NBER WORKING PAPER SERIES

CONNECTIVE CAPITAL AS SOCIAL CAPITAL:
THE VALUE OF PROBLEM-SOLVING NETWORKS FOR TEAM PLAYERS IN FIRMS

Casey Ichniowski
Kathryn L. Shaw

Working Paper 15619
http://www.nber.org/papers/w15619

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
December 2009

We thank the National Science Foundation and the Alfred P. Sloan Foundation for their generous support, and the many participants at seminars at Cornell University, Harvard University, London School of Economics, MIT, Northwestern University, Stanford University, University of Chicago, University of Illinois, UCLA, the Society of Labor Economics, the American Economic Association meetings, and Jon Gant, and discussants Edward Lazear and Bentley MacLeod for their detailed suggestions. The views expressed herein are those of the author(s) and do not necessarily reflect the views of the National Bureau of Economic Research.

Connective Capital as Social Capital: The Value of Problem-Solving Networks for Team Players in Firms
Casey Ichniowski and Kathryn L. Shaw
NBER Working Paper No. 15619
December 2009
JEL No. J24,J3,J31

ABSTRACT

Traditional human capital theory emphasizes a worker's investment in knowledge. However, when a worker is faced with day-to-day problems on the job, the solutions to the problems often require more knowledge from a team of experts within the firm. When a worker taps into the knowledge of experts, the worker develops his "connective capital." Firms that value problem solving highly will develop the human resource management practices that support the environment of sharing knowledge. Data from the steel industry displays these concepts. For seven large steel mills, we gather data on the communications networks of steelworkers. The data shows that networks are exceedingly diverse across mills, and that the mills that have human resource management practices that support teamwork are the mills that have with much more dense high-volume communications links among workers. That is, workers in team-orientated mills have much higher levels of personal connective capital used for problem-solving.

Casey Ichniowski
Graduate School of Business
3022 Broadway Street, 713 Uris Hall
Columbia University
New York, NY 10027
and NBER
bei1@columbia.edu

Kathryn L. Shaw
Graduate School of Business
Stanford University
Stanford, CA 94305-5015
and NBER
kathryns@gsb.stanford.edu

"Capital consists in a great part of knowledge and organization."

-- Alfred Marshall, Principles of Economics

Many growing firms today – firms across high-tech to bio-tech to consulting to banking industries – are comprised of experts. Skills are deep; individuals specialize in expert knowledge. Workers may be experts in new wireless programming code, or chemical compounds, or client relationships. The firm's production function is to solve problems – to create a new wireless phone, or a new drug, or to install new planning software that meets a client's specific needs. Solving these problems requires that experts work together – no one person has all the skills to solve a typical problem. Therefore, each person's output in solving his problems depends on his own human capital, and also on the human capital of all others in the firm whom he 'connects with' to solve his problems.

We model each person's optimal investment in "connective capital," which is a new definition of capital in the firm: connective capital is the sum of the person's own capital and the knowledge capital of others who he taps into to solve a problem he faces. Just as economists have modeled the investments by workers and firms in general human capital and firm-specific human capital, we introduce this new firm of human capital into the firm's production function, and model what induces workers and firms to invest in connective capital. Given a simple production function in which connective capital raises the firm's output, the questions for workers are: how much should each worker tap into the skills of others, and how much should others be willing to share their skills? For firms, the question is, how much should the firm invest in a structure that supports workers' investments in connective capital? Due to the externalities arising from connective capital and the group-based rewards in most firms, workers will tend to under-invest in connective capital. Therefore, firms that value problem solving in production will invest in organizational practices to increase individual investment in connective capital. Given data we've collected on the communications patterns of skilled workers in the steel industry, we examine patterns of connective capital empirically from the workers and from the firms perspectives.

Our model of connective capital has some of the elements of social capital. Social capital is now a very broad and very widely used term. The rise of the Internet has made it a household term. Consider, for example, the use of the websites LinkedIn or FaceBook. The users of these websites develop a social network of contacts of people who are friends or friends of friends (and thus not known to the person). Social capital is then the value that arises because the person can tap into their social network to solve problems of some form. It is capital, because these social networks have value—the network can be used to obtain information, to find a job, achieve social mobility, or to undertake collective action, etc. Social capital arises at different levels – at the individual level, at the firm level, or at the community level. It is increasingly discussed as the fabric on which the successes of communities and of firms are based.

Social capital is modeled by researchers in many different ways – at different levels (i.e., individual or firm or community), and with different attributes or properties that underlie the social networks or the social capital. Economists introduce social network relationships when ways they develop models of hierarchies.[1] A more vertically hierarchical firm will have more information flowing through indirect network ties up the hierarchy; a flat organization will have information flowing through direct ties, or direct network communications. Thus, researchers model the value of hierarchical ties and the decision rights implied by hierarchy. Other economists look empirically at the value that arises from social capital that varies across communities.[2] Some economists model the underlying microeconomic features of network relationships – such as the game theoretical models of why and where links develop in the network – that could arise in firms or in communities.[3] Economists are recent entrants to the literature on the theory of social capital.[4] Non-economists have modeled social networks for many years, and have a very deep literature, but that literature has tended to focus more on the value of the social network to individual's rather than the firm, and most empirical evidence is on the value of networks to individuals.[5] Looking deeper within these models, there is also a multi-disciplinary literature on trust and reciprocity, which are often features of social capital (described below). We mention here a few elements of the social capital literature to emphasize

[1] For models of hierarchies, see Garicano (2000), Garicano and Hubbard (2006), Bolton and Dewatripoint (1994), Aoki (1984), Geanakopolos and Milgrom (1991).
[2] For empirical models of social capital that model capital between individuals or communities see Costa and Kahn (forthcoming, 2005), Golden and Katz (1999), Agrawal, Cockburn and McHale (2003), Charles and Kline (2002), Glaeser, Laibson and Sacerdote (2002).
[3] See, for example, Jackson and Sonnenschien (2007), and the references in footnote 4.
[4] For a summary of the entry of economists into social capital theories, and a summary of social capital in economics, as well as new models of social networks, see Jackson (2008, 2007, and forthcoming). For an additional review of social capital in theoretical economics, see Durlauf and Fafchamps (2004).
[5] See Burt (2005), forthcoming.

that it is a broad and deep and massive literature, and the phrase social capital has many meanings. In this paper, our goal in developing a model defined as "connective capital" is to emphasize a few features of social capital that enter the theory of the firm.

