The Life Cycle of Collaborative Partnerships: evolution of structure and roles in industry-university research networks.

Robert T. Trotter, II
Northern Arizona University, Department of Anthropology

Elizabeth K. Briody
General Motors Research and Development Center, Vehicle Development Research Laboratory

Gülcin H. Sengir
General Motors Research and Development Center, Manufacturing Systems Laboratory

Tracy L. Meerwarth
General Motors Research and Development Center, Vehicle Development Research Laboratory

ABSTRACT

Global corporations have initiated collaborative partnerships with university research institutions, private-sector firms, and other strategic partners at an increasingly rapid pace over the last decade. These partnerships create collaborative networks that leverage knowledge acquisition and technology transfer necessary to keep corporations and universities at the cutting edge of competition. Consequently, corporations have a competitive need to be able to predict the ideal structure, dynamics, and life cycles of these partnerships in order to effectively initiate, maintain, repair, and exit them in a way that retains the potential for future collaboration for both sides of the partnership. This paper provides an empirically validated model of the evolutionary structures and role relationships found in successful collaborative partnerships. The research combined ethnographic methods with qualitative and quantitative social network paradigms to identify the key structural frameworks and role configurations critical to the health of partnerships over their typical life cycle. The results include a description of the structures and the key player dynamics of these partnerships through six life cycle stages (approach, initiation, start-up, growth, maturity, and transition).

Corresponding Author Information: Robert T. Trotter, II. Arizona Regent's Professor, Department of Anthropology, Northern Arizona University, Flagstaff, AZ 86011. Email: Robert.Trotter@nau.edu, phone: 928-523-4521 (cel. 928-380-8694): web site: http://jan.ucc.nau.edu/~rtt/

We would like to acknowledge the warm welcome we received when we made site visits to the four CRL universities, and the assistance they provided throughout the study. We appreciate the time that the GM and CRL participants spent with us in discussions and for their responses on the social-network survey.

INTRODUCTION

Global competition is accelerating the trend for corporations to leverage university knowledge and expertise through formal collaborative partnerships (Barringer and Harrison 2000, Neill et al. 2001). The overall goal of these partnerships is to spur diffusion of innovation (Sussman et al. 2006, Valente and Rogers 1995) and keep up with rapidly changing research needs (Lewis 2000). In the late 1990s, General Motors Research and Development Center (GM R&D) initiated a Collaborative Research Laboratories (CRL) strategy as a strategic initiative. Previously, connections between GM R&D and universities were based largely on pre-existing dyadic relationships between researchers or R&D contracts with specific professors. In 2002, GM R&D management requested an examination of the structure and functioning of their successful collaborative research partnerships to identify ways to maintain and improve their effectiveness.

While the industrial literature has been primarily directed towards general organizational evolution (Laszlo, 2001, Learned, 1992) or focused on inter-organizational theory and practices (Anderson et al.1994, Prescott et al. 1998), the need to explore the overall evolutionary processes of collaborative partnerships has been identified, but only moderately addressed (Ring and Van de Ven 1994, Doz 1996). Consequently, there are a few social network studies (Borgatti and Foster 2003) that explore the evolution of partnerships (Stuart 1998, Ahuja 2000), the durability of networks (Kogut and Walker 2001), longitudinal analysis of alliance formation (Gulati 1995), transitional networks (Madhavan et al. 1998), and the concept of social capital in the formation of industry networks (Walker et al. 1997). However, one of the gaps in this literature was the lack of a description of the structural and role based changes that might predictably occur over the life of a partnership.

Our initial CRL data analysis produced a cultural model of collaboration (Sengir et al. 2004, Trotter et al. 2004) that highlighted key patterns in the relationship dynamics of partnerships. The original systems dynamics model of these partnerships was focused on relationship conditions (trust, cooperation, conflict, communication, joint work, etc.) and was designed as a diagnostic tool for industry-university collaborations (Sengir et al. 2004), utilizing a life cycle baseline data set. This article provides a substantial enhancement of the original model by elaborating the key structural (network) and role functions imbedded in the original model. This article focuses on describing the stage-based evolutionary (life cycle) conditions found in successful collaborative partnerships. The hypothetical and empirical data presented in this article can be used to form a "best practices" model for this type of partnership.

METHODS

We employed three synergistic methodologies: 1) ethnographic studies at GM R&D and at four CRL sites, using standard applied ethnographic methods (Trotter and Schensul 1998); 2) a social network survey that allowed us to investigate partnership structures, dynamics, and roles in the target partnerships; and 3) qualitative reliability and validity checks of our findings through formal validation sessions (see Kirk and Miller 1986). Each approach followed a comparative-empirical analysis strategy focusing on themes and patterns (Bernard 1998, Schensul and

LeCompte 1999) informed by prior ethnographic research on partnerships (Meerwarth, Briody, and Kulkarni 2005), and informed by general network analysis theory (Wasserman and Faust 1994, Wellman and Berkowitz 1997), with an emphasis on the qualitative aspects of network relationships.

Ethnographic Research Methods

Ethnographic interview, focus group, observational and documentary data were collected at four collaborative labs (Zeta, Gamma, Delta, and Alpha Universities -- pseudonyms following standard ethnographic confidentiality conventions) and at GM R&D. The primary ethnographic methods included in-depth semi-structured and *in situ* interviews based on iteratively developed interview and focus group guides; direct observation of collaborative laboratories and the accompanying interactions between partners; participant observation of key processes; culture-in-context observations that identified the normative behavior at the various collaborative sites and venues; and focused qualitative data collection (free listings, cultural model interviews) on the meaning of collaboration, roles and role definitions and information on the formal and informal structures of the collaborative laboratories. This approach allowed us to describe the context as well as the basic cultural viewpoints on collaboration and social networks within and between the partner organizations. It also allowed us to develop and refine the key variables that we included in a social network survey of the partnerships.

We conducted in-depth ethnographic interviews with 65 individuals, 38 from GM and 27 from the partnering institutions. Ethnographic informants were selected using a nominated expert sampling process. The core research and administrative personnel at GM and the CRL (CRL Director, GM champion, GM and CRL thrust area leaders, department heads and chairs, etc.) were identified and interviewed (expert saturation sample). This core expert group then nominated additional individuals who were qualitatively representative of the whole "experience and expertise" configuration of the CRL, including graduate students, technicians, post-doc students, faculty, ancillary GM personnel, and administrative assistants. 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, individual roles that were important to the development and maintenance of the CRL, and expectations about the future of the partnership. Eight focus groups (average 8 persons each) 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. A set of 6 field observation studies provided data on interactions, key collaborative processes, and meetings both at GM and at the partnership institutions. Finally, CRL documents provided insight into the formally-stated goals and activities of these partnerships.

GM had established four CRLs at U.S. universities by 2002 when this research was initiated. The first Lab was established at Alpha University in 1998. This lab was nearing the end of its first partnership cycle and was exploring options for renewal. It provided us with baseline information about all of the key stages that CRLs experience and the transitions that are likely in the later

part of the partnership cycle. In 2000, GM established the second CRL at Gamma University, which allowed us to investigate both the early stages and some middle stages of cooperation and the transitions faced during those times. Delta University became the third collaboration early in 2001. The fourth CRL at Zeta University also commenced in 2001, several months after the GM-Delta University. Both of these partnerships provided extensive data on the selection and recruitment stages of the partnership life cycle, and solid information on the start up stage. The overall data set provided details on the ways successful partnerships are initiated, gain momentum, and go through end of cycle transformations. It also provided information on the changes in individual roles, numbers of participants and types of participation that are necessary for a healthy partnership life cycle (Sengir et al. 2004, Trotter et al. 2004).

Social Network Survey

We administered two email-based social network surveys to both the GM and CRL participants. The surveys were sent to every individual who was identified by either GM or the CRL as being involved in any role or activity in the partnership. The first survey was sent to 176 participants in the original four CRLs and followed general network data collection guidelines (cf. Wasserman and Faust 1994). The instrument included demographic questions (name, position, and experience with collaborative relationships) followed by a general "name generator" matrix requesting each respondent to identify the complete list of individuals that they were in contact with as part of the CRL. For each individual named, alters were ranked on perceived levels of communication, joint work, trust, conflict, and cooperation.

The survey response rate of 62.5 percent (of the 176 surveys delivered) was methodologically acceptable, based on an expected response rate of approximately 35 percent (Stork and Richards 1992). The second survey was conducted 18 months later, as a "time two" validation test for the general model. At that time, there were a total of 8 CRLs in operation and 270 surveys were sent out, with a response rate of 68.1 percent. There was only one active refusal to participate in either of the surveys. The only observable difference between the response and non-response groups was a trend towards a lower response rate among the more peripherally involved graduate students and technicians compared with faculty, post docs, GM researchers, and administrators from both sides of the partnership. The trend does not appear significant and does not appear to have had a substantial impact on either the structural or the key player data presented below.

The analytical techniques applied to the survey data included free listing, egocentric, sociometric, and network visualization analysis. The free listing analysis provided information on changes in the size, content, and configuration of named relationships (Weller and Romney 1997). The egocentric analysis allowed us to compare individual role types and institutional groups (GM participants, University participants, etc.) for a range of variables including communication, trust, conflict, and work importance, among others, following Borgatti et al. (2002a, 2002b), and Cross et al. (2002) The sociometric data allowed us to construct network structures for visualization analysis, sociometric comparisons of the networks at various life cycle stages, as well as individual roles, subgroups, and measures of association and communication. We utilized one

ethnographic (ANTHROPAC 4.98: Borgatti 1996) and four network programs (UCINET 6: Borgatti et al. 2003, Key Player: Borgatti 2002b, NETDRAW: Borgatti 2002a, Mage: Richardson 2001 for 3-D visualization). The network visualization process allowed us to compare the structures of the various CRL networks within the framework of the life cycle stages established in the ethnographic data. The role analyses combined ethnographic and network data using both Key Player software (Borgatti 2002d) and sociometric and visualization analysis of the survey data (Borgatti 2002c). We also utilized the visual analysis characteristics of NETDRAW (Borgatti 2002a) to identify key positions and subgroups in the CRL networks at various stages in their life cycle.

Validation and Triangulation Process

We conducted 10 independent validation sessions attended by 145 study participants. We presented findings and gathered input on data validity and any potential gaps in data collection. These sessions were designed to qualitatively test the soundness of our analyses, to integrate new insights into our work, and to collect additional data (Kirk and Miller 1986, Bernard 1998). This validation process is a hallmark of strong ethnographic projects and provides the qualitative equivalent of the reliability and validity testing conducted in any well designed quantitative project.

RESULTS

All CRL partnerships undergo a selection and approval process, followed by a start up period, a growth period, a mature stage, and an end of cycle transition stage. Table 1 briefly summarizes the key characteristics of the stages, as well as some of the predominant characteristics of their network structure and key player (role) dynamics.

Table 1: Summary of Defining Characteristics: Structural Elements and Role Dynamics of Successful Collaborative Research Partnerships

Partnership Stage	Defining Characteristics	Structural Characteristics of Collaborative Networks	Role (Key Player) Characteristics of Collaborative Networks
Approach	Informal exploration of mutual interests; formal requests for statement of interest	Mostly dyads and triads in informal discussions	Management and administrative roles predominate
Initiation	Formal negotiation of goals, processes, intellectual property issues	Small densely connected work groups	A mix of managerial, technical, and support roles representing both sides of the partnership.
Start Up	Creation of core partnership membership; establishment of key relationships	Relatively small core-periphery structured network; high density, strong ties predominate	Key players create and maintain a core group that will be relatively stable throughout the partnership life cycle
Growth	Consolidation of relationships; initiation and elaboration of collaborative work processes, initiation of joint work productivity	Growing core-periphery structure group with core maintaining goals and direction of partnership and peripheries increasingly focused on specific work tasks	Increased differentiation and growth in key players. Key players in core primarily serving integrative functions, key players in periphery structures acting as bridges, catalysts, etc.
Mature	Fulfillment of common goals; maintenance of core values, direction; full focus on productivity	Core and periphery structure elaborated into distinct subgroups (subgraphs) primarily focused on joint work; core focused on integrative roles	Key player roles have increased emphasis on problem solving and adjudication, as well as integrative roles. Key player roles in subgroups are elaborated.
Transition	Assessment Period focused on quality and outcomes of partnership (goals met and unmet); relationship dynamics reviewed; risks to continuation, modification, and termination assessed	Mature structure is maintained up to actual transition or is modified over a relatively short period leading up to transition. Four end-game structures are possible: minimal change, added or subtracted thrust areas, split and increase number of CRLs, or close down.	Tension and ambiguity lead to threat to quality of relationships; Key roles modified from maintenance to transition roles (emphasis on damage control, problem resolution, or revitalization); Temporary or permanent reduction or suspension of technical roles.

The following two sections combine the basic stage descriptions from our interview and observational data with the structural and role data from the social network surveys to describe the conditions that apply to successful collaborative partnerships through their life cycles. The first section emphasizes the evolution of basic network structures that are found in successful partnerships. The second section provides information on the role and position data that helps define each stage. The result is a complex and detailed, but utilitarian model for the primary network elements of a collaborative partnership.

Structural Characteristics of Successful Collaborative Networks

Each of the life cycle stages can be identified and differentiated from the others on the basis of their network characteristics, including size and growth, differences in their core-periphery structures, and differences in positions necessary to the functioning of the partnerships at each stage.

Approach Stage: The earliest interactions between GM and potential CRL partners constitute the Approach Stage. This stage begins with the identification of a specific GM R&D research need. R&D personnel then nominate prominent universities and programs that are leaders in the area of interest. Once a potential field of candidate schools is identified, each is contacted, usually through existing connections between GM R&D personnel and the respective universities. There is a 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 participant group is then narrowed to include one or two programs that are requested to enter into formal discussions. The primary network connections for this stage are weak ties (often based on interactions at scientific meetings) or strong dyads (school ties of both the relationship sort, and the sartorial variety).

Courtship Stage: The Courtship Stage encompasses formal and informal negotiations about the specific goals and structures of the partnership. The Courtship Stage begins with general negotiations and ends with a joint identification of thrust areas and a formal Agreement. A small number of individuals explore common ground (potential joint work) and negotiate key institutional concerns such as intellectual property rights, resources, and commitment of personnel. Key players begin to emerge on each side of the partnership. One key player described how GM and Delta University worked out many of the details of their new formal relationship:

> *It took us almost five months to develop the contract…Those five months 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.*

Initiation Stage: The first deliberately constructed networks begin at the initiation stage. Our qualitative interview data allows us to represent the Initiation Stage visually as a ladder (Figure 1). This is a typical business organizational structure that involves individuals in administrative roles (hierarchical organization -- top of ladder) and research roles (horizontal organization--

lower rungs of ladder). The ladder shape, rather than the dendrogram shape of a standard organizational chart, results when the partners deliberately include one or more individuals from each key level of both organizations and formally pair them with their counterparts at the same organizational level. This hypothetical structure was deliberately created for each CRL, with the expressed hope that additional vertical and horizontal cross-connections would rapidly follow. Individuals from the two partnering organizations are represented by red or blue nodes, respectively.

Figure 1: Hierarchical Initiation Phase Network "Ladder Configuration"
[Hypothetical Construction]

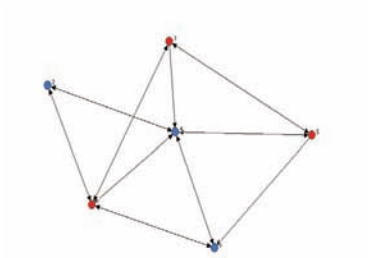

Figure 2: Initiation Phase Configuration with two Pre-Existing Relationships
[Empirical Qualitative Data]

Figure 2 illustrates a typical reconfiguration of the original ladder hierarchy that reduces the rigidity of the initial structure. The successful partnerships had at least one or two people who were previously connected through their work, but were not at the same hierarchical level in their respective organizations. When those individuals are included in the start up process for the partnership, their ties cross connect between levels and across organizations, changing the structural configuration of the partnership. Figure 2 depicts an Initiation Stage partnership in which there are two pre-existing relationships among the individuals initiating Start-Up. This non-ladder configuration is more effective for rapidly developing the necessary partnering relationships than the hierarchical structure. Communication flow and decision making can be faster and more consensual, avoiding "red tape" and other bureaucratic impediments at a critical stage of partnership development. The overall demands of collaboration require that people talk and work with one another up, down, and across both organizational hierarchies.

Start-Up Stage. The Start-Up Stage emphasizes relationship dynamics and the interactions that hold the overall collaboration on course, including communication, the development of trust, and overall positive reciprocity between individuals (reduction of conflict, initiation of cooperation). One participant stated:

> *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.*

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 Gamma] and we go to the quarterly reviews.*

Figure 3 is a hypothetical network structure comprised of 15 individuals (modal number for start up groups) constructed from ethnographic descriptions of the relationships our informants felt should ideally exist at Start-Up. Figures 4 and 5 are empirical network representations of two CRL networks surveyed at the Start-Up stage. The globular structure (core-periphery structure in social network terminology) of all three networks focuses the efforts of one or two key players who are connected through communication and interactions with everyone else in the network. This structure becomes the enduring network glue that holds the collaboration together throughout the partnership life cycle.

Figure 3: Start Up Structure [Hypothetical Construction]

Figure 4: Start-Up Structure at 1 Year (GM-Zeta-empirical)

Figure 5: Start-Up Structure at 1.5 Years (GM-Delta-empirical)

The core-periphery structure of all start up partnerships has a common condition visible in figures 4 and 5. The core contains a group of people who are densely connected across both sides of the partnership. The periphery contains some individuals with a single connection or tie to one of the core members. This gives the structure a "prickly" look, from a qualitative perspective. The qualitative data indicated that these single connection individuals are usually either graduate students (on the university side) who are tied to the overall partnership by a single faculty member, or they are technicians or GM researchers who have a single tie (due to their specific expertise) to only one of the GM participants. One visible difference between the partnership stages occurs when these single tie individuals develop connections to each other and to other core individuals. This process elaboration of the number and complexity of ties at the periphery is a key condition that defines the difference between the Start Up and Growth stages for the network data.

Growth Stage The Growth Stage begins when stable core relationships allow joint work processes to emerge as distinct subgroups within the overall partnership. During the Growth Stage the partnership emphasis is on increasing productivity, in addition to maintaining positive relationships. At this stage "thrust areas" (formally established technical areas for specific joint research collaboration) emerge, increase in size, and form visible sub-groups (subgraphs). They protect their localized dynamics by establishing key player gatekeepers who keep the demands from the overall partnership relationship reasonable, while increasing the productivity in the subgroup. One participant commented:

> *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 illustrate the hypothetical and empirically derived structures for the Growth Stage. In Figure 6, two thrust areas are beginning to develop as new participants are added to the core (represented by red nodes). These thrust areas are represented by a cluster of yellow and blue nodes, respectively, at the peripheries. These thrust areas show increasing local density separate from the connectivity of the core. Figure 7 illustrates emerging thrust area structures at the "northwest," "southeast" and "northeast" quadrants of the Gamma network visual data.

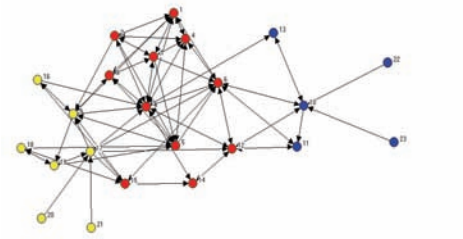

Figure 6: Growth Stage Structure with two Emerging Thrust Areas [Hypothetical Construction]

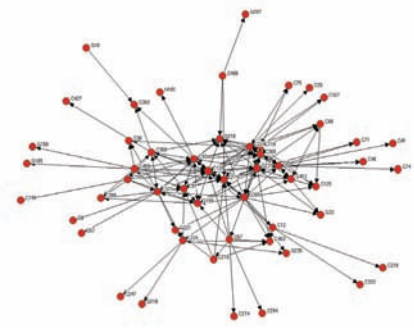

Figure 7: Growth Stage Structure at 3 Years with three Thrust Areas (GM-Gamma-empirical)

This structure is technically also a core-periphery network structure similar to the start up stage structure (or a continuation and elaboration of it). It qualitatively differs from the start up stage as the periphery visually shows the growth of the whole network and the elaboration of localized subcomponents.

Mature Stage. The mature stage is the highest productivity stage and has the most complex structure. It allows productivity to be increased or maintained, while balancing the need for overall integration of the partnership through common vision and goals. There is a continuing effort by core key players to keep the collaboration on track (integration), complemented by focused productivity to meet joint work goals. One participant stated:

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 structural result of these complementary processes (integration and productivity) is represented in Figure 8. Visually the overall structure looks like a boat propeller, fitting nicely with the metaphor behind thrust areas and positive forward directions for the partnership. The integrative core is displayed in yellow (the hub of the propeller), and three mature and productive thrust areas are illustrated by red, blue, and green nodes respectively. While reality is somewhat messier than the ideal, the visual presentation of the empirical data (Figure 9) reveals the core and periphery structure is sufficiently close to the ideal to state that the hypothetical structure has appeared in a real world situation. Figure 9 also illustrates that some individuals at the peripheries are connected to only one other individual in the fan structure. This is the same condition demonstrated in the start up and growth phase. This data suggests a growth pattern that continues to occur throughout partnership. The overall structure suggests that innovation for these partnerships typically moves from the peripheries to the core, with the core controlling technological transfer into the broader institutions that support the partnerships.

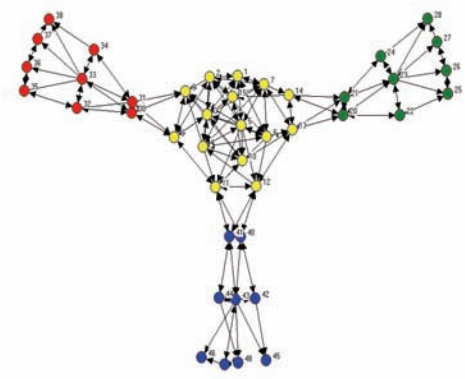

Figure 8: Mature Structure [Hypothetical Construction]

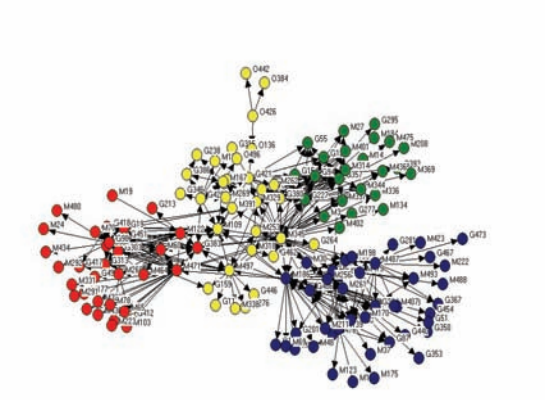

Figure 9: Mature Structure at 4.5 Years (GM-Alpha-empirical)

Transition Stage. The Transition Stage represents the end of the formal CRL life cycle. The processes that govern both the unilateral and bilateral decisions about the partnership come into prominence at this stage and potentially threaten the relationships and the networks that have been created. One or both partners become concerned over transition decisions. One CRL participant stated,

> *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 often refocus the emphasis of the partnerships away from joint work and back to the core structure at the center of the partnership. Relationships become more ambiguous and prone to misinterpretation or negative interpretation. Conflict can arise based on both rumored and actual changes, and "whole group" communication becomes important. Four transition options were identified in the ethnographic data. The CRL can continue in its original form, as was the case for the GM-Gamma CRL when it was renewed at the end of three years. The existing structure and key player roles continued largely without interruption. A second option is to modify the CRL by adding or eliminating thrust areas, producing a reconfigured structure and key player configuration. Typically one or more thrust areas are disbanded; alternately, one or more thrust areas may be added. The GM-Delta CRL represents this option where three out of four thrust areas were abandoned by mutual consent and the fourth was continued. A third option is to split a mature CRL into two or more independent CRLs. This option occurred with the GM-Alpha CRL. One of the original three thrust areas was dissolved, and the two remaining were allowed to separate and form two new CRLs with multiple thrust areas. The fourth option is for the CRL to be terminated. If the termination process is conducted appropriately, the formal structure of the CRL will disappear, but many of the key dyadic relationships persist, and the overall partnership experience is judged to have been positive and productive.

The following section presents the data on the changing roles and positions that simultaneously occur throughout the CRL life cycle, in conjunction with the structural changes described above.

The Key Player Mix: Changing Roles and the CRL Life Cycle:

The GM and CRL participants provided substantial qualitative and sociometric data on key player roles within the overall CRL life stage model. Both the interview and observational data emphasizes the importance of these individuals, without whom the 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].*

Following Borgatti (2002b) we identified leaders through a "key player" analysis, informed by our qualitative data on roles and positions. We operationally defined key players as individuals who take on critical roles in the formation and maintenance of CRL networks. We compared their sociometric positions with the qualitative data we had available on both the individuals and their roles.

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 or be maintained throughout the partnership life cycle. One participant commented:

> *What I've learned is that it's essential to have a committed person at Alpha and at GM. The partnership is going to survive or fall on the personal interactions between these two people.*

This role continues throughout the CRL life cycle, supported by the accretion of additional key players who stabilize and solidify the functional aspects of the network structure. Additionally, it is possible for key players 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. Others may not be successful in changing roles, and may need to be removed to improve the health of the partnership. One participant stated:

> *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.*

Three types of key player analyses (reach, fragmentation, and cut points) are very useful for understanding the organizational-role aspects of partnership life cycles. The evolutionary aspects of the integrative role are described below in our "reach" analysis section. CRLs also have key players whose function is to stimulate and direct work activities in subgroups within the network. If these individuals are removed, there is an immediate need to "repair" the network to keep it meeting work related goals. We found that a "fragmentation" analysis of the CRLs was very useful in identifying key players whose replacement was very high

priority if they left the network for some reason. Finally, we found it very useful to use the concept of "cut points" to identify the bridges to subsegments of the CRL networks. This allowed us to potentially match the organization roles and responsibilities of key players to the empirical data on their position in the CRL network structures, to see if any changes were needed. It also identified parts of the overall structure that were "natural" cut points during the transition phase of the CRL.

Reach: Ability to Easily Communicate with or Influence All CRL Participants.

We conducted a "reach" analysis (proportion of the network each individual is in contact with) to identify the key players who establish or maintain the maximum connection with alters in a network. Reach is one way of indirectly estimating the relative amount of time and effort that are necessary for getting accurate information to everyone in a network, as well as estimating the minimum number of people who need to adopt this role for different sizes of partnerships. One CRL participant described an individual filling the "reach" 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.*

Table 2 identifies the extent of reach of one, two or three key players who have the maximum unique reach for their networks. Newer and smaller networks, such as GM-Zeta and GM-Delta, have single individuals, or at most pairs of individuals, who can contact everyone directly, or through only one intermediary. More mature networks, such as GM-Gamma and GM-Alpha, typically must utilize three or more people to make all of the linkages work.

Table 2: Stage Based Analysis of Reach: The Impact of Time and Network Size on Reach in Successful Collaborative Partnerships

CRL	Partnership Stage	Network Reach, One Key Player	Network Reach, Two Key Players	Network Reach, Three Key Players
GM-Zeta	Start-Up	**100** (U-1)	**100** (U-1, GM-1)	**100** (U-1, GM-1, GM-2)
GM-Delta	Late Start-Up	**89.6** (U-1)	**100** (GM-1, U-1)	**100** (GM-1, U-1, GM-2)
GM-Gamma	Growth	**92.7** (GM-1)	**98.2** (GM-1, U-1)	**100** (U-1, GM-1, GM-2)
GM-Alpha	Mature	**89.6** (U-1)	**97.8** (U-1, U-2)	**100** (U-1, GM-1, U-2)

The "U" and "GM" designations indicate which side of the collaboration (U for university, GM for GM) that the persons represent. The numbers (1, 2) represent the order in which the person appeared in the reach data.

The key player with the greatest amount of reach is typically from the university rather than GM side of the partnership. When reach is calculated for two key players, both university and GM key players emerge, with the exception of Alpha. At the most complex stage, at least one GM participant is required to achieve 100 percent reach. This finding emphasized the need for the partnerships to be truly collaborative, rather than to follow a market model of buying knowledge, since any lack of appropriate

attention to the key players on the university side are very likely to result in reduced effectiveness and productivity for the partnership and a loss of knowledge and technology transfer for GM. Our analysis also demonstrated that there is considerable redundancy (i.e., overlapping reach) in the networks. Commonly, two or more individuals share very similar sets of relationships even though one has slightly more reach. This redundancy helps protect the network against problems produced by the loss of key individuals. Reach analysis can be used to identify individuals who would be good role or position replacements for other individuals, everything else being equal, because their reach "footprint" is virtually identical to the person being lost.

Fragmentation

One threat to CRL health and productivity comes from the loss of key players and the subsequent fragmentation of the collaboration. This threat is exacerbated by the natural development of clique-like subgroups in any longer term network. 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.*

In early partnership stages, losing virtually any key player from the core structure translates into serious fragmentation or even destruction of the partnership. In later stages, individual loss is less damaging, although the loss of multiple key players is still problematic. Following Borgatti (2002b), fragmentation is defined as the removal of a key player from a network when their removal means that individuals or other subunits in the network are no longer connected to the network as a whole. Stage-based fragmentation is illustrated in Table 3, which shows the levels of fragmentation caused by the removal of the highest impact one, two or three persons respectively in each CRL network.

Table 3: Stage Based Impact of Fragmentation in CRLs: Removal of Highest Impact Key Players

CRL	Partnership Stage	Fragmentation* One Key Player Removed	Fragmentation Two Key Players Removed	Fragmentation Three Key Players Removed
GM-Zeta	Start-Up	**0.21** (U-1)	**0.40** (U-1, U-2)	**0.56** (U –1, U-2, U-3)
GM-Delta	Late Start-Up	**0.36** (U-1)	**0.48** (U-1, GM-1)	**0.58** (U-1, GM-1, GM-2)
GM-Gamma	Growth	**0.11** (U-1)	**0.21** (U-1, GM-1)	**0.23** (U-1, GM-1, U-2)
GM-Alpha	Mature	**0.14** (U-1)	**0.24** (U-1, U-2)	**0.33** (U-1, U-2, GM-1)

*A fragmentation value towards 1 indicates 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 nodes are still connected within the network (cf. Borgatti 2002d).

The survey data is consistent with the qualitative data. The new CRLs are more dependent on one or two central individuals than the older established CRLs. The impact of removing a single key player is higher in GM-Zeta and GM-Delta), than in GM-Gamma or GM-Alpha. The more established CRLs have more complex core-periphery structures that provide some protection against the "whole network" impact of fragmentation. Repairs to the network can proceed more rapidly in a more established CRL. On the other hand, the "fracture" points identified by the fragmentation data can also be used to identify individuals within the overall structure to target during the transition stage of the CRL life cycle, where special care must be taken to maintain a key relationship. This data is also consistent with the reach data, above. The highest-impact key player in any CRL, at any stage, is normally a university key player. This condition provides some leverage and influence for the university that is a counterweight to the fact that GM is providing the bulk of the resources that fund and support the partnership. As two or more key players are identified for any CRL, they tend to represent both the university side and the GM side of the partnership; both sides are critical to cohesion and success as the CRLs pass through the various stages of the partnership cycle.

Bridges and Cut Points

Some key players act as primarily as bridges to distinct subgroups in the CRL networks. These positions, sometimes called "cut points," link distinct segments or regions of the network. If they are removed a new bridge must be formed or contact will be truncated or lost with part of the network. Figures 10 and 11 visually identify cut points (red nodes) in a new and a mature CRL.

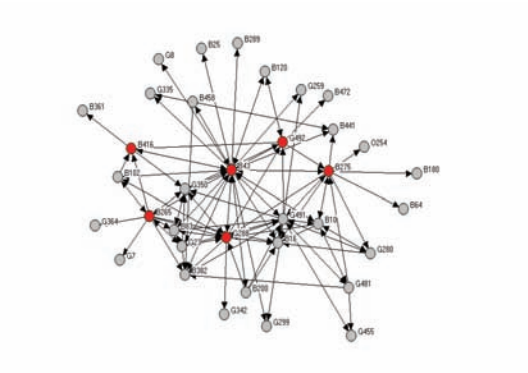

Figure 10: Cut Points and Bridges in a Start-Up Stage CRL (GM-Zeta)

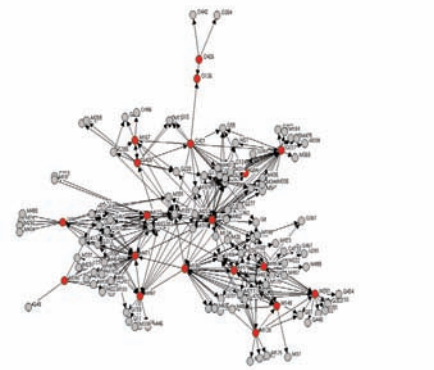

Figure 11: Cut Points and Bridges in a Mature Stage CRL (GM-Alpha)

The number of bridges needed in any CRL increases with both the size and the complexity of the CRL at each stage. The Start-Up Stage CRL contains six cut points that bridge its smaller segments and more homogeneous structure. The Mature Stage CRL contains about three times as many points (17) that bridge the more numerous sub-components embedded in the overall network. University cut points outnumber GM cut points throughout the partnership cycle, for each of the CRLs. During Start-Up, Zeta had four persons occupying cut points while GM had only two. During the Mature Stage, Alpha individuals occupied 10 cut points while GM personnel occupied seven. While this finding has to be considered preliminary, the consistent trend in our data suggests that there may be important differential contributions from the two sides of a collaborative partnership, depending on the nature of the participating organizations. This is an area that we intend to investigate further.

DISCUSSION

Our overall goal was to produce an empirically tested model illustrating how key social network elements of successful collaborative research laboratories change over time. The following conclusions and implications were both presented and validated in our ten formal validation sessions and are currently being used as "best practices" by the CRLs, since the practical use of the model is to describe the critical characteristics of collaborative partnerships that can be used to both replicate successful collaborations and to diagnose and address problems in failing partnerships.

CRLs grow in size and structural complexity over the course of the partnership even though the resource base for the partnerships remains unchanged. Recently established CRLs show a lower connectivity between pairs of individual participants, as indicated by the average distance between dyads, than do the more mature CRLs. Increasing connectivity in the early stages is a critical function of the core key players. This suggests that a significant start up period, to increase the strength of ties in the CRL, is necessary for success. Relatively informal communication methods and styles operating at the outset of the CRL (e.g., impromptu discussions, informal polling of opinions) are gradually replaced by more formal patterns, and the informal processes appear to be less effective as the CRL ages. Mature CRLs require more structured and pre-planned communication methods. The more mature CRLs have dense working subgroups, which maintain a sense of community, but their structure reduces the overall connectivity in the CRL as a whole.

Structural similarities and differences by partnership stage suggest that CRLs require continuity, growth, and role flexibility for critical human resources and task allocations as they age. A core of participants whose turnover is low helps to stabilize the CRLS throughout the partnership cycle. All of the CRLs, regardless of life cycle stage, 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 and be maintained. 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. At the same time, elaborating the connections within and between the thrust areas and the core makes the CRL stronger and more productive, and ultimately is the structure that achieves the primary goals of the partnership.

Key player and role analysis indicate the actual structure of relationships in these partnerships is compatible with, but is not dominated by formal hierarchical organizational structures. This "reconfiguration" from the standard

organizational chart is one of the strengths of the partnerships. 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, based on single individual personnel changes. If a key player leaves an older CRL, the network is able to adjust more rapidly than a newer CRL.

There is a need in the more mature CRLs to both recognize and reward individuals who are changing roles, or taking on roles that are not as visible as they would be in the young CRLs. These differences can be used to change or target the way in which the CRLs are managed at different stages, and the way that problems are addressed. For example, individual key players in the newer CRLs have a higher degree of "reach" and the simpler structures of new CRLs make it relatively easy to contact and communicate with all CRL participants through informal means. 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 network reach of at least one key player from each side (GM and University) is necessary for complete "reach." This information can be used to determine the ways in which goals and accomplishments can be communicated to the CRLs, as well as ways in which emerging problems can be addressed through either formal or informal organizational interventions.

We feel that these details and elements of our elaborated model of successful networks will allow a direct application of ethnographic and network paradigms to the process of establishing, monitoring and maintaining existing and emergent collaborative partnerships for the future.

References

Ahuja, G. (2000). Collaboration Networks, Structural Holes, and Innovation: A Longitudinal Study. Administrative Science Quarterly, 45, 425-55.

Anderson, J.C.,Hakansson H., Johanson J. (1994). Dyadic Business Relationships within a Business Network Context. Journal of Marketing, 58, 1-15.

Barringer, B.R., and. Harrison J.S. (2000). Walking a Tightrope: Creating Value Through Interorganizational Relationships. Journal of Management, 26, 367-405.

Bernard, H.R., (1998). Handbook of Methods in Cultural Anthropology, Walnut Creek, CA: Altamira Press.

Borgatti, S.P. (1996) ANTHROPAC. Ver. 4.98 Boston, MA: Analytic Technologies..

Borgatti, S.P. (2002a). NETDRAW. Boston, MA: Analytic Technologies. .

Borgatti, S.P. (2002b). Key Player. Boston, MA: Analytic Technologies. .

Borgatti, S.P. (2002c). A Brief Guide to Using NetDraw. Boston, MA: Analytic Technologies.

Borgatti, S.P. (2002d). KeyPlayer 1.1 User's Guide. Boston, MA: Analytic Technologies.

Borgatti, S.P. and Foster, P. (2003). The network paradigm in organizational research: A review and typology. Journal of Management, 29, 991-1013.

Borgatti, S.P., Everett M.G., Freeman L.C. (2003). UCINET 6. Harvard, MA: Analytic Technologies.

Cross, R., Borgatti, S.P., Parker, A., (2002). Making Invisible Work Visible: Using Social Network Analysis to Support Strategic Collaboration. California Management Review, 44, 25-46.

Doz, Y. (1996). The Evolution of Cooperation in Strategic Alliances: Initial Conditions or Learning Processes? Strategic Management Journal, Summer Special Issue, 17, 55-84.

Gulati, R. (1995). Social Structure and Alliance Formation Patterns: A Longitudinal Analysis. Administrative Science Quarterly, 40, 619-52.

Kirk, J. and Miller M.L. (1986). Reliability and Validity in Qualitative Research. Beverly Hills, CA: Sage Publications.

Kogut, B. and Walker G., (2001). The Small World of Germany and the Durability of National Networks, American Sociological Review, 66, 317-335.

Laszlo, A. (2001). The Epistemological Foundations of Evolutionary Systems Design, Systems Research and Behavioral Science, 18, 307-321.

Learned, K.E. (1992). What Happened Before the Organization? A Model of Organization Formation. Entrepreneurship:Theory and Practice, 17, 39-49.

Lewis, S.R. (2000). Corporate Partnerships Define the New R&D. R & D, 42, 1-12.

Madhavan, R., Koka B., Prescott, E. John. (1998). Networks in Transition: How Industry Events (Re) Shape Interfirm Relationships. Strategic Management Journal, 19, 439-459.

Meerwarth, T.L., Briody E.K., Kulkarni, D.M.. (2005). The Discovery and Exploration of Partnership Rules: A Methodological Perspective. Human Organization Human Organization, 64, 286–302.

Neill, J.D., Pfeiffer G.M., Young-Ybarra, C.E.. (2001). Technology R&D Alliances and Firm Value. Journal of High Technology Management Research, 12, 227-238.

Prescott, J. E., Koka B., Madhavan, R.. (1998). Networks in Transition: How Industry Events (re)Shape Interfirm Relationships. Strategic Management Journal, 19, 439-460.

Richardson, D.C. (2001). MAGE. Duke NC: Little River Institute, Duke University.

Ring, P.S. and Van de Ven, A.H.. (1994). Developmental Processes of Cooperative Interorganizational Relationships. Academy of Management Review, 19, 90-118.

Schensul, J.J. and LeCompte M.D. (1999). Designing and Conducting Ethnographic Research. Vol. 1, Walnut Creek, CA: Altamira Press.

Sengir, G.H., Trotter, R.T II, Briody, E.K, Kulkarni, D.M, Catlin, L.B., Meerwarth, T.L.. (2004). Modeling Relationship Dynamics in GM's Research-Institution Partnerships. Journal of Manufacturing Technology Management, 15, 541-559.

Stork, D. and Richards, W.D., (1992). "Nonrespondents in Communication Network Studies: Problems and Possibilities. Group and Organization Management, 17, 193- 210.

Stuart, T.E. (19980. Network Positions and Propensities to Collaborate: An Investigation of Strategic Alliance Formation in a High-Technology Industry. Administrative Science Quarterly, 43, 668-98.

Sussman, S, Valente, T.W. Rohrbach, L.A., Skara S., Pentz, M.A. (2006). Translation in the Health Professions: Converting Science into Action. Evaluation & the Health Professions, 29, 7-32.

Trotter, R.T. II, and Schensul, J.J. (1998). Methods in Applied Anthropology. In Handbook of Methods in Cultural Anthropology (pp. 691-736), H. Russell Bernard, ed., Walnut Creek, CA: Altimira Press.

Trotter, R. T. II., Briody, E.K., Sengir, G.H, Meerwarth, T.L., Catlin, L.B. (2004). The Evolving Nature of GM R&D'S Collaborative Research Labs: Learning from Stages and Roles. Warren. MI. GM Research & Development Center. R&D Publication No. 9907. 15 October.

Valente, T.W., Rogers, E.M. (1995) The Origins and Development of the Diffusion of Innovations Paradigm as an Example of Scientific Growth. Science Communication, 16, 242-273.

Walker, G., Kogut, B., & Shan W. (1997) Social Capital, Structural Holes and the Formation of an Industry Network**.** Organization Science. 8, 109-125.

Wasserman, S. & Faust, K. (1994). Social Network Analysis: Methods and Applications. Cambridge: Cambridge University Press.

Weller, S. & Romney, A.K.. (1997) Systematic Data Collection. Menlo Park, CA: Sage Publications.

Wellman, B. and Berkowitz, S.D. eds. (1997) Social Structures: A Network Approach Greenwich, CT: JAI [Elsevier] Press