that GM was interested in. We gave an overview of different areas that we wanted to focus on, gave our CVs and short descriptions of areas, and also made a presentation to the GM team, which included around six to seven people.*

The lab was housed in the School of Engineering in a department composed of two formerly separate departments. In addition to economic support and the opportunity to work on industrial applications, the faculty at Western viewed the lab as a focal point around which the department's diverse research interests could coalesce. One of the Co-Directors described the lab in this way:

> *It cuts across all the department areas from social science to optimizers…It is extremely important for optimizers to see the real world, to see where their work is actually used, and it's extremely important for social scientists after they've seen the real world to understand modeling and what optimizers are doing. When I saw the meeting at GM last fall [2001] on work practices, I saw all of the areas working together.*

Thus, the lab fulfilled an additional function of integrating the work of faculty in the same department but from very diverse specializations.

This three-year research lab was charged with studying "work systems" – the way people use materials and information to make products and services. Specifically, the lab was to focus on creating new ways to use the latest information-based tools and methods. Though seven technical areas for the CRL's focus were identified initially, CRL leadership honed them to four:

- Enterprise Strategies
- Product Development
- Work Practices
- Supply Chain

These four areas were referred to in the Western Agreement as "thrust" areas, a term subsequently adopted by the other three collaborative labs to describe their technical areas. Another innovation that became apparent with this lab was that a senior corporate leader became the key spokesperson for the creation and selection of the lab, further centralizing the vision within GM.

A key change in the Western Agreement, which was diffused to the other Agreements, was to describe the lab as "collaborative," rather than using the term "satellite." One thrust-area leader commented, *In the negotiation process, they [Western personnel] objected to the phrase Satellite Research Labs. They felt it reflected a sense of them being subservient.* A Western leader stated, *Western negotiators thought that the term 'satellite' had the connotation of incorrectly implying 'ownership' of the lab by GM. The GM negotiators agreed and changed the term 'Satellite' to 'Collaborative,' a change that the Western negotiators welcomed.* One of the GM researchers stated, *We put out another phrasing, which was Collaborative Research Lab and that involves working together, doing joint work, relying on one another, being equal partners.* When this terminology change was proposed, the GM-Mid-Western and GM-Mid-Atlantic Labs adopted this new phrasing to describe their GM-sponsored labs. This name change was intended to emphasize the joint nature of the work undertaken in the partnership between the university and GM R&D researchers.

As with some of the other university partners, GM and Western agreed that there would be twice-yearly reviews of the CRL's research program; university personnel typically took on the role of presenting any results or updates. While these meetings served as formal evaluations and gave a large number of interested GM researchers the opportunity to get an overview of the Lab's activities, there were several other, less formal methods for building and maintaining relationships in the CRL. Several GM researchers made frequent trips to Western in an attempt to bridge the distance between Michigan and California. Several graduate students spent a summer as GM interns and continued to work with their mentors after returning to campus in the fall. And, some GM researchers attended a variety of seminars and presentations, along with other organizations near Western, at which Western faculty and graduate students shared the results of their research. By Spring 2002, there were approximately 47 GM and Western participants in the CRL.

By Fall 2003, approximately 59 GM and Western participants were active in the CRL. About this time, renewal discussions were underway; the Agreement was set to expire in 2004. While GM R&D viewed some of the CRL work favorably, a number of other projects were not producing the kind of results that GM had hoped for. A decision was made to disband much of the CRL, though projects related to work systems are expected to continue under a CRL umbrella, and a small number of projects are likely to be contracted to individual professors. The "new CRL" is anticipated to exhibit distinctive structural characteristics including a higher funding/participant ratio, a five-year partnership cycle, and two co-directors on each side of the partnership. The opportunity to explore the Western CRL enabled us to document additional variation in CRL transitions. While the GM-Mid-Atlantic CRL continued in much the same form, and the GM-Mid-Western's was split into two CRLs, a portion of the GM-Western CRL is expected to be retained.

GM-Eastern University

Eastern University is the site of the fourth CRL in the U.S. It also commenced in 2001 several months after the GM-Western University CRL. Eastern was chosen over several other universities because of its expertise in solid mechanics and materials science and because, as one GM R&D researcher put it, *The people at Eastern talked to each other [about their mutual research interests]*. This obvious communication among faculty members from different areas, as evidenced in the proposal they submitted as an application for the CRL, was in marked contrast to other institutions that GM considered; at those latter institutions, GM researchers saw little or no evidence of interaction or collaborative work among the faculty.

As was the case at the other CRLs, Eastern had several research activities funded by grants from other entities that were potentially synergistic with the work of GM R&D (e.g., National Science Foundation, U.S. Department of Defense). One of GM's purposes in setting up CRLs at Eastern and elsewhere was to capitalize on the complementarities of projects underway at the universities with GM research interests.

The basic structure of the Eastern CRL follows the pattern of the other CRLs; the lab has Co-Directors at Eastern and at GM, and there are two thrust areas:

- Design of Lightweight Materials for Enhanced Performance
- Design of Engineered Surfaces.

Eastern and GM researchers agreed on two projects in each thrust area, for a total of four projects in the CRL. There has been no change in these projects since the CRL began.

The funding for the Eastern CRL was different from funding for earlier institutions. The term was five years, rather than three

Eastern followed Western's pattern of twice-yearly reviews and, at the time of our study, was seeking ways to present research results in a more informal setting. One apparent success was the establishment of workshops focused on particular technical issues. Researchers from both sides of the partnership indicated that they preferred the workshops over the informational reviews. They found the workshop problems intellectually stimulating and the format engaging. These workshops were opportunities to interact, share expertise, and actively participate in problem solving. Indeed, they revealed a similar kind of interest and excitement apparent in the informal discussions prior to and following the Mid-Atlantic retreats. They also had the effect of enhancing the development of working relationships among researchers. After the initial year of the Agreement, the GM-Eastern CRL had about 22 active participants; this number had grown to 28 by Fall 2003.

Further evolution and solidification of the overall plan for collaborative laboratories occurred at Eastern when the Memorandum of Understanding explicitly identified the process of faculty exchange and student internships as a key expectation of the university partnerships. According to this document, one goal of the partnership was to "…facilitate the exchange of technical personnel between GM Research & Development and Planning and Eastern University." This emphasis resulted in faculty short-term stays at R&D during the summer months, in addition to the Eastern summer interns; more recently, R&D researchers have spent time at Eastern during the two-week GM shutdown in July. Neither Mid-Atlantic or Western faculty, nor their GM counterparts, were similarly involved in extended stays at each other's institutions, though this pattern had developed at the Mid-Western. By highlighting the centrality of such exchanges – even for institutions that were geographically distant from each other – GM's expectations were formalized and a new chapter was formulated in the evolving management of the CRLs.

The Eastern CRL also faced a significant leadership change when the Eastern Co-Director decided to step down after approximately two and one half years. This transition occurred about halfway through Eastern's initial partnership cycle and, in this way, it was similar to the Co-Director transition at Mid-Atlantic. In both cases, the original Co-Directors have remained active CRL participants, mitigating some of the transition difficulties.

EVIDENCE FROM THE PROFILES OF INDIVIDUAL CRL EVOLUTION

While the partnership profiles offer descriptive historical accounts of the individual GM-CRL relationships, they also serve as foundation for an analysis of CRL evolution. In this section, we focus on the various changes in size and composition, stage, and roles as these CRL partnerships age over time. We demonstrate that partnerships are associated with a life cycle, that is, a defined period of time in which participants are entertaining the possibility of, planning for, or executing specified joint work activities. CRL partnership cycles are framed by the agreed-upon time conditions set by the Agreements between GM and the partnering universities; the partnerships are then considered for renewal in some form – leading to a second cycle – or termination. Partnership cycles are marked by the presence of certain stages, each of which is linked with particular work and relationship matters requiring attention by the participants. We draw on the partnership profiles for our initial evidence of partnership cycles and stages and ultimately link those patterns with the patterns emerging from the survey data.

Rising CRL Participation

As these partnerships are initiated, gain momentum, and then transition, they experience changes in the number of participants and types of participation. From our interview data we find that there is an initial core group of participants on both sides of the partnership that steadily increases in size as the CRL ages. The eventual size of the partnership is limited by the availability of funds and the targeted joint work. However, CRL size does increase as new faculty expertise and student participants are added on the university side, as new GM researchers are brought into the joint work plan, as the technical work becomes a primary focus for the partnership, and as connections are made with GM divisions and product programs.

With the administration of a follow-up survey to CRL participants in Fall 2003,[11] we were able to examine the changes in the number of CRL participants since our initial survey in Spring 2002. In general, we find that CRL participation has increased over time (See Table 2). The percent change in the number of participants associated with the Spring 2002 survey compared with the Fall 2003 survey ranged from a 17 percent increase in the GM-Mid-Western CRL to a 27 percent increase in the GM-Eastern CRL. On the whole, expansion occurred throughout the partnership cycle both on the university side and the GM side.[12]

[11] We are utilizing the follow-up survey data for this particular comparison.

[12] While the percent increase in survey participants provides an indication of changing CRL size, additional analysis of the surveys is needed to verify the extent of the participants' involvement.

Collaborative Partnerships	Spring 2002 Survey: Total Participants Identified	Fall 2003 Survey: Total Participants Identified	Percent Change
GM-Mid-Western	**59**	**69**	**17%**
GM	20	23	15%
Mid-Western	39	46	18%
GM-Mid-Atlantic	**48**	**59**	**23%**
GM	14	24	71%
Mid-Atlantic	34	35	3%
GM-Western	**47**	**59**	**26%**
GM	15	15	0%
Western	32	44	37.5%
GM-Eastern	**22**	**28**	**27%**
GM	7	9	29%
Eastern	15	19	27%

Table 2: Number of CRL Participants by Survey Date

Progressing Through Stages in the Partnership Cycle
The qualitative interviews that allowed us to construct the CRL profiles also provide insights on patterns in partnership behavior that seem to be associated with particular periods or stages in the life of the partnership as it ages. For example, all of the CRL partnerships underwent some kind of selection and approval process. During this stage, either the university side (in the case of the Mid-Western) or the GM side (in the case of the other CRLs) initiated contact with the intent of creating a formalized, long-term relationship. Discussions ensued between the parties and plans developed to specify technical areas. The selection process took nearly six months in the GM-Western CRL.

As the collaborative work gets underway between the various CRL partners, expectations are shared, work practices are established, and specific projects are formulated under the thrust areas. During this stage the work of the CRL is now in process. GM-Mid-Atlantic found that engaging university classes in discussions of GM-specific technical problems was a useful way to proceed. GM-Eastern and GM-Mid-Atlantic quickly discovered that some time for informal, intellectual discussion and problem solving was optimal for their interactions, rather than relying solely on the formality of the technical reviews. GM-Mid-Western had to learn patience since the equipment installation took far longer than anyone expected.

From the profiles we can glean what might happen at the end of a given partnership cycle. Uncertainty among CRL university participants has characterized this stage; these participants expressed concerns about not knowing whether the CRL and its associated funding would be renewed. Renewal would directly affect graduate student support, and indirectly, the numbers of incoming students making the decision to attend the particular university. The profiles also provide insight into partnership longevity and transitions. For example, we find that CRLs may continue (e.g., GM-Mid-Atlantic) or be transformed (e.g., GM-Mid-Western). Each of these outcomes has direct implications for sustaining and enhancing, or draining CRL relationships.

The Emergence and Succession of Key Players

CRL evolution is also evident in role changes or modifications that occur at certain points in the partnership cycle. One change we observed in the profiles was the expansion in the number and types of individuals considered central to the operation of the CRL. For example, when the CRLs were established, individuals were appointed on both sides to fill a set of formal roles (e.g., Co-Director, Thrust-Area Leader). As the partnership work progressed, those formal roles were complemented by a set of informal roles; selected CRL participants emerged as highly visible and valued in the CRL. Thus, key players[13] ultimately were drawn from among the formally-designated leaders and from the ranks of interested participants. In some cases, we found that the roles of key individuals in the partnerships changed along with the change in stages associated with the CRL life cycle. The ability to modify their role, or allow it to change, allowed some key players the opportunity to maintain their key position, while changing the way they played out their roles to support the other changes going on at that point in the partnership cycle.

Another change we noted in the profiles involved the impact of a leadership change on a CRL. There have been instances when individuals filling selected leadership roles have stepped down or have planned to step down from their CRL positions. Typically, one or both of the partners raise concerns about the future leadership of the CRL. In the cases involving the Eastern and Mid-Atlantic Co-Directors on the university side, there was time to develop succession plans. These Co-Directors specified that they would remain active in the CRL, though in a specific technical area rather than in CRL administration. GM-Mid-Atlantic also lost its GM Co-Director; the position was not filled for several months until GM hired a new person to fill that role. In the interim, one of the GM thrust-area leaders temporarily acted in the capacity of the GM Co-Director. With GM-Mid-Western, GM decided not to renew one of the three technical areas.

EVIDENCE FROM THE SURVEY OF COMBINED CRL EVOLUTION

Increasing CRL Size and Complexity

In conducting an exploratory analysis of the survey data, we hypothesized that CRL size and complexity would increase over time. This general hypothesis was based largely on the descriptive accounts of the CRLs that we heard in both the interviews and focus

[13] We are using the phrase “key players” to indicate individuals who take on critical roles in the formation and maintenance of CRL networks. In many cases, they are individuals in formal positions of leadership, but they also can be individuals who have assumed more informal roles that bind the networks together and make the CRLs work. In part of our research, we use the concept of key player to indicate individuals who have formal network characteristics (e.g., centrality, influence) that make them key players in a CRL partnership.

groups. As we examined the partnership profiles in detail, we found additional support for it. Therefore we proposed three specific hypotheses that could be tested using the survey data. First, we hypothesized that *the number of individuals named by CRL participants should increase over time*. As a proxy for time, we compare the CRLs by start date, anticipating that the most recent CRL would have the lowest frequency of those named, while the oldest CRL would have the largest number of individuals named. We used a free list (Weller and Romney 1997) analysis technique (see Appendix C) to explore this data.

Table 3 shows changes in CRL size and complexity over time. It shows support for our hypothesis of a consistent increase in the number of respondents, and the total number of individuals named by those respondents[14] (i.e., their ego networks), by stage. As such, the GM-Eastern CRL, which is the most recently-created CRL, has the smallest number of respondents of the four CRLs (N=17), and names seven individuals on average. By contrast, the GM-Mid-Western CRL has the highest number of respondents (N=38) and names 10.6 individuals on average as part of their CRL network.

CRL	**Partnership Stage**	**Respondents**	**Total Unique Individuals Named by Respondents[15]**	**Individuals Named by Respondents**	**People Listed Per Respondent**	**Average Distance Between Partnership Dyads**	**Overall Network Density**
GM-Mid-Western	Mature	38	131	403	10.605	3.022	.0223
GM-Mid-Atlantic	Mid-Term	22	50	188	8.545	2.256	.0633
GM Western	Late Start-Up	33	92	246	7.455	2.481	.029
GM-Eastern	Start-Up	17	35	120	7.059	2.057	.1008

Table 3: Changes in CRL Network Size and Complexity by Partnership Stage

Second, we hypothesized that there would be changes in some of the simple sociometric measures of association and relationship as CRLs grow in both size and complexity. The two measures we chose to support this contention were geodesic distance[16] and overall network density. We assumed that the average distance between all pairs of connected individuals (i.e., "dyads") would increase. The distance algorithm measures the number

[14] It is highly probable that there is an "ideal" upper limit to the size of network that can be handled, based on the need to stay connected, but to also get individual and joint work done. We did not try to test for this limit in this study.
[15] This column represents the total list of names, including duplicates, listed by all the survey respondents. It provides the basic data for determining the average size of individual networks for each CRL. Calculations were run using Anthropac (Borgatti 1992).
[16] We use average geodesic distance (i.e., the minimum distance or the minimum number of links between partnership dyads). Geodesic distance and overall network density measures were calculated using UCINET V (Borgatti et al. 1999).

of edges (i.e., known connections) in the shortest path between all pairs of individuals and then calculates the average length of the shortest path among all reachable dyads (Borgatti et al. 1999). An increase in distance means that it will take longer for information to be transmitted through the system because it has to go through more intermediaries. It also means that it is easier for a single individual to keep in closer contact with everyone in the network at earlier stages of the partnership, than in later stages.

In general, Table 3 shows a lower average distance between dyads in the more-recently created CRLs than in the more mature CRLs. For example, the average geodesic distance in the GM-Eastern CRL is 2.057 while in the GM-Mid-Western CRL it is 3.022. The GM-Mid-Atlantic CRL is a slight outlier on this sociometric measure with a somewhat lower distance than the GM-Western CRL despite being two years older. Mid-Atlantic faculty have configured CRL participation to include members of selected undergraduate and graduate classes. Since those students only participate in the CRL on a temporary basis, and at the request of a particular CRL faculty member, leaving them out of the calculations decreases the distance between the named individuals in the CRL.

Another expected change over the different stages of the partnership cycle is captured in the concept of network density. Density is defined as the ratio of the number of actual links between individuals in a network, divided by the total possible number of links that could exist (Borgatti et al. 1999). If no one is connected to anyone else, there is no network, and the density is measured as zero. If everyone is connected to everyone else, then the network has a density of 1.0. We hypothesized that each successive stage in the partnership cycle would be associated with decreased overall density of the whole network (a function primarily of increasing size, since it is harder for everyone to stay connected with everyone else in larger networks), coupled with higher thrust-area density (there is a need for people working together to be highly interconnected); thus, we anticipated fewer connections between each individual and all others, but more connections with those a person is closest to. Table 3 also shows a general trend from higher density in the newer and smaller partnerships, to lower overall density in the partnerships that are older and more complex.

Our results pertaining to the three hypotheses on CRL size, distance, and density support the notion that there is a steady progression of predictable change in the structure and nature of the relationships that form the basis for collaborative partnership networks. We now turn to a discussion of partnership stages based on the survey data to examine these structural and dynamic changes in more detail.

Partnership Stages and Their Corresponding Activities and Networks

In this section, we combine our data sources and present evidence for six partnership stages. We provide a summary of the qualitative data through the use of quotes, generate hypothetical graphs of the networks based on descriptions offered by participants of their partnering relationships, and display visual data illustrating the actual partnership networks from the social network survey data.

The interviews, focus group discussions, and reported partnership interactions from the survey data allow us to confirm a progression of partnership stages as the CRLs age. The result is our documentation of the pattern that the typical CRL structure progression, from a very simple start up involving a small number of people, through intermediate conditions in which people begin to connect and work more closely with one another, to a later point when complex subgroups of people jointly working on a common task emerge.

Initiation Stage. The earliest interactions between GM and potential CRL partners can be labeled the Initiation Stage. This stage begins with the identification of a relatively specific research need on the part of GM R&D management, accompanied by fairly extensive knowledge of the prominent universities and/or professors. Once there is sufficient momentum for management to justify the establishment of a collaborative lab initiative, a potential field of candidate schools is identified and contacted, often through existing relationships between GM R&D scientists and managers. There is a relatively brief period of informal interaction between key players in GM R&D and the various university key players to explore the initial level of mutual interest. The field is then narrowed through a combination of lack of interest on the part of some universities, and increased interest and specificity of ideas and resources from others. The interactions become increasingly more formal and more specific, including written prospective research suggestions, until a primary candidate is identified and mutual interest grows to the level of initiating a formal statement of Agreement. There is no hypothetical or empirical network data currently available for this stage, since it does not have a significant network structure in the strict sense of the term.

Courtship Stage. The Courtship Stage marks the initial negotiation about the specific content and structure of the partnership once a particular university has been selected as a CRL lab. A small number of key individuals on both sides of the partnership explore the common ground in terms of potential joint work, combined with negotiation over key institutional concerns such as intellectual property rights, resources, and commitment of personnel. This stage includes an overriding emphasis on discussions of the goals and objectives of the CRL. Key players begin to emerge on each side of the partnership. The Courtship Stage begins with general negotiations and ends with a joint identification of thrust areas and a formal Agreement. The Western lab provided us with an excellent view of both the early explorations, and the later clarifications of purpose and structure. One participant describes how GM and Western worked out many of the details of their relationship:

> *It took us almost five months to develop the contract…Those five months, I think, were very important…I couldn't be happier that we spent those five months. They defined what the deliverables were,… how we are [were] going to approve different projects and propose different projects, what were the intellectual property issues that we need[ed] to deal with. Who does what, basically and also figuring out what objectives we will be following. That time and planning was very, very helpful to us.*

As with the Initiation Stage, we have no survey data on the reported interactions occurring between the GM and university sides of the CRLs. Therefore, we relied on the qualitative data, along with the theoretical literature on social networks, to represent the Courtship Stage graphically. Figure 1 depicts a ladder configuration, the most basic theoretical starting point for a partnership.[17] Interestingly, one member of R&D management articulated the ladder structure by stating that individuals from key levels of both organizations would be paired (i.e., connected) with their counterparts in the other organization. The hope was that additional cross-connections would rapidly follow that would allow for the successful development of the partnership. This depiction of the early partnership network follows traditional organizational hierarchy lines; key individuals from the two partnering organizations are represented by red and blue dots that are connected up and down within their organization, and cross-connected between the two organizations.

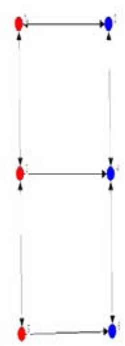

Figure 1: Courtship Phase Ladder Configuration

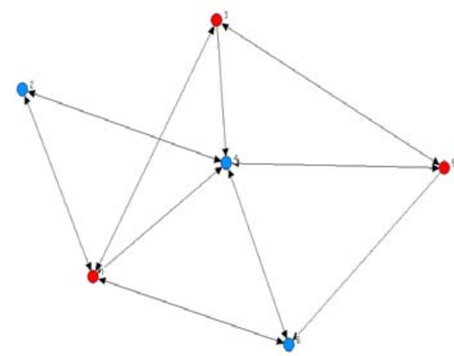

Figure 2: Courtship Configuration With 2 Pre-Existing Relationships

Figure 2 is a visual depiction of a more likely Courtship Stage relationship diagram in which there are two non-hierarchical pre-existing relationships among the individuals discussing the CRL Start-Up. Our qualitative data indicates that some pre-existing relationships between GM and its CRL partners are the norm. During this stage, the actual CRL network structures would have cross connections that do not exist in the ladder configuration. Figure 2 shows a more likely configuration when there is at least one pre-existing relationship between partners. It is a simple one thrust area "ladder" with only one prior cross connecting relationship. Multiple pre-existing relationships combined with multiple thrust areas would make the structure even more complex than Figure 2, and much different in shape than Figure 1. This configuration is actually more effective for rapidly developing the necessary partnering relationships than the hierarchical ladder configuration.

Regardless of the actual network structure during the Courtship Stage, this structure does not appear to last any longer than the time it takes to get people together and start talking about the CRL and its goals. The overall demands of collaboration require that people talk and work with one another up, down, and across both organizational hierarchies. Key participants very rapidly begin to create a new structure as their relationships cross

[17] All of the diagrams below were constructed using NETDRAW, a network visualization program (Borgatti 2002a).

connect both partnering organizations. Their new interactions rapidly crystallize into the structure visible in the Start-Up Stage.

Start-Up Stage. The Start-Up Stage emphasizes the dynamics that hold the overall collaboration on course, including good communication, the development of trust, and an increase in the overall quality of relationships. One participant stated, *One element and one only – the people who end up working together need to understand and appreciate each other. They need mutual respect and this is the major element of success for us.* In many ways, relationship development is a precondition for mutually satisfying joint work. The following statement provides a glimpse into one participant's CRL network:

> *He (the Co-Director) sees his job as director to clearly articulate the long-term goals, to clearly the articulate the directions that we want people to go on, but then, to not tell people what to do [which might restrict creativity], to essentially tell them where we want to get, and provide the freedom for them to actually get there in the best way they can.*

Another participant described the relationship-development process in this way:

> *In my area it has taken these two years to establish a real good, collaborative, collegial relationship. It takes regularly attending [working meetings] to get out of it what we should be getting out of it…So, we drive down every few weeks [to Mid-Atlantic] and we go to the quarterly reviews.*

Participants share their advice on achieving success during the Start-Up Stage. They recommend having at least one individual with the role of holding the collaboration together and actively facilitating the creation of a stable context and supportive culture in which the new partnering relationships can thrive. One participant commented, *What I've learned is that it's essential to have a committed person at the University of Mid-Western and at GM. The partnership is going to survive or fall on the personal interactions between these two people.*

Figure 3 is a visual theoretical network structure comprised of 15 individuals and constructed from comments about what relationships should exist at Start-Up. By contrast, Figures 4 and 5 are based on our survey data and represent two actual CRL networks during Start-Up. When comparing these Start-Up figures with those associated with the earlier Courtship figures, we can see the transformation of the initial ladder configurations into a globular core structure connected through communication and interactions on CRL projects. This globular structure becomes the network glue that holds the collaboration together throughout all successive stages of the partnership cycle.

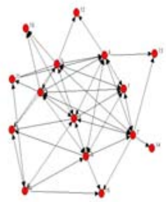

Figure 3: Theoretically-Constructed Start-Up Core Structure[18]

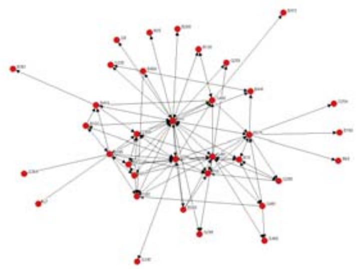

Figure 4: Start-Up Core Structure at 1 Year (GM-Eastern)

Figure 5: Start-Up Core Structure at 1.5 Years (GM-Western)

Mid-Term Stage. The Mid-Term Stage begins as soon as the core relationships, based on trust and other relationship features, are stabilized enough to be the foundation for establishing predictable joint work processes. During this stage, sub-groups (i.e., thrust areas) begin to form a set of connections that are visibly and functionally attached to the partnership core. These sub-groups appear as increasingly separate networks within the overall partnership network.

During the Mid-Term Stage of the partnership, the qualitative emphasis is on increasing productivity and joint work, in addition to maintaining existing positive relationships. One participant commented, *We underestimated this need for a lot of interaction.* Another remarked, *We've established a closer interaction. This is due to the maturity of the program. Now, we are working on stuff. It would have been less helpful to have more [technical] interactions earlier.*

Figures 6 and 7 show the theoretical and actual structures for the Mid-Term Stage. In Figure 6, two thrust areas are beginning to develop as new participants are added to the "peripheries" of the core; the core is illustrated by red dots. These thrust areas are represented by two clusters of yellow and blue dots. Most of the connections (i.e., working relationships) are internal to the thrust areas. As a result, those in those thrust areas can work without too much need for contact with the rest of the network. Figure 7 demonstrates that the same types of core and periphery structures are present in a mid-stage partnership. The basic core is extended to include periphery clusters representing the thrust areas. As the thrust areas become defined structurally, the joint work in which the CRL is engaged gathers increasing momentum.

[18] All of the network diagrams are constructed from "edge lists" which are lists of partnership dyads. The dyadic relationship lists are imported into UCINET and converted into square person-by-person network matrices. We can then analyze them using basic sociometric algorithms and display them. The "hypothetical" diagrams are constructed from our ethnographic data in which participants tell us how people should be (or are) connected to one another based on how they are working together at each stage of the partnership. We used this information to construct idealized edge lists, which we then converted to network matrices, and finally to the visual depictions.

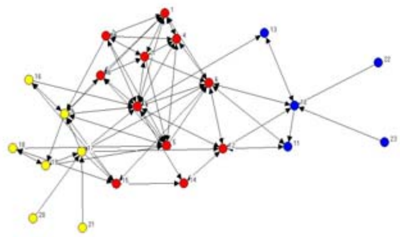

Figure 6: Theoretically-Constructed Mid-Term Structure With Two Thrust Areas Emerging

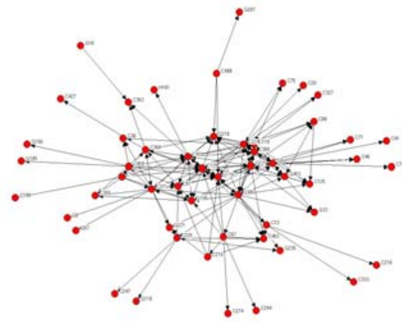

Figure 7: Mid-Term Structure at 3 Years With Four Thrust Areas (GM-Mid-Atlantic)

Mature Stage. In the Mature Stage, there is continuing effort by a core group of key players to keep the collaboration on track and meet joint work goals. One participant commented, *Above the thrust areas …, there is the integration function. If we do something in one area, we want to know how this will affect other areas and how it will affect how GM does business.* The major emphasis in the partnerships shifts much more fully to a focused effort on joint work. This technical focus is captured in the following quote:

> *We (GM R&D) have to provide them (the CRL partners) with the final goal, but we also keep them on course…By them coming here, we have engineers critiquing their work. It's a true technical interaction as opposed to a presentation. You can save them time. You can save their students time because you can redirect them.*

Our survey data provides visual evidence for a phase in the partnership cycle that we have labeled the Mature Stage. In its pure theoretical configuration, the overall structure would look like a boat propeller (See Figure 8). It provides a theoretically designed visualization of this structure, with the core in yellow, and three thrust areas illustrated by red, blue, and green dots respectively. Collaborative groups engaged in joint work are connected by a core central global structure. While reality is somewhat messier than the ideal, an inspection of the visual presentation of the survey data (See Figure 9) reveals a core and fan structure that is sufficiently close enough to the ideal to indicate that the hypothetical structure is not only approachable, but has appeared in a real world situation. Here, the core is represented by the yellow dots, while the fans are represented by red, green and blue dots respectively. Figure 9 illustrates some additional complexity at the peripheries where there are individuals who are not connected to each other, only to someone in the fan structure. A typical example of a CRL participant on the periphery of the network might be a graduate student who is only connected to the thrust area and to the overall network through one person – his/her professor.

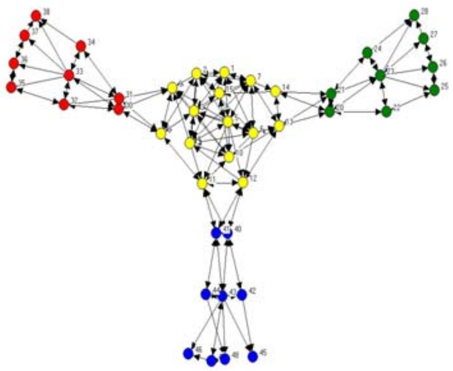

Figure 8: Theoretically-Constructed Mature Structure

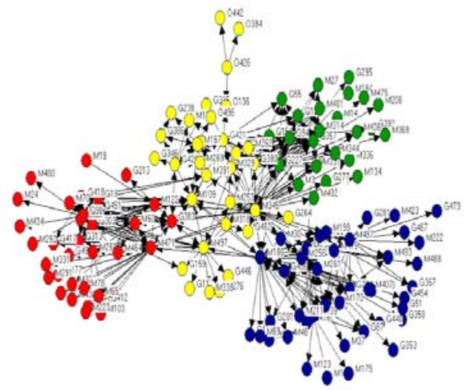

Figure 9: Mature Structure at 4.5 Years (GM-Mid-Western)

<u>Transition Stage</u>. The Transition Stage begins when the social processes that govern both the unilateral and bilateral decisions about the partnership come back into prominence and potentially threaten the relationships and the networks that have been created. Our ethnographic data provides a number of important findings about the Transition Stage. For example, one or both partners may become concerned over any one of a number of transition decisions. One CRL participant stated,

> *Some things could be improved, however. We are in the fourth year of the partnership and starting the fifth. The funding runs out in …2002. We have built a mechanism and an infrastructure for this work. It would be good to know ahead of time if we'll be renewed by GM. We've got students lined up that need the support.*

Transition issues become the predominant theme directly impacting partnership dynamics. They often refocus the emphasis of the relationships away from the thrust areas and back to the core structure at the center of the partnership. CRL relationships become, at least temporarily, more ambiguous. There can be a relatively high level of "distrust," or at least a lowering of the trust, characterizing the partnering relationships during this stage. Communication becomes an increasingly important element in the partnership. Conflict can arise based on both rumor and actual changes. All of these conditions have an impact on both the existing network, and on any projected future network for the partnership.

Figure 10 helps place the Transition Stage in context. This graphic shows the life cycle progression in functional structures for CRLs up to the point of transition. The structures represented begin with Courtship, progress through more complex configurations that allow increasingly-focused joint work to occur, and then move into Transition.

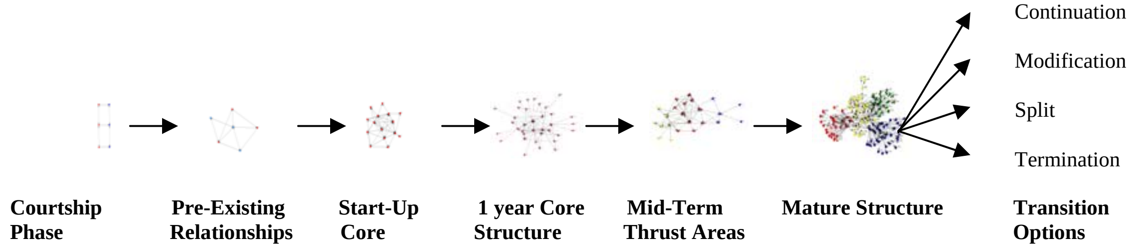

Figure 10: Evolving Network Structures in the Partnership Cycle

During the Transition Stage, several transition options are possible. One option is for the CRL to be continued in its original form, as was the case for the GM-Mid-Atlantic CRL when it was renewed. With the continuation option, both the existing joint work structure and its progress continues largely without interruption. Structurally, it is similar to the representation of the Mature Stage in the first partnership cycle.

A second option is for the CRL to be modified. This option allows the CRL to continue, but in a reconfigured format. Typically one or more thrust areas are disbanded; alternately, one or more thrust areas may be added. The GM-Western CRL likely represents this option. GM and Western leaders intend to retain one of the initial four thrust areas, establishing a new CRL cycle for that particular area.

A third option is for the CRL to be split into two or more independent CRLs. This option occurred with the GM-Mid-Western CRL. One of the original three thrust areas was dissolved, and the two remaining ones were allowed to separate and form two new CRLs. We suspect that this type of transition will cause the two new CRLs to advance through the early stages of the partnership cycle (e.g., Courtship, Mid-Term), but probably at an accelerated rate. The pace of the new partnerships in a subsequent cycle depends on such factors as how much change occurs in the overall goals of the joint work, the extent to which the roles of the key players are accommodated, and the number and rate at which new participants join the CRL.

A fourth option is for the entire CRL to be terminated. If the termination process is conducted appropriately, the formal structure of the CRL will disappear, but many of the individual relationships may persist. Additionally, some contract work may result from a termination if GM is interested in funding projects that have a well-defined focus and set of deliverables. We have observed the dissolution of individual thrust areas within a CRL, but not the termination of the entire CRL.

Our Fall 2003 survey data will provide additional insights on these transition structures. We believe that the modified and split CRLs will be characterized by structures that are closer to the 1-Year Core Structure rather than the Mature Structure found at the end of the partnership cycle. If our hypothesis is supported, or if the resulting CRL structure is a Mid-Term Structure, expectations for CRL productivity may have to be tempered. In these cases, some start up and reconfiguration time would be necessary before the CRLs achieved full joint work status and output.

The Changing Key Player Mix

Both our qualitative and survey data demonstrate that there are predictable changes in the overall structure and dynamics of CRL relationships. Similarly, the data also emphasizes the importance of key individuals, without whom these partnerships would have foundered. One participant stated,

> *You absolutely have to have people who provide leadership. Leaders are individuals who are aware of what's going on in the program and who are providing leadership to the program, but they are also providing monitoring. They are very, very critical to the success of the program because they are willing to identify where people are making contributions, and identify and reward those contributions. But they are willing to identify people who are not making contributions [also]. Maybe they (individuals not making contributions) were originally, but their contributions faded through time and they should move them off of projects and keep the energy and the productivity of the project up.*

All of the CRLs have at least one, and often two or three individuals whose primary role is to keep communication lines open, solve problems, and help solid relationships develop. They are the glue that holds the collaboration together, in large part because they foster connections between individuals on both sides of the partnership. Without their efforts, CRL work would be much less successful because the coordination of CRL activities, resources, and deliverables, including oversight of the technical work, would be lacking. As such, these "key players" are central to CRL functioning and operations.

From an evolutionary perspective, some of these individuals must be present during the early stages of the CRL life cycle and some may emerge later. It is possible for key individuals to begin in one role, and as the CRL changes, for them to adapt or change their roles and remain key players throughout the life of the partnership. Key players learn their role largely in the process of forming and sustaining the collaboration, and in talking with others who are involved in CRLs. Typically GM key players are appointed to a CRL leadership position, while those on the university side volunteer. Once the leadership positions are filled, other key players may emerge, based largely on their own interests in the technical work being done.

The basic data from the survey allowed us to analyze some of the structural and relationship impacts of these key players on the CRL networks.[19] The importance of specific key individuals, or key roles, changes from partnership stage to partnership stage. One evolutionary trend for key players is the number of individuals needed in specific roles, and the relative balance of those roles between GM and the university partners. We present two types of our key player analyses to support our view of partnership evolution. The first of these analyses involves the concept of fragmentation.

<u>Reduced Fragmentation Severity</u>. Our qualitative data indicates that CRL partnerships depend on a small but steadily growing number of key players throughout the partnership cycle. In the early partnership stages, there are often only one or two critical individuals.

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[19] We used UCINET X (Borgatti et al. 1999) to investigate the sociometric measures of the networks.

Their loss translates into serious fragmentation of the partnership. In later stages, the loss of a single individual is less damaging, though the loss of multiple key players is still problematic. One participant commented, *There's a very natural tendency for two institutions to set up a collaborative project and then have that collaboration naturally fragment or naturally segment.*

Fragmentation is defined as the removal of a key player from a network when their removal means that either individuals or other subunits in the network are no longer connected to the network as a whole. We can calculate the degree of fragmentation or "natural damage" caused by the removal of selected key players from a CRL network. A value toward 1 means that the loss of the particular individual has created many small clusters of people such that the network is highly fragmented. A value toward 0 means that most people are still connected within the network.

Figures 10 and 11 illustrate the importance of key players in the CRL networks. In Figure 10, there is one key player, shown as a blue dot, in the center of the network; that individual is directly connected with most of the other CRL participants. Loss of this person has a very strong impact, as does the progressive loss of the other two individuals in blue. All other CRL participants are shown as red dots. At later stages, the removal of a single key player causes less fragmentation. We differentiate among the key players in Figure 11 by illustrating them with either blue or yellow dots. Key players shown as blue dots represent the three highest-impact positions while those shown as yellow dots represent the second highest-impact positions. The networks sustain greater damage when a key player depicted in blue is removed compared with a key player shown in yellow.

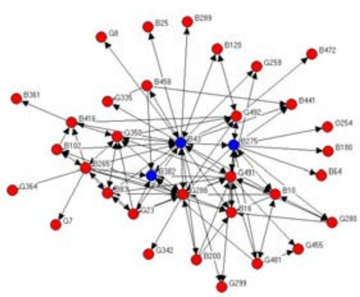

Figure 11: Start-Up Stage CRL Fragmentation (Value = .56, Removal of Three Key Players)

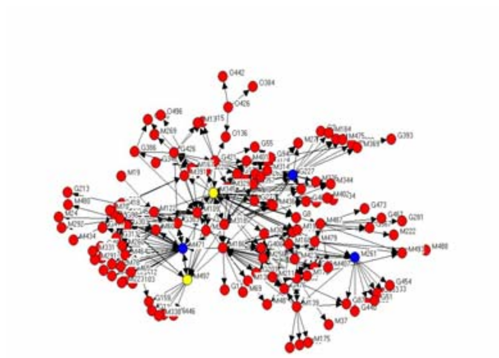

Figure 12: Mature Stage CRL Fragmentation (Value = .32 and .46, Removal of Three [blue dots] and Five [blue and yellow dots] Key Players)

We observe the same stage-based pattern in Table 4; it shows the results of three levels of fragmentation (i.e., 1 person, 2 persons, and 3 persons removed) on each CRL network. The cost or impact of removing a key player is higher in the new CRLs (i.e., GM-Eastern, GM-Western), than the impact on the more established CRLs (i.e., GM-Mid-Atlantic, GM-Mid-Western). Indeed, there is almost 60 percent fragmentation with the removal of three people from the newer CRLs, and about twice as much fragmentation for the removal of one person from the newer CRLs. Thus, the survey data is consistent with the qualitative data in that they indicate that the new CRLs are more dependent on one or two central individuals than the older established CRLs. The more established CRLs are more "specialized" or have a combination of core structures and separated thrust-area structures that provide some protection against fragmentation. While any fragmentation can affect a network, any repairs to the network can probably proceed more rapidly in a more established CRL.

CRL	Partnership Stage	One Key Player Removed	Two Key Players Removed	Three Key Players Removed
GM-Eastern	Start-Up	**0.21** (U-1)	**0.40** (U-1, U-2)	**0.56** (U –1, U-2, U-3)
GM-Western	Late Start-Up	**0.36** (U-1)	**0.48** (U-1, GM-1)	**0.58** (U-1, GM-1, GM-2)
GM-Mid-Atlantic	Mid-Term	**0.11** (U-1)	**0.21** (U-1, GM-1)	**0.23** (U-1, GM-1, U-2)
GM-Mid-Western	Mature	**0.14** (U-1)	**0.24** (U-1, U-2)	**0.33** (U-1, U-2, GM-1)

Table 4: Fragmentation Caused by Removal of University or GM Key Players[20]

We also examined the institutional affiliation of the key players by stage in the partnership cycle. The letter "U" refers to a university key player while "GM" refers to a GM key player. The number(s) following the designation refer to whether it is the highest or second-highest impact key player from that organization who is being removed. The highest-impact key player in any CRL, at any stage, is a university key player. The removal or loss of that individual causes the greatest fragmentation in the CRL network. As a result, we find that GM is heavily dependent on its university key players to serve as the critical cohesive force in the CRL partnerships. As two or more key players are removed from any given CRL, we see that they represent both the university side and the GM side of the partnership, with the exception of the GM-Eastern relationship in which no GM key players emerge, even with the removal of three key players from the network. Thus, for the CRLs generally, the GM side of the collaboration is also critical to its cohesion, and tends to be increasingly so as the CRLs pass through the various stages of the partnership cycle.

Our network analysis strategy also allowed us to identify individuals who act as key players by being bridges to distinct groups in each of the CRL networks. This data is an extension of the fragmentation data for the whole CRLs. These key player positions, called "cut points," function to bridge between distinct segments or regions of the network. Identifying these cutpoints for the different networks allows us to identify the people that are in key "bridging" positions. These individuals can be considered "lower level" key players. If they are removed, a new bridge must be formed, or contact will be lost with that part of the network, even though the overall network will probably stay intact.

[20] KeyPlayer 1.0 (Borgatti 2002b) was used to identify the key players and the levels of fragmentation and reach included in this and other tables.

Figures 12 and 13 visually identify the cut points in a new and a mature CRL. The red dots are people in cut point positions in two actual networks. The differences are striking. The Start-Up Stage CRL contains only four cut points that bridge its smaller segments. The Mature Stage CRL contains five times as many points that bridge the various smaller components embedded in the overall network. The number of bridges needed in any CRL increases with both the size and the complexity of the CRL in each stage. The bridging function of the people in the cut points can be restored much more easily and quickly if these particular positions are recognized in the overall structure of the CRL. This type of information allows repair of smaller segments of the CRL to be undertaken even when the person leaving is not a major key player, but does occupy one of the more minor key player positions. Interestingly, university cut points are more frequent during the partnership cycle, though the proportion of GM cut points increases as the partnerships age. For example, during Start-Up, Eastern had four cut points while GM had two. By contrast during the Mature Stage, Mid-Western had 10 cut points while GM had six.

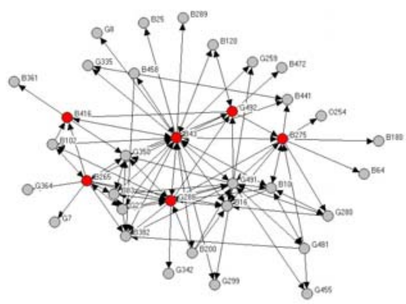

Figure 13: Cut Points and Bridges During Start-Up Stage

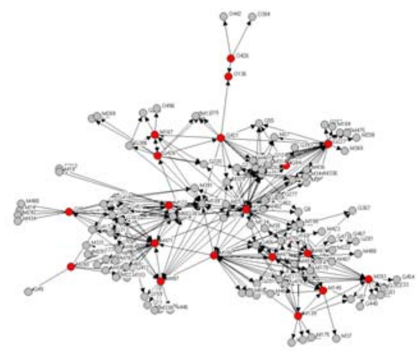

Figure 14: Cut Points and Bridges During Mature Stage

<u>Reduced Ability to Reach All CRL Participants</u>. The “reach” data-analysis process calculates how many key players are necessary to contact everyone in a network directly. The reach analysis can be extended to include both direct and indirect contact, by any path among individuals, by going through a specified number of other individuals. Reach is one way of estimating both the relative amount of time, and the amount of effort that are necessary for getting important and accurate information to everyone in a network. One CRL participant described an individual filling the role of a key player: *{He} does an excellent job of keeping us informed, and involved, and his faculty involved. During the [joint meetings], he does an excellent job of presenting to us, bringing in others from outside his department, and that has led to some relationships.*

As with Figures 11 and 12, the visual depiction of the linkages within the CRLs in Figures 13 and 14 shows key players as blue dots; all other CRL participants are shown as red dots in the visual construction of the CRL networks. A reach analysis is useful in identifying the effects, and the need for key players as the size and complexity of the CRLs changed during the partnership cycle. Figure 13 illustrates the Start-Up Stage with one key player who has 100 percent reach. As the CRLs age and become more complex, more key players surface. Figure 14 shows the Mature Stage of the cycle with three key players accounting for 97 percent of the reach in the network.

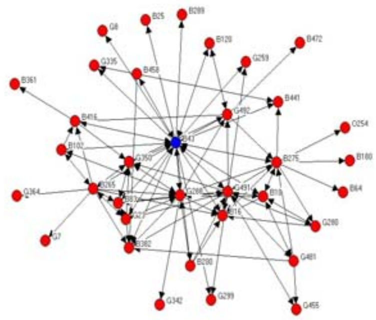

Figure 15: Start-Up Stage with 100 Percent Reach (1 Key Player)

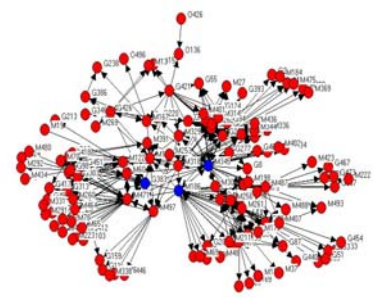

Figure 16: Mature Stage with 97 Percent Reach (3 Key Players)

Table 5 provides information from our survey data on the extent of the reach of one, two or three persons for the networks. Newer networks, such as GM-Eastern and GM-Western, have single individuals, or at most pairs of individuals, who can make contact with everyone directly, or through only one intermediary. More mature networks, such as GM-Mid-Atlantic and GM-Mid-Western, typically utilize three people to make all of the linkages work. The evolution of the networks is evident in that it takes more individuals to reach all parties in the more mature and more complex networks, fewer in the newer ones. These reach findings reinforce the important role of key players throughout all partnership stages.

CRL	**Partnership Stage**	**Maximum % Network Reach, One Key Player**	**Maximum % Network Reach, Two Key Players**	**Maximum % Network Reach, Three Key Players**
GM-Eastern	Start-Up	**100** (U-1)	(U-1, GM-1)	(U-1, GM-1, GM-2)
GM-Western	Late Start-Up	**89.6** (U-1)	**100** (GM-1, U-1)	(GM-1, U-1, GM-2)
GM-Mid-Atlantic	Mid-Term	**92.7** (GM-1)	**98.2** (GM-1, U-1)	**100** (U-1, GM-1, GM-2)
GM-Mid-Western	Mature	**89.6** (U-1)	**97.8** (U-1, U-2)	**100** (U-1, GM-1, U-2)

Table 5: Amount of Reach Accomplished Through University or GM Key Players

The key player with the greatest amount of reach is typically from a university rather than GM, although Mid-Atlantic is an exception to the general rule.[21] When reach is calculated for two key players rather than one, both university and GM key players

[21] The individual who had the most reach in the GM-Mid-Atlantic CRL was from GM, though there was a Mid-Atlantic participant who had virtually the same amount of reach. The Key Player formula selected the Mid-Atlantic participant second, but the general rule is not seriously violated by the data.

emerge, with the exception of the Mid-Western which has a complex structure that requires multiple university key players to have the greatest reach. However, even in the most complex stage, we find that at least one GM participant is required to achieve 100 percent reach, as can be seen in the columns from Table 5 identifying 100 percent reach. In all cases, our sociometric analysis demonstrated that with no more than three people, and sometimes fewer, there is redundancy (i.e., overlapping reach) in the network in which two individuals share very similar sets of relationships, even though one has the most reach. This redundancy, combined with the reach found in specific key players, helps protect the network against problems produced by the loss of key individuals.

THE EVOLUTION OF CRLs AS A PARTNERSHIP TYPE

Up to this point, we have stressed two dimensions of CRL evolution. First, we summarized evolutionary elements associated with the partnership profiles by documenting historical changes. Second, we emphasized the evolutionary evidence based on comparisons of the social network structures derived from the survey data. We now turn to a discussion of CRLs as a partnership type. We focus on the evolution of CRLs as an organizational form. In combining our multiple data sets, we were struck by the important symbolic, structural, administrative process, and work practice changes that CRLs have undergone. Table 6 identifies the key attributes that have changed as this partnership type itself has changed. For heuristic purposes, we have separated the four CRLs by time period. The GM-Mid-Western and GM-Mid-Atlantic CRLs were created prior to or during 2000, while the GM-Western and GM-Eastern CRLs were established after 2000. The attributes we list typically fall into one of the two time periods. The attribute changes we have observed seem to have strengthened the CRL partnership program as a whole, while also strengthening the individual collaborative relationships. We begin with the key symbolic change in the CRLs' evolution.

Key Attributes	CRLs Established by 2000	CRLs Established After 2002
Perceived Symbolism in Partnership Label	GM is primary beneficiary of Satellite Lab's work	Benefits for both partners are articulated for CRL work
Strategic GM Emphasis (e.g., time, money, impact)	Limited	Significant
Length of Partnership Cycle	Variable: three to five years	Required to be five years*
CRL University Selection Criteria	Specific technical expertise; university reputation; pre-existing ties between GM and university	Specific technical expertise; GM perception of internal faculty collaboration
GM Awareness of and Sensitivity to Partnership Transitions	GM not focused on CRL renewal concerns	GM increasingly aware of CRL renewal concerns and financial support implications
Relative Emphasis on Formal and Informal CRL Interactions	Variation in relative importance between CRLs	Growing importance of informal CRL interactions relative to formal reviews
Two-Way Researcher Exchanges Between GM and University Despite Distance	Variation between CRLs	Researcher exchanges between GM and CRL universities more common
GM Knowledge about CRL Management	Trial and error approach	Increasing cumulative knowledge and experience

*The Western cycle was three years.

Table 6: Evolution of CRL Features by Time Period

From Satellite to Collaborative Research Lab

The momentum gained following Western's request to be titled the Western Collaborative Research Laboratory – rather than Satellite Laboratory – led to a GM decision to re-label all such partnerships as CRLs. This name change represented an evolutionary change in CRLs as a partnership type. It symbolized a shift to a leveraging orientation – a shift that emphasized a change from directed research that primarily benefits one organization, to a partnership in which each side leverages the knowledge of the other. Additionally, the re-labeling highlighted the mutually-beneficial – but often different – goals for each partnering organization.

More CRLs with Longer Partnership Cycles
In general, CRLs as a partnership arrangement have flourished. By 2000, GM's emphasis on CRLs was limited since only two CRLs had been created (i.e., at Mid-Western and Mid-Atlantic). Since 2000, several new CRLs have been created in the U.S.; GM also has established some CRLs outside the U.S. Thus, since 2000, GM's emphasis on CRLs has grown dramatically in terms of researcher time, budget, and impact.

The CRL partnership cycle has solidified into a five-year cycle. There was variation in the length of the cycle for the early CRLs. The GM-Mid-Western CRL had an initial five-year cycle, while GM-Mid-Atlantic and GM-Western had three-year cycles. By the time the GM-Eastern CRL was established, R&D management made a decision that all future CRLS would have five-year cycles. This new cycle length has been formalized in subsequent Agreements between GM and the universities.

Tightened Selection Criteria and Transition Sensitivity
From an administrative process standpoint, GM participants have modified some of their views on CRL management. One dimension of CRL management entails the exploration and ultimate selection of a CRL candidate university. Interviewees told us that the early CRLs (e.g., Mid-Atlantic, Western) were selected based on their specific technical expertise and institution's reputation. Pre-existing ties between GM and university personnel also may have been a contributing force. With Eastern's candidacy, another selection criterion emerged – the perception of internal faculty collaboration. The reasoning was that if the faculty worked well with each other, they would be more likely to collaborate with the GM researchers. Our interviewees also revealed that other candidate CRL universities were eliminated when such collaboration was not evident.

As partnership cycles have wound down, we have noticed some increasing awareness on the GM side about its CRL partners' circumstances. Partnership transitions typically involve uncertainty about the future; a key uncertainty from the CRL perspective revolves around partnership renewal and its implications for financial support. Interviewees identified CRL renewal concerns both in the Mid-Western and Mid-Atlantic CRLs; we later learned that Western also expressed such concerns. Now that this issue has emerged and been discussed among leaders on both sides of the CRLs, we are hopeful that one of more solutions can be proposed to address it.

More Informal Work-Related Interactions to Complement CRL Reviews
CRL leaders typically specified the number of formal reviews per year in their Agreements. The intent was to furnish updates to GM management on the progress associated with the various partnership projects. In the case of three of the CRLs, we heard participants from both sides of the partnership complain about the insufficient emphasis accorded informal working arrangements. Researchers, in particular, indicated that technical discussions and interactive sessions were far more stimulating than listening to an agenda full of project presentations. We noticed that as the three youngest CRLs aged, participants created additional informally-structured interactions to facilitate the collaboration.[22] Efforts were made to carve out time from or add time to a visit, resulting in a combination of ways in which individuals could participate in the CRL's work.

Another work practice that appears to be on the rise is the number and length of two-way personnel exchanges among partnering organizations. This pattern, initially evident with the GM-Mid-Western CRL, seems to have been adapted for CRLs that are more geographically distant from their partners. In the case of the GM-Western CRL, participants were involved in short visits at each other's work site on a number of occasions. While longer stays such as student internships have been a prominent part of the Western CRL activities, GM sent its first researcher to the university on a short sabbatical in Spring 2004. The GM-Eastern CRL has actually been a pioneer in this regard since they specified the importance of two-way exchanges in their Agreement. From the outset of the CRL, selected Eastern faculty have spent a portion of their summers on sabbatical at GM – complementing the Eastern student interns; some GM researchers also have participated in short stays at Eastern each year.

Tapping Into Accumulated CRL Knowledge
All CRL partners have first-hand experience in working with their counterparts as part of GM's CRL partnerships. For individual participants, this experience is acquired in various ways including direct observation and participation in CRL activities and communications. CRL participants also talk among themselves – sharing information, offering explanations, proposing alternative strategies, and changing CRL work practices. Individual knowledge and experience is shaped by a participant's length of association with a CRL, or affiliation with more than one CRL.

Experiences also are retained at the partner level (e.g., GM or Mid-Atlantic, GM or Eastern) and at the partnership level (e.g., GM-Mid-Atlantic, GM-Eastern) in the form of events, stories, and issues. Such information typically surfaces when orienting newcomers to the CRL, when attempting to resolve CRL problems, when proposed CRLs are under consideration, or when new CRLs seek advice from more seasoned CRLs. As the partners' cumulative experience with CRLs as an organizational arrangement increases – due to the duration of individual CRLs, number of CRLs overall, and diversity in CRL technical focus – they become more adept at such matters as understanding and responding to concerns, facilitating contacts, and learning from previous mistakes. Participants in the early CRLs (e.g., GM-Mid-Western, GM-Mid-

[22] We never had any indication that the GM-Mid-Western CRL experienced a dearth of informal work-related interactions, possibly because of the close proximity between the partners.

Atlantic) learned largely by trial and error. They made their decisions based largely upon knowledge acquired in non-CRL contexts and the uniqueness of the situation at hand.

In newer CRLs, we have seen that the GM learning curve is reduced when it is possible to call upon the store of knowledge within GM's vast array of CRL networks. These newer CRLs benefit from a shorter, easier, more systematic, and less confusing ramp-up than those faced by the older CRLs, even though they too may face unique issues. GM has been able to call upon the diverse sets of experiences with multiple CRLs as CRLs as a partnership type evolve. For example, GM has become more knowledgeable about student and researcher exchanges, and the development of culturally-acceptable collaboration designs of interest to universities. This kind of knowledge is acquired in discussions with GM participants in other CRLs, or in communications from R&D management. Such knowledge may be shared with university CRL participants as appropriate.

CONCLUSIONS

Evolving CRL Size and Complexity

- **CRLs grow in size and structural complexity over the course of the partnership cycle.** Data from the interviews, focus groups, and survey indicates that the number of participants steadily increases over time, and that the structure of the partnerships increases in complexity. A follow-up survey to CRL participants confirmed the finding that the number of CRL participants also continues to increase over the course of the partnership cycle.

- **Recently-established CRLs show a lower connectivity between pairs of individual participants, as indicated by the average distance, than do the more mature CRLs.** Relatively informal communication methods and styles operating at the outset of the CRL (e.g., impromptu discussions, informal polling of opinions) will be less effective as the CRL ages. Mature CRLs, because of their increased size and complexity, require more structured and pre-planned communication methods.

- **Recently-established CRLs exhibit a higher density of connections between numbers of individuals than do the more mature CRLs.** Higher density is an indicator of clique formation and is interpreted in literature as an indicator for higher levels of communication. Higher density may also correlate with a sense of community among CRL participants, particularly if the participants feel that they are engaged in an exciting and interesting endeavor. The more mature CRLs have dense working groups, which maintain the sense of community, but their size and complexity reduces the overall density of relationships in the CRL as a whole.

The Emergence of Partnership Stages and their Associated Attributes

- **Six stages in the partnership cycle emerge from our combined data with each stage linked to definable network structures, activities, issues, and decisions.** Selected patterns in partnership behavior are associated with particular periods in the life of the partnership. Consequently, CRL behavior and perceptions are somewhat predictable. Participant understanding of stages and their associated milestones enables them to gauge the progress of their particular CRL collaboration vis-à-vis a typical CRL.

- Initiation Stage – Comprises the earliest interactions between GM and potential CRL partners. GM identifies a primary candidate university and mutual interest grows to the level of initiating the negotiation of a formal Agreement.
- Courtship Stage – Marks the initial negotiation about the specific CRL content and structure once a particular university has been selected. This stage includes an overriding emphasis on CRL goals and objectives as well as a definition of thrust and project areas.
- Start-Up Stage – Emphasizes the dynamics that hold the overall collaboration on course, including good communication and the development of trust. Indeed, the development and maintenance of relationships emerge as critical conditions for collaborative work.
- Mid-Term Stage – Entails the initial working formation of thrust areas that are attached to the partnership core. Partnering relationships are stable enough to be the foundation for establishing joint work processes, and subsequently, output from the joint work.
- Mature Stage – Allows the strongest focus on joint work and CRL goal accomplishment. There is continuing effort by key players to keep the collaboration on track and accomplish the joint work, so as to avoid drift from the overall CRL goals.
- Transition Stage – Occurs when decisions are made towards the end of the partnership cycle to renew, transform, or terminate the partnership. Increased ambiguity and conflict, and lessened trust appear due to the uncertainty present at the end of the partnership cycle.

- **The visual images of the CRLs offer a realistic portrayal of the evolution of the social structure of the CRLs, illustrating the linkages between participants and the clues about the extent of relationships and joint work during the partnership cycle.** With each successive stage in the partnership cycle – whether in the theoretical or actual configurations – connections in the CRL network expand. A collection of interested individuals (Initiation Stage) is structured by pairing specific participants from the partnering organizations together (Courtship Stage). As participants become linked with one another, a globular core forms (Start-Up) and then expands outward (Mid-Term Stage) until thrust areas are solidified (Mature Stages). At the end of the partnership cycle, several network configurations are possible based on decisions to renew, modify, or terminate the CRL (Transition Stage).

- **A stable core of participants whose turnover is low helps to anchor the CRL's work and throughout the partnership cycle.** Nevertheless, structural differences by partnership stage suggest that CRLs require different resources as they age. Funneling resources and allocating sufficient time to the thrust areas enables them to flourish. Solidifying the connections between the thrust areas and the core makes the CRL stronger and more diversified from a technical standpoint. The CRL can then build on its array of people and projects.

The Importance of the Key Player Role

- **All of the CRLs have at least one, and more often two or three individuals whose primary role is to keep communication lines open, solve problems, and help solid relationships develop.** They are the glue that holds the collaboration together, in large part because they foster connections between individuals on both sides of the partnership. Without their efforts, CRL work would be much less successful because the coordination of CRL activities, resources, and deliverables, including oversight of the technical work, would be lacking. These individuals are called "key players" in this paper.

- **Recently-created CRLs are more susceptible to damage if key players leave the network (e.g., due to retirement, job transfer, loss of interest) compared with more mature CRLs.** Newer CRLs are largely dependent on one or two key players to hold the network together. By contrast, more established CRLs do not experience the same degree of "fragmentation" because there are more "cores" of participants who are connected to each other within the network. Consequently, if a key player leaves an older CRL, the network is able to sustain more damage and adjust more rapidly than a newer CRL.

- **Individual key players in the newer CRLs have a higher degree of "reach" – the ability to make contact with nearly everyone in the CRL directly, or through only one intermediary.** The simpler structures of new CRLs make it relatively easy to contact and communicate with all CRL participants. More mature networks experience a lower degree of reach since they typically require a minimum of three people to ensure complete contact within the total network. The combined "reach of at least one key player from each side (GM and University) is necessary for complete "reach."

- **Some key players act as important bridges to smaller segments of the CRL, such as working groups, teams, or thrust areas.** These individuals, who reside in positions called cut-points or bridges, are important to the operation of the CRL networks. As the networks mature and become more complex, there is an increase in the number of bridging key players in each CRL, allowing the system to function more smoothly as it becomes larger and more complex.

RECOMMENDATIONS

Coping with CRL Size and Complexity

- **Use a combination of informal (e.g., word of mouth) and formal mechanisms (e.g., emails, meetings) to gather and disseminate information, goals, and recognition among CRL participants as the CRL ages.** Relying solely on formal methods can stifle the importance of relationships from developing in the early stages. More formal means of communication are appropriate in the later stages because they will ensure that participants hear the same message, hear it consistently (rather than in some distorted form), and hear it quickly.

- **Focus participant attention on a few key projects at the outset of a CRL**. This concentrated project attention while the CRL is young will help create a critical mass for the projects. As a result, project completion is more likely to be timely. The number of CRL projects, and the appointment of new CRL leaders and participants, can expand as the need or opportunities arise.

Managing the Stages in the Partnership Cycle

- **Create processes at the outset of the partnership (e.g., site visits, technical discussions, joint presentations) to build and strengthen the collaboration.** Get participants together on a regular basis, allow ties to develop within the CRL, and encourage the formation of ties among CRL participants who will work together. Use these processes to supplement the formal reviews that CRLs. Participants will be in a better position to understand each other's knowledge base and work styles, and can begin to develop a way of working together.

- **As the thrust areas form, ensure that thrust-area participants remain linked to the core so that their CRL contributions are acknowledged, shared, and implemented.**

- **Conduct a mid-term and an end-of-cycle review of all CRLs.** There should be a formal discussion and assessment of each CRL so that ideas can be discussed, issues can be raised, and solutions can be proposed and adopted. In addition, insights gleaned from such reviews add to the accumulated knowledge about managing the particular CRL, or CRLs as a type.

- **Celebrate CRL successes.** Select times during the partnership cycle to review progress and showcase achievements. A joint meeting of partnership participants could be a forum for recognizing both technical and business gains.

- **Work to synchronize or accommodate fiscal cycles between at the time of renewal decisions.** When these partnerships approach the end of their cycle, anxiety about renewal is exacerbated by the mismatch between fiscal years. To the extent possible, this mismatch should be identified and accommodated during the renewal negotiation process.

- **As the end of the partnership cycle approaches, make it a priority to enhance and extend partnering relationships even if the CRL, or some portion of it, is terminated.**
    - <u>Option to Continue</u> – Identify specific activities to revitalize any parts of the CRL that have become too routine. There is an opportunity at transition to reinvigorate these CRL relationships and their goals through joint discussions and increased energy and attention.

- Option to Modify – Refine and redefine the overall goals and objectives for the CRL, as technical areas are retained or dropped. Modify or reinforce the direction by continuing selected joint work activities. Revitalize the CRL as appropriate by adding new dimensions and goals.
- Option to Split – Use the split option to create two or more new CRLs. The new CRLs should be provided the same general attention to detail and direction given to new CRLs. They are likely to go through start-up and maturation processes that are similar to what was experienced during the first partnership cycle. Consequently, expectations for their progress should be tempered accordingly.
- Option to Terminate – Terminate gently to preserve positive relationships and the potential for future collaboration in alternate forms. If a decision is made to terminate an entire CRL, consult with the CRL partner about a termination plan that allows a positive closure on projects – particularly in cases when projects are close to completion or when graduate students may need bridge funding.

Maximizing the Effectiveness of Key Players

- **Use key players as one important means of orienting newcomers to the CRLs.** Key player knowledge, contacts, and experience have the potential to be very helpful to those just entering a CRL network.

- **Create opportunities for CRL leaders from a cross-section of CRLs to exchange ideas about CRL management.** Sharing insights will help speed the learning curve, assist in problem solving, and help participants recognize the stages and patterns associated with the stages.

- **Develop succession plans for all CRL Co-Directors and Thrust-Area Leaders.** Consider the extent of their connections, as well as their people skills and technical specialties. Assign current CRL leaders to mentor potential successors for the positions they hold. Help them develop a broad understanding of the CRL and thrust areas respectively. Ensure that their knowledge of CRL accomplishments and projects is up-to-date.

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APPENDIX A: SOCIAL NETWORK SURVEY

We designed an e-mail survey to gather data on partnership structure, dynamics, and roles from all possible participants in the partnerships. This survey followed a standard nominated ego network format (Wasserman and Faust 1994), which allowed us to gather reciprocal data on a significant proportion of the individuals involved in each partnership. Each respondent was asked to provide rank order data on the nature and dynamics of their relationship with each person they named. The specific relationship elements included hierarchical position in the partnership, levels of frequency and importance of communication, levels of frequency and importance of work, level of trust, level of cooperation, level of conflict, and a question that determined the locus of decision making between the respondent and the people they named. We asked the following questions on our survey.

Your Name ____

Your Organization______________________________________

Your Position Title ____________________________

Date ___________

Q1. Please name your GM Partnership
____

Q2. What is your role on the partnership?____

Q3. What is the name of your project(s) in the GM-Eastern partnership?
____

Q4. Have you had experience working with other collaborative partnerships (any organization)?   Yes __ No___

Q5. Please name all of the people you have a relationship with as part of your partnership (named in Q1). Use full name if possible.

Q6. Put GM if the person works for GM. Put HRL if the person works for HRL

Q7. Please indicate the formal relationship between you and the person named.
1 = peer
2 = someone who has lower rank or status compared to you
3 = someone who has higher rank or status compared to you

Q8. Does your relationship with the named person pre–date the initiation of the partnership?
1 = yes, it predates the start of the partnership
2 = no, it began with or after the partnership

Q9. Using a scale of 0 to 6, where
0 = none
1 = lowest
6 = highest
Please rate the frequency that you communicate with this person compared with the others on your list.

Q10. Using a scale of 0 to 6
0 = none
1 = lowest
6 = highest
Please rate the importance of the communication with this person

Q11. Using a scale of 0 to 6
0 = none
1 = lowest
6 = highest
Please rate the level of trust you have for this person

Q12. Using a scale of 0 to 6
0 = none
1 = lowest
6 = highest
Please rate the frequency that you work with this person compared with the others on your list.

Q13. Using a scale of 0 to 6
0 = none
1 = lowest
6 = highest

Please rate the importance of work you do with this person.

Q14. Using a scale of 0 to 6
0 = none
1 = lowest
6 = highest
Please rate the level of cooperation that exists between you and this person

Q15. Using a scale of 0 to 6
0 = none
1 = lowest
6 = highest
Please rate the level of conflict you have with this person.

Q16. When decisions are made, which of the following describes the normal pattern, in relation to the named person?
0 = No decisions need to be made in this relationship.
1 = You normally make the decisions in the relationship.
2 = The decisions are normally joint decisions.
3 = The other person is normally responsible for making the decisions

APPENDIX B: SOCIAL NETWORK ANALYSIS PROGRAMS

ANTHROPAC is a cognitive anthropology data management and analysis program. It accepts qualitative/nominal level data, as well as several forms of quantitative data (including survey instrument construction). The primary analysis routine utilized for this project was the free listing data project. Data is input in the form of individually generated lists of items from cultural domains (in this case, partnership relationships). These lists are converted to either similarity or distance matrices, and can be analyzed within the program using a wide number of statistical routines. The standard output for the free listing routine includes a saliency list of named individuals, simple descriptive statistics, and both person by person and item by item output data sets that can be further analyzed (Borgatti 1992).

UCINET is a social network analysis tool. Data can be imported or directly entered in a number of different formats. UCINET data analysis routines include most of the standard sociometric measures of network structure and dynamics including a) cohesion (distance, reachability, point connectivity, etc.), b) regions (components, k-cores, etc.) c) subgroups (cliques, k-plexes, factions, etc.), d) centrality (e.g., degree, closeness, betweeness), e) eg o networks, f) core-periphery, g) roles and positions, h) and whole network properties (e.g., density, transitivity) (Borgatti et al. 1999).

NETDRAW imports UCINET data files and provides an optimized two-dimensional display of the network nodes (people) and edges (connections), including the directionality of the connections. The program allows for a visual analysis of several key attributes of the network data, including a) isolates, b) components, c) blocks and cutpoints d) k-cores, and e) subgroups. The program also allows several different kinds of transformations of the shape of the data, including circle layouts, Gower metric scaling layouts, node repulsion layouts, as well as deleting isolated and pendent nodes (Borgatti 2002a).

KEY PLAYER imports UCINET data and performs three basic analyses. The first two analysis are based on the removal of one or more key nodes, and provide the level of impact on the network, based on the fragmentation caused by the removal of the key player(s), and the increase in average distance between nodes caused by the removal of the key player(s). The third analysis identifies the overall reach of one or more key players, depending on the number of edges that connect them to other people (Borgatti 2002b).

MAGE is a network visualization program. It creates a three-dimensional kinetic image that can be interactively rotated from any point of reference (node) within the matrix. The program allows different attributes of nodes and edges to be color coded, to assist in visualization analysis (Richardson 2001).

APPENDIX C: INDIVIDUAL CRL FREE LISTING COMPARISONS

CRL	Number of Respondents	Unique People Named	Total of Individual People Named (Including Duplicates)	Average Number of People Named Per Respondent	Range: People Named Per Respondent	Unique People Named At Least Twice	Number of Unique Singles Named	Percent Singles: Total Number Named	Ratio: Singles to Number of People Named At Least Twice
Mid-Western	22	112	245	11.136	3-43	58	54	48.2	.931
GM-Mid-Western	16	70	158	9.875	2-26	34	36	51.4	1.06
Mid-Atlantic	15	44	122	8.133	2-17	25	19	43.2	.76
GM-Mid-Atlantic	7	31	66	9.429	1-19	18	13	41.9	.684
Eastern	10	32	70	7.0	3-23	17	15	46.9	.882
GM-Eastern	7	22	50	7.143	3-15	13	9	40.9	69.2
Western	22	84	165	7.50	1-15	39	46	54.8	1.18
GM Western	11	44	81	7.36	1-73	17	27	61.4	1.59