Our goal in defining connective capital is to emphasize that it is optimal for firms to develop human resource management practices that will raise the productivity of their employees by inducing employees to solve problems using connective capital.[6] Firms will invest in human resource practices – such as developing norms of behavior through indoctrination, training, and teamwork – that have value to the firm because they support the investment by workers in connective capital. This is a model of teamwork, where the firm is the team. Because we focus on individual behavior, we introduce connective capital directly into the firm's production function as a non-linear form of human capital. Just as there are many forms of human capital (such as firm-specific skills or occupational skills), we treat connective capital as a special form of human capital and we identify some properties of connective capital that produce differential investments in it across individuals and firms. We then tie our model of connective capital to data from steel mills, to draw illustrative links between the development of connective capital at the worker level, the use by the firm of HR practices to induce individuals' connective capital, and the productivity gains that can result from connective capital.[7]

Our model is also an extension of the literature on teams, in that we emphasize the value to firms of employees working together in a complementary fashion to solve problems. However, we follow the tradition in economics of focusing on how individuals do their jobs to be the most productive.[8] Individuals are the unit of analyses within the firm, not teams. The model of connective capital specifies that individuals are faced with problems, call upon the skills of other experts, and then solve the problem by tapping into the other expert skills. This is

[6] This theoretical point – that firms invest in human resource practices aimed at increasing social capital – is not new to the organizational literature. See Leana and Van Buren (1999), Nahapiet and Ghoshal (1991), Coleman (1988), and Burt (2005, forthcoming).

[7] The empirical literature showing a link between social capital and the productivity of workers and firms is just developing. In the economics literature, see Bandiera, Barankay, and Rasul (2005, forthcoming); Sabatini (2005); Kalnins and Chung (2006), Gil and Hartmann (2007); and see Heliwell and Huang (2005) for effects on worker well being in firms. More broadly, see Leana and Pil (2006), Yli-Renko, Autio, and Sapienza (2001), Reagans and Zuckerman (2001), The advent of datasets based on email archives and on open source software projects is increasing the ability of researchers to model the performance of networks – see Aral and Van Alstyne (2008) and Singh, Tan, and Mookerjee (2008). For work showing peer effects that have similar social capital issues, see Mas and Moretti (2009)

[8] That is, our decision-making production unit is the individual worker, not a team of workers. Individuals solve problems by taping into the knowledge of other to form a 'team' output, but the team is not our unit of analysis.

teamwork, but we model it as individual activities. The model of connective capital focuses on how the organization is structured so that individuals can get access to the skills of others as needed. In keeping with the quote by Marshall above, our overarching goal is emphasize, as many organizational or personnel economists have done, that the returns to human capital, or to the firm's 'knowledge' base, depend on how the firm is organized. In section I, we develop the model, and in section II, we provide empirical evidence on the determinants of the investment in connective capital.

I. A Model of Investments in Connective Capital

This section presents a model of teamwork among employees. We define the idea of "connective capital" as a form of knowledge and human capital sharing that helps employees solve problems in the workplace. We consider why workers would decide to share human capital with one another even in large firms where workers may not work with one another in the future. We also consider how firms can invest in human resource policies to develop a culture of teamwork inside the firm that would further promote problem-solving activity.

A. A Definition of Connective Capital

Just as human capital refers to knowledge and skills of individuals, connective capital is the sum of the person's own human capital and the human capital of others that he taps into to solve his problems. The definition of connective capital has three components: the specification of a group, a measure of connections made among these group members, and the human capital that is shared. The group is an N-person firm, with i and j the subscripts denoting the workers. *Connective capital* of worker i in period t, $\mathbf{CC}_{\mathbf{it}}$,, is the (N-1) element vector that measures the knowledge that the other workers share with worker i:

(1) $\mathbf{CC}_{it} = (cc_{i1t} * HC_1, \ldots cc_{ijt} * HC_j, \ldots cc_{iNt} * HC_N)$ for $j \neq i$

In the j-th element of the connective capital vector, cc_{ij} is a (0,1) dummy variable that as the key connective capital link between workers c_{ijt}=1 when worker j talks to worker i and HC_j measures worker j's knowledge. What matters for whether worker i accesses new human capital through the communication link with j is the difference in knowledge of the two workers. We create these differences by assuming each worker in the firm as an expert in his or her own individual area with unique knowledge. This is described further at the end of Section IC below.[9] In our steel data below, the steel operating workers are each different experts in the techniques of operating a steel production line.

Our model of connective capital is therefore a model of when communication links are formed, or when cc_{ijt} =1 versus cc_{ijt} =0. When a worker i need the unique expert knowledge of worker j, then worker i asks for help and worker j responds, and then cc_{ijt} =1. Thus, after specifying the production function that introduces CC_{it}, we model the communications links, cc_{ijt}.

B. The Output from Connective Capital and Team Problem-Solving

Productivity gains result from solving complex problems using connective capital. When worker i confronts a problem he cannot solve on his own, but is successful at getting knowledge from the necessary experts in the workforce, he solves the problem and increases his output.[10] Let a worker's output be a function of two human capital variables – the individual worker's own human capital, HC_i, and the connective capital he collects while working on problems, $\mathbf{CC}_i$.[11] In any period t, output of worker i is reduced whenever workers i and j spend time communicating to solve problems, but this joint problem solving leads to an increase in output in the next period. Therefore, define output, q_{it}, for person i at time t as:

(2) $$q_{it} = \alpha HC_{it} + \boldsymbol{\delta}'\mathbf{CC}_{i,t-1} - (OPCOST)_{it}$$

[9] The assumption that the workers have their own unique areas of expertise only serves to simplify the presentation. To allow more detailed differences in knowledge, one would allow worker i to have some knowledge in all N areas, and rewrite the j-th element of the connective capital vector in (1) as cc_{ij} * HC_{ij} where HC_{ij} equals the difference between two workers' human capital. Throughout, we assume a worker's amount of human capital is exogenous.

[10] The model below will assume that workers know whom to contact by the nature of the problems and thus do not incur search costs involved in finding the right employees. With search costs, the past stock of connective capital would lower the costs of investing in current connective capital, because workers build knowledge about whom to contact. Such a state dependence effect in which past CC builds current CC would complicate the model, but would slow the process of moving to higher levels of CC because of the adjustment costs involved in learning where knowledge resides. Such search costs could be seen as a component of the opportunity costs of communication in the model below.

[11] Thus, the model here is analogous to productivity effects of spillovers of R&D knowledge across firms in an industry (see Griliches, 1979).

where we assume for simplicity that HC_{it} and $\mathbf{CC}_{i,t-1}$ are additively separable in producing q_{it}.[12] We also assume that the output of the firm is additively separable in personal output q_{it}, so that firm-level output $Q_t = \sum q_{it}$. In (2), α is the production return to person i's human capital. OPCOST is lost output in period t due to worker i spending time on new problem solving during this period, or $\tau\alpha HC_{it}$, where τ is the fraction of time in period t that worker i spends communicating. Finally, the vector $\boldsymbol{\delta}$ is the production return to worker i from the connective capital he obtained in the prior period. The j-th element of the vector (δ_j) is the return to i from gaining information from j. Thus, $\boldsymbol{\delta}$ is an index of the value of problem-solving activity. $\boldsymbol{\delta}$ is higher when a worker encounters many problems and when solving these problems has a larger impact on output.[13]

While workers in all organizations confront problems in their workplaces that impact productivity, the data we analyze below pertain to workers in finishing lines in integrated steel mills. An example illustrates how knowledge sharing through connective capital raises output in this setting. In these lines, long rolls of thin steel sheets unwind and run through machinery that stretch the steel and apply various protective coatings. If steel coating forms bubbles or has an uneven texture, the finished steel product cannot be sold since quality will be below required standards. To identify the source of the problem from many possible sources, an employee can draw upon his own training and experience, or can tap into the expertise and experience of others. Co-workers can have different technical expertise or they may have unique knowledge given their particular vantage point on the production line, each of which could be useful in solving new problems. Lines that can tap into the problem-solving capabilities of teams of workers often realize large improvements in performance from these efforts.[14]

[12] Multiplicative interactions between individual human capital and the human capital that constitutes connective capital would complicate the analysis but not change the essential points to follow.

[13] We keep the definition of $\boldsymbol{\delta}$ quite simple: some firms have high $\boldsymbol{\delta}$ because during the course of the year, each person i will face problems that are best solved with skills from person j. We could complicate this much more by making the arrival of problems, and thus the value of $\boldsymbol{\delta}$, a random process with a variance, but that wouldn't change the essence of the model.

[14] Some finishing lines reported to us that the number of continuous improvement problem solving projects range between 40 and 60 projects per line each year. We observed numerous examples of consequential problem solving projects during our line visits, such as the installation of dust collectors and tents to keep particulates from settling onto the steel, improving clamps for stabilizing steel coils so they can be trimmed to customer orders more accurately, redesigning the engineers' original designs for coating machine rollers so that surfaces were coated more uniformly, and improvements in the durability of welds that prevented breaks between successive coils of steel.

In other organizations, critical business activities, such as designing a new product, devising a marketing campaign, or developing a business strategy, can all involve this kind of collaborative problem solving. The question we consider in this section is why some organizations are more likely to have employees working together to solve problems than others.

C. Connective Capital Investments: The Workers' Optimal Decisions to Connect

The model thus far assumes three points. Some problems that workers confront are too complex for the workers to solve on their own. Knowledge sharing among workers creates connective capital. And connective capital is a productive input in the production process because it leads to problem solving.[15] The essential idea of these initial assumptions is that they allow the N-person group to be smarter and more productive than the N individuals would be if they acted independently. Because group organization leverages the knowledge of individuals, the model provides a fundamental reason why organizations will form.

If connective capital does increase productivity as assumed in equation (2), the central question to address becomes: what determines the level of connective capital observed in the firm? We are modeling why information sharing occurs in a large social network such as a firm where an individual may be asked to share with someone he is not likely to work with again. That is, we are modeling reciprocity: reciprocity means that when people act friendly or helpful to me, I will respond by acting friendly or helpful, even when there are no apparent personal gains to helping. Small firms or small groups may have personal bilateral contracts—if you share today, I will share with you tomorrow. But in larger firms, where the problems vary constantly over time, bilateral contracts between pairs are unlikely. Each new problem requires a different set of experts. Thus, we are modeling a process of reciprocity – or mutual interdependent sharing – in which people reciprocate by sharing when asked because it will elevate the performance of the entire group (and thus their group pay) even when it does not build mutual personal gains between the pair. This notion of reciprocity among strangers within a large group is a common theme in the literature of the social capital of communities and firms.

---

[15] The model posits that connective capital is "borrowed" to solve that period's problems. One could allow for learning dynamics where worker i remembers some portion of $\mathbf{CC_{it}}$ which augments $HC_{i(t+1)}$. For simplicity in presentation, we present the model with workers remaining experts in their own areas but can call on experts in other areas again in the future as new problems arise. Put somewhat differently, we are assuming that learning a whole new area of expertise is prohibitively costly and that workers could never learn enough about these other areas to eliminate the need to call in the other experts when multi-person problems arise in the future.

The key endogenous variable in connective capital investment is cc_{ij}, – the measure of whether two workers form a communication connection. Worker i encounters a problem and faces the decision of whether to ask worker j for his help. $A_{ij} = 1$ if worker i asks j and $A_{ij} = 0$ if he does not. Worker j faces the decision of whether to respond: $S_{ji} = 1$ if worker j shares human capital knowledge with the asker and $S_{ji} = 0$ if j does not. Therefore, define the communication channel between i and j as:

(3) $$cc_{ij} = A_{ij} \bullet S_{ji}$$

$cc_{ij} = 1$ only if both $A_{ij}=1$ *and* $S_{ji}=1$. Once two workers decide to ask and share, they establish a communication channel and are now engaged in team problem solving.

There is a production loss that arises when "askers," or $A_{ij}=1$, and "sharers," or $S_{ji}=1$, forge the communications link, in which $cc_{ij} = 1$. The production loss is the opportunity cost of the time they spend communicating – the value of time spent working on a problem with others that could have been spent instead on producing output individually: $\tau(\alpha_j HC_j + \alpha_i HC_i)$, where τ is the percent of time spent working together on joint problem solving activities by i and j. 'τ' includes the time it takes to identify and contact coworkers as well as the time spent communicating with them to solve a problem. This opportunity cost of time is higher when workers can produce high value output on their own ($\alpha_i HC_i$). [16]

There is also a person-specific disutility (or utility) cost of communicating. The cost of asking is φ_i^A. This cost can be related to personality – for example, a "shy" or "proud" worker may have more difficulty telling others that there are problems he cannot solve – or to ability – for example, a worker with poor organizational skills may have higher communication costs because he cannot manage multiple communication channels. The person-specific cost of sharing is φ_j^s. These sharing costs could reflect costs of effort or time, or other influences the worker faces, as when promotions are based on individual output and not on team problem solving.[17]

[16] If individuals were given individual incentive pay as a function of individual output then highly skilled, high $\alpha_i HC_i$ experts would never share. This is one reason why firms do not offer individual incentive pay, or offer a very low return to individual output. Alternatively, firms can pay individual incentives, but hire teams of equally skilled experts. So the gains to teamwork are equal across workers. It has been widely modeled that individual incentive pay undermines teamwork.

[17] The model does not incorporate promotions based on teamwork as part of the pay increase in the model, but we acknowledge that sharing costs would fall if the firm rewarded teamwork in this way.

The worker's benefits of sharing come in the form of increased compensation from sharing due to increased output in the period after a problem has been addressed minus the personal costs of sharing. Let worker compensation from sharing be determined by group incentive pay where all workers divide output gains among themselves.

The output gains are from problem solving occur when connective capital is created because A_{ij} and S_{ji} both equal one. If asked, worker j will share (S_{ji}=1) when his marginal benefits of sharing exceed his marginal costs of sharing:

(4) $$S_{ji} = 1 \text{ if } B_{ij} > \varphi_j^s \text{ given } A_{ij} = 1$$

B_{ij} represents the marginal net monetary gains of sharing which is given by:

(5) $$B_{ij} \equiv (\mathrm{R}[d\delta_{ij}HC_j - \tau(\alpha_i HC_i + \alpha_j HC_j)]/N)$$

Worker j and worker i benefit from j's sharing because each obtains his increased share of the net output gains, B_{ij}, that result from solving the problem that i faces. In (5), d is the discount factor (1/(1+r)), and τ is again the percent of time (or percent of base period human capital) that is spent on communicating rather than producing. R is the percent of net problem solving revenue allocated to workers as compensation.[18] We assume that workers are risk neutral, so workers share when the marginal income gain from the personal output gain in period t, given by $Rd\delta_{ij}HC_j/N$)- $R\tau(\alpha_i HC_i + \alpha_j HC_j)/N$, exceeds the marginal personal disutility costs associated with sharing knowledge (φ_j^s)[19].

Assume there is a distribution across workers, $F^s(\varphi^s)$, of the personal costs of sharing knowledge. Then the probability of sharing knowledge conditional on being asked is:

(6) $$P_{ji} = P_e(S_{ji} = 1 | A_{ij} = 1) = \int_o^{Bij} f(\varphi_j^s) d\varphi_j^s$$ for all persons j=1,..,N

[18] We assume that the firm allocates a percent (R) of net revenue to workers and retains a percent for shareholders, as is typical for profit-sharing plans or worker-owned firms. We will assume R is fixed at some value related to workers' alternative wage rates and not address its value in the model.

[19] We are making some strong assumptions to simplify our model. We are assuming individuals decide to share when the personal output gains from sharing exceed the personal disutility. To focus on internal development of connective capital we ignore the incentive pay as part of the model. We assume each worker earns a base wage W_i that reflects their skills and attracts them to the firm. The capital gains from sharing are offset by the disputing of sharing, and therefore there is no incentive compatibility constraint in our model that encourages the workers decisions to stay with the firm as a function of his incentive pay disutility of sharing. We assume that workers are tied to the firm and that firms do not choose the skill set of workers. Clearly in the long run, workers do decide whether to work at the firm and firms choose the skill set of workers. Clearly, workers that have a low durability of sharing will be attracted to high sharing firms.

Worker i will ask for help when the marginal expected benefits exceed marginal costs:

(7) $A_{ij} = 1 \text{ if } B_{ij} P_{ji} > \varphi_i^A$

so that worker i will ask as a function of the probability that worker j will share.

In large social networks as is the case in many firms, a worker will often have limited information about whether some specific co-worker will share. However, *the worker will have information about the typical level of sharing he sees around him* and he uses this information to assess the elements of (7). That is, the asking worker i does not know worker j, so he is assessing the *probability* that j will share, or $P_e\left(S_{ji} = 1 \mid A_{ij} = 1\right)$ from (6) assuming i knows the elements of (6). As in (6), worker i knows two things about j: he knows worker j's skills so that i knows the value of B_{ij}, and he knows the distribution of sharing costs, $f\left(\varphi_j^s\right)$ across all j workers. If sharing costs in the firm fall because the distribution of $f\left(\varphi_j^s\right)$ shifts to the left, then the probability of sharing rises and the probability of asking rises. In the next section, we introduce the firm's influence on costs, and thus, alter levels of networking in their firm.

The model implies a very simple form of contagion effects in networking: the more you see others share (or high probability of sharing), the more you will ask for help. The probability that a communication link is formed is given by pr(A_{ij}=1 and S_{ji}=1) = 1, or:

(8) $$\text{pr}(cc_{ij}) = 1 = F^A\left(B_{ij} P_{ji}\right) \cdot F^S\left(B_{ij}\right) = \int_0^{B_{ij} P_{ji}} f^A(\varphi_i^A) d\varphi_i^A \int_0^{B_{ij}} f^S\left(\varphi_j^S\right) d\varphi_j^S$$

That is, if the probability of sharing rises, that will raise the probability of asking, and thus raise the amount of connective capital.

Equation (8) gives the conditions under which workers invest in forming connective capital. Connective capital increases with increases in the net productivity benefits (B_{ij} = $R[d\delta_{ij} HC_j - \tau(\alpha_i HC_i + \alpha_j HC_j)]/N$) generated by information sharing. Therefore, individual investment in connective capital is governed by the following (see Appendix A for derivations):

1. Benefits of forming connective capital are increasing in the value of problem solving, or δ_{ij}. The more productive that the problem solving activity is for the firm, the more that connective capital will be formed, since $\frac{\partial B_{ij}}{\partial \delta_{ij}} = \frac{R}{N} dHC_j > 0$;
2. High levels of personal human capital, HC_j, can increase connective capital (all else constant) because human capital increases the benefits of problem solving: $\frac{\partial B_{ij}}{\partial HC_j} = \frac{R}{N} \cdot \left(d\delta_{ij} - \tau\alpha_j\right)$.
3. High levels of personal human capital, HC_j, can also decrease connective capital (all else constant) because benefits are decreasing in α_j, the output gain from individual performance. The more productive that individuals are when they are working on their own, the less connective capital will be formed, since $\frac{\partial B_{ij}}{\partial \alpha_j} = \frac{-R(\tau HC_j)}{N} < 0$, for all j; [20]

Higher levels of human capital raise both the (opportunity) costs and (productivity) benefits of problem solving since workers with more human capital are more productive when they work on their own and when they problem solve with others: connective capital rises with human capital when $d\delta_{ij} > \tau\alpha_j$. Despite these opposing effects, problem solving and connective capital will increase with increases in human capital as long as there is some positive benefit to sharing expert knowledge as described next.

It's important to recall an assumption we made to keep the model simple. We assumed that the HC_j differ across the j=1.,,N individuals in the firm: we assumed that firms are

[20] While we focus on the prediction from the model about the effects of individual human capital on connective capital formation since the data for this study allow us to examine this prediction, comparative statics from the model also predict that when problem solving is time consuming less connective capital is formed, since $\frac{\partial B_{ij}}{\partial \tau} = \frac{-R\left(\alpha_i HC_i + \alpha_j HC_j\right)}{N} < 0$.

* If all workers had the same type of general human capital, there would be no reason to tap into the skills of others to solve your own problems as they arise. See Lazear and Shaw (2008) for a model of the value of experts versus generalists in teamwork.

collections of experts. Therefore, connective capital is higher in when the *variance* of skills is high across firms – when the firm is comprised of high-level experts (Lazear and Shaw, 2007).[21]

When are firms most likely to be comprised of experts developing connective capital? New technologies might be more likely to be associated with firms that are teams of experts, because in new technologies, rapid evolution of information makes it difficult for any one person to have an absolute advantage in everything. Then, as technologies mature, very talented individuals may, over time, acquire knowledge in a multitude of skills, making connective capital lower because the firm is composed of generalists and is more hierarchical.[22] Firms that are exploring new areas of innovative problems will have a flat flexible structure with high levels of connective capital. Firms that are exploiting existing product brand value will be more hierarchical, with generalists making decisions alone dominating the firm's structure.[23]

D. The Firm's Influence on its Workers' Connective Capital

The model of connective capital formation implies underinvestment in this shared human capital because of the standard free-rider problem: the benefits from information sharing are divided among the group of N workers in the group-based incentive pay (Kandel and Lazear, 1992). Therefore, firms with high values to problems solving, or high δ_{ij}, will find it in their best interest to find ways of influencing workers to increase their investments in connective capital. Assuming that workers and their skills are fixed in the short run, we focus on how the firm uses its organizational practices to alter workers' costs of asking and sharing.

We begin by letting the workers' costs of communication be a function of a workplace "culture" that determines norms about information sharing among workers.[24] In firms that have

[21] The variance of skills is critical: when worker i faces a problem he cannot solve with his HC_i , there must be another person j with different HC_i who can solve the problem. If one person is a generalist who knows everything he will not call upon others. Firms do not hire generalists because they are to costly to hire given the problem firms face.

[22] Connective capital is a model of team problem solving, not one of hierarchical control. Connective capital emphasizes problem solving, not decision-making. When person *i* is faced with a problem to solve, he gathers the advice of others and makes a recommendation. In a flat organization, these recommendations would be followed. In a hierarchical organization, these recommendations might not be followed: For models of hierarchy, see Garicano (2000). Note also that the volume of communications may be very high in the hierarchical firms, as information is passed up to the hierarchy. Our model of connective capital is a model of the 'direct" communication links between people. A complete network analysis would follow the "indirect links" between people at different levels of the firm to fully map the communications network in a hierarchy.

[23] For models of "explorer" and "exploiter" firms, see the strategy literature of Saloner, Shepard, Podolny (1999).

[24] Firms will introduce additional HR practices to increase sharing that are not modeled in this paper. These include individual pay for teamwork, or training for expert skills and teamwork. Moreover, we assume no incentive pay for individual effort (no $\beta\alpha_i HC_i$) for increase $\beta>0$).

a culture where sharing is typical and expected, the *SharingNorm* is high and there are low costs of sharing (or personal disutility of sharing) because workers get positive reinforcement for sharing. Represent this effect of the sharing norm on the distribution of workers' sharing costs by:

(9) $\varphi_j^s = \gamma_j^s(SharingNorm)$, where $\gamma^s_j<0$

Equation (9) simply states that higher norms reduce the workers' sharing costs. The model here is in the spirit of Kandel and Lazear's (1992) model of peer pressure in which workers experience added costs when they fall below the group's effort norm. Other models in which worker effort or utility is affected by behavior in the work group include Akerlof and Kranton's (2003) model of self-image and identity in which a worker's personal utility is higher when his self image matches the firm's ideal behavior for its employees.

We now allow firms to develop higher sharing norms by investing in various HR practices that promote a culture of teamwork and information sharing among workers. The distribution of the workers' costs of sharing, conditional on workplace culture about sharing, becomes:

(10) $f(\varphi_j^S \mid SharingNorm) = f(\varphi_j^S \mid \text{HR=practices that create norms about sharing})$

Sharing Norm in (10) is the firm's desired level of sharing which exceeds the value of the norm in the absence of high returns to problem solving. In many firms today, human resource policies are used to build a sharing norm by encouraging teamwork and sharing: firms indoctrinate workers with a teamwork norm during the selection process, during orientation at time of entry, during on-going labor-management communications and meetings, or during supervision after the time of hire. Firms that have a high value to problem solving will introduce these practices that emphasize the sharing norm. Firms that have a high value to independent activity will not.

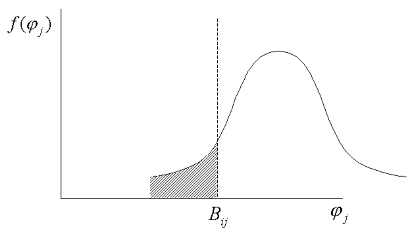


Fig. 1a: Sharing Costs with HR=HR$_0$ = 0

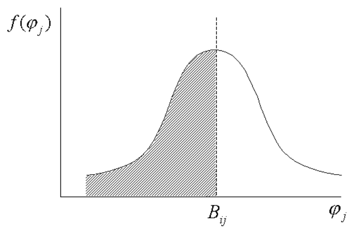


Fig. 1b: Sharing Costs with HR=HR$_1$>HR$_0$

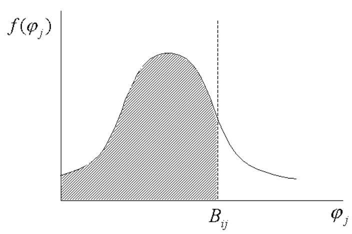


Fig. 1c: Sharing Costs with HR=HR$_2$>HR$_1$

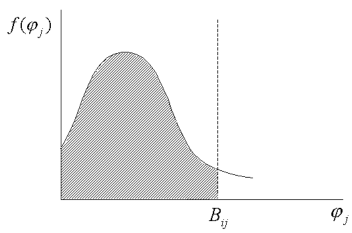


Fig. 1d: Sharing Costs with HR=HR$_3$>HR$_2$

Figure 1:
Shifts in the Distribution of Communication Costs Under Successively Higher "Sharing Norms"

Figures 1a-1d illustrate the decrease in sharing costs that occur as the firm makes greater HR investments to promote a higher sharing norm. In the figure, the benefits of connective capital, B_{ij}, are fixed. As the distribution of costs is progressively shifted left due to HR practices that increase the *SharingNorm*, as a greater proportion of the sharing cost distribution lies below the benefits. Given the bell-shaped distribution and very high initial sharing costs, there is a huge acceleration in sharing between Figures 1a and 1b when the entire distribution of costs shifts left, and then as costs are lowered further in Figures 1c and 1d, sharing goes up, but it goes up at a lower rate. The increase in sharing rises rapidly and then tapers.

While higher sharing norms will promote connective capital formation, the human resource practices that the firm adopts to establish a higher sharing norm are not free. When the firm invests in HR policies to establish a pro-sharing culture in any given period t, it bears two costs in that period – the costs of the policies that raise the norm, and the increased opportunity cost of the employees' communications time when additional sharing occurs.[25] In period t+1, the firm earns returns to these investments in the form of productivity increases from the connective capital problem solving activity. The expected present value of the firm's profit over the period of investment and the period of increased productivity is given by:

$$(11)\quad E(\pi)=(1-R)\left[(1+d)(\boldsymbol{\alpha HC}-W)+\sum_{i}^{N}\sum_{j\neq i}^{N} pr(cc_{ij}=1)B_{ij}(N/R)-\eta HR\right]$$

where (1-R) is the percent of the firm's net revenues reserved for shareholders, W is fixed wage bill and material costs, ηHR are the costs of HR initiatives that cultivate workplace sharing norm culture, d is the discount factor (1/(1+r)) for the second period profits, and $\boldsymbol{\alpha HC}$ measures output obtained when workers use their own human capital to produce independently. From equation (5), B_{ij} (N/R) captures the net gain of the (i,j) communication.

Redefine the probability that workers i and j will form a communication link and share human capital from equation (8) above to be conditional on HR:

$$pr(cc_{ij}=1)=F^{A}\left(B_{ij}P_{ji}\,|\,HR\right)F^{S}\left(B_{ij}\,|\,HR\right)$$

[25] To simplify the presentation here, we assume that that the depreciation factor for own human capital in equation (2) above is zero, as seems reasonable if the worker is working throughout the period. We also continue to assume that the memory factor for any acquired connective capital is zero (i.e., connective capital is only "borrowed"), an assumption which reduces the benefits of connective capital and would work against connective capital formation.

Therefore, the expected net revenue gains to the firm for any i,j sharing relationship are defined as Y_{ij}:

$$Y_{ij} \equiv pr\left(cc_{ij} = 1\right) \cdot B_{ij}\,(N((1-R)/R)) = \left[\int^{B_{ij} \int_0^{B_{ij}} f^S\left(\varphi_j^S \middle| HR\right) d\varphi_j^S} f\left(\varphi_i^A \middle| HR\right) d\varphi_i^A \int_0^{B_{ij}} f^S\left(\varphi_j^S \middle| HR\right) d\varphi_j^S \right] B_{ij}\,(N((1-R)/R))$$

A comparison of the gains in net revenue and the costs of HR determine the firm's optimal HR investment. Figure 2 illustrates this decision. Under the assumptions that $f^A = f^S$ and that $f\left(\varphi \middle| HR\right)$ is lognormal with mean $= \dfrac{1}{HR}$, the plot of Y_{ij} as a function of HR, assuming a fixed level of B_{ij}, is the cumulative distribution of a lognormal density function which Figure 2 labels as the "Net Revenue Gain" curve. When the firm increases the HR Index to promote a culture of sharing, it raises the value of the sharing norm, and the entire communication cost distribution shifts left, as shown above in the progressive movements from Figure 1a to 1d. The probability of sharing increases, as does the probability of asking because it depends on the average level of sharing observed in the firm. This increase in information sharing due to increases in HR then produces the nonlinear increase in the Net Revenue Gain for higher values of HR that is shown in Figure 2.

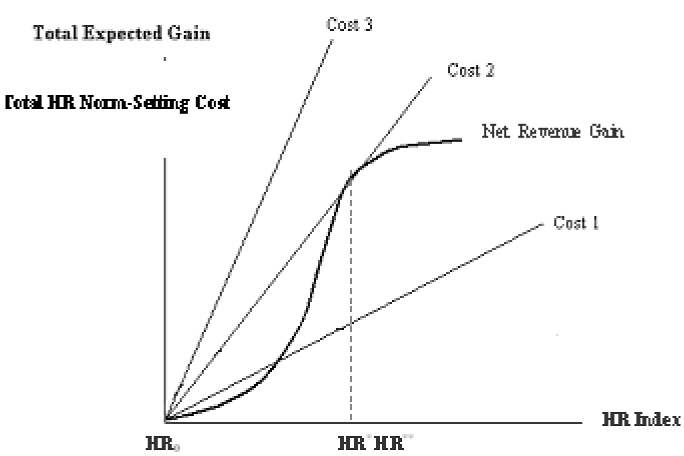


Figure 2: Net Revenue Gains to Investing in Connective Capital Relative to the HR Costs

Given these gains in net revenues that occur as HR increases, the optimal value of HR for the firm then depends on the costs of HR. Figure 2 displays several possible functions for costs associated with increasing the sharing norm, ηHR. Cost 1- Cost 3 in Figure 2 show three linear cost functions that are successively higher.

The firm selects the level of HR which maximizes expected present value of profits where marginal costs, or η, are equal to marginal benefits. Thus, the optimal level of HR occurs where the slope of the revenue function is equal to the slope of the cost function, as long as net revenue is above costs. Figure 2 implies that firms will tend to choose extreme positions with either little or no investment in cultivating a pro-sharing culture (and correspondingly low levels of connective capital), or fairly high levels of HR (with correspondingly high connective capital), because the benefit function accelerates and then plateaus. For example, given cost function Cost 2, the optimal investment in HR is either zero or HR* across all firms along Cost 2. The conclusion that firms will tend to have either high or low levels of connective capital is a result of the non-linearity of the expected gains function, described above in Figure 1 as the firm progressively raises HR to shift costs lower.

Of course, firms that have a high return to problem solving, or high δ_{ij}, can increase connective capital using other mechanisms in the long run. They can select workers who are skilled at communicating and collaborating, not just skilled at design or operations. Firms that are comprised of experts working on team-based problem solving often report that they look for collaboration skills in hiring. Firms will also want to hire more experts, or train more on the job for human capital skills or sharing skills.

E. Summary of the Model's Assumptions and Implications

The model of connective capital makes the following overall predictions:

> *Connective capital increases productivity when the production function values problem solving by a collection of experts. Individuals invest in connective capital* when the productivity increases from team problem solving, or high δ, are greater than the productivity the firm would obtain when employees worked independently.

Workers invest in connective capital when the asking and sharing costs of communicating are low. The level of human capital, $\alpha_i HC_i$, has an ambiguous effect on connective capital. However, the more the firm is comprised of experts, rather than generalists who solve their own problems, the greater the connective capital.

The *Firm's HR practices can elevate connective capital formation.* The firm's HR practices shape workplace culture. This culture can offer positive reinforcement to workers when they share ideas about how to solve problems, and thus can decrease the employees' costs of making connections and creating connective capital.

Distinctive features of this model of teamwork are related to the fact that firms are comprised of groups of experts. The model describes one reason why a worker would share knowledge with a co-worker even in a large social setting like a big firm where the worker is not likely to be personally rewarded by that co-worker. Furthermore, HR policies that influence norms of behavior for the group are also important determinants of this productivity-enhancing problem solving and the ultimate level of connective capital is likely to be either at low or high levels in the group.

II. Empirical Evidence on Connective Capital Using Data from Steel Mills

The predictions of the section II model can be summarized as follows: human resource practices and worker characteristics determine the extent of connective capital which in turn affects the firm's level of productivity. Previous studies offer empirical support for the proposition that systems of Team-Oriented HR practices increase productivity in a number of industries.[26] Connective capital can be a critical intervening variable that helps explain the link between Team-Oriented organizational practices and increased productivity: firms with Team-Oriented HR practices are more productive because workers and firms invest more in connective capital to solve problems. To test the full set of implications from the model would require a

[26] Positive effects of Team-Oriented HR practices on productivity are observed in industry-specific studies including MacDuffie (1995) for auto assembly, Dunlop and Weil (1997) and Berg, Appelbaum, Bailey and Kalleberg (1996) for apparel and textile manufacturing, Boning, Ichniowski, and Shaw (2008) for steel minimills; and in studies of cross-industry samples of establishments including Black and Lynch (2001), Cappelli and Neumark (2001) and Huselid (1995).

unique data set that included information on workers' communications, workers' characteristics, HR policies of firms, the technology of the firm to measure the firm's value placed on problem solving activities, and the productivity of firms. Such rich data are not available. However, through new data collection and previous research, we will address the links from human resource practices, to connective capital, to productivity.

We collected data on the communications networks and skills of 642 workers on seven steel finishing lines.[27] Three of these lines are characterized by "Team-Oriented HR practices" such as the use of problem-solving teams, information sharing between managers and workers, high training and group-based incentive pay. The other four lines are characterized by more "Traditional HR practices" that do not emphasize team work and information sharing.[28] The production environment was described in section IB above: workers are operating comparable steel production lines in which flat-rolled coiled steel is going through a continuous production line in which the steel is coated or processed. The mill is more productive when the quantity of steel coming off the line is higher per unit of steel input.

In previous work, we show that mills with team-orientated production are more productive in a large sample of 36 steel mills (Ichniowski, Shaw, Prennushi, 1997). Productivity is measured as "uptime" – the percent of time the line is running when it is scheduled to run. Mills with the set of Team-Oriented practices have a predicted uptime of 95%, based on our regressions. In contrast, Traditional lines have a predicted uptime of 90%. This five percentage point difference arises from the differences in HR practices. These are very large differences monetarily. We suspect that Team-Oriented lines achieve performance gains due to higher levels of connective capital for solving uptime performance problems. It would be impossible to survey all workers in all these mills, so we survey all 642 workers in seven representative mills. Our aim is to look for patterns of individual investment in connective capital among these workers, and to look for differences in connective capital across the two different HR environments.

[27] These data were collected in collaboration with Jon Gant for Gant, Ichniowski, and Shaw (2002).

[28] Each of the lines with Team-Oriented HR practices has: group-based incentive pay for quality output, broadly defined job; formal processes for informative sharing, formal procedures for participation in problem-solving teams, high levels of training in skills and problem solving techniques, and careful selection of new employees who have the skills and positive attitude towards group work. These finishing lines with Traditional HR practices are all characterized by a set of HR practices including: more narrowly defined jobs, communication largely managed through conventional grievance procedures, hiring largely through employee referrals with limited pre-hire screening, on-the-job training but with no training in teamwork skills.

A. Data and Sample

Section II defines each individual's connective capital as the knowledge he obtained from other co-workers in the firm. We conduct worker surveys in these seven finishing lines to measure workers' communications to address operating problems. We also collect data on the education and tenure of workers from a subsample of workers as proxies for their level of human capital. Finally we measure whether mills have organizational HR practices supporting problem solving.

The Worker Survey and Communication Data

Appendix B shows a sample of the worker survey used to collect data about communication among the workers on the lines. The worker communication survey has three main features. First, it lists the names of every worker with responsibilities for running or managing the line and asks the employee put a check mark next to the name of each person with whom he communicates. Second, respondents identify the *frequency* of their interaction with other workers for the various communication topics. The three categories are "daily", "weekly", or "monthly," and no check mark indicates that the workers communicate less than monthly or not at all. Third, as the respondent checks off these names, the survey asks employees to identify the *topic area* of the communications with other employees*:* operation-related issues, customer-related issues, and work routines. Survey responses were obtained from all line workers by going to the seven mills and handing out and picking up the survey from all workers.

Human Capital Measures

Data on the demographic characteristics related to human capital were available for a subsample of the workers surveyed. This information includes years of schooling and highest degree attained, age, and years of tenure at the mill location. We use these measures in the empirical work as proxies for the level of human capital that co-workers can tap into when they establish communication links with each other.

Sample Size

There are typically about 90 workers per line, ranging from 87 to 118 workers. The number of blue-collar workers – operators and maintenance workers – ranges from 47 to 51 workers across most lines. Samples in regression analyses below include responses for up to 642 employees across the seven lines. All line workers completed communication surveys**,** though in some analyses there are missing observations primarily due to missing data on the human capital measures.

B. Hypotheses

Our data dictates which hypotheses are testable. We first use the worker-specific communications data that we collect from these seven lines to test for differences in the level of communication under Team-Oriented HR practices versus more Traditional HR practices. Next, we examine communication patterns as a function of differences in the characteristics of the workers. Because the lines have nearly identical technologies and production processes, the data are not suited to tests of other hypotheses from the model, such as the effects of differences in value of problem solving (i.e., $\boldsymbol{\delta}$ in the section II model) on worker communications. Based on plant visits, we assume that all there will have a high value to problem solving, or high δ Some will have Team-oriented HR practices and some do not because transition to new HR costs are high [F]. We test only whether those plants having Team-oriented HR also have the communication links that would reflect high levels of connective capital.

> Hypothesis H1: At the firm level, steel mills that have Team-Oriented HR practices that promote information sharing and problem solving will have greater amounts of connective capital among workers.[29]

> Hypothesis H2a: At the individual level, connective capital could be higher or lower for workers with high levels of $HC_{i,}$ when the highly skilled offer expert skills others lack. The variable HC_i is unobserved in most data sets, so some potential proxies education and tenure for it are considered.

> Hypothesis H2b: At the individual level, connective capital will be higher for workers with low costs of communicating, all else constant. Workers near each other physically

---

F The costs of organizational transformation are the costs of changing all the HR Practices; job design, incentives, etc. In the five years that we follow 36 miles, none of the mills succeeded in changing all of their practices (Ichniowski and Shaw, 1995)

[29] Because the Team-Oriented and Traditional lines have entirely different sets of HR practices, we cannot test whether there are specific HR practices that are used to enhance the development of connective capital. For example, we cannot test whether any observed differences in communication and connective capital mills are due to selection policies (e.g., selecting workers who enjoy teamwork and would therefore have low communication costs) or to a training program (e.g., developing workers' solving skills which would also encourage connective capital development).

should communicate more, because it is easier (or less costly) to communicate with those near you, and also because workers near each other can exert more peer pressure on each other to share ideas.

C. The Firm's HR Policies and Differences in Connective Capital

This section reports three kinds of evidence about hypothesis H1 testing for differences in connective capital under Team-Oriented vs. Traditional HR practices. We show network diagrams of communication patterns among the workers in different lines; descriptive statistics on communications and connective capital for workers in different lines; and estimates from regression models that express a worker's total number of communication links as a function of the plant's HR policies.

Network Diagrams

In Figures 3 and 4, we present the first evidence on differences in worker communication under different HR practices.[30] These figures show a series of network diagrams that depict the existence of communication links among workers in lines that have Team-Oriented HR practices and in lines that have Traditional HR practices. In Figures 3 and 4, any line drawn between two workers indicates that a communication about an operations issue occurred between those two workers. For the purpose of these illustrative figures, we restrict our attention to two representative lines with Team-Oriented HR practices and two representative lines with Traditional practices. These figures depict the communications network links between workers when the worker pairs have discussed the operating problems of the steel mill on a daily, weekly, or monthly.

Figures 3a-3d show dramatically higher amounts of communication between the operators *within* the crews of the lines with Team-Oriented HR practices compared to the lines with traditional HR practices. The finishing lines in our sample run continuously, and allowing for days off during the week, four operator crews (A, B, C and D crews) are required to man the line on a continuous basis. Crew sizes range from 6 to 10 at these sites. Nearly all crew members in these lines communicate with 70% to 100% of employees on their own crews. In

[30] These same network figures for steel mills are also presented in Gant, Ichniowski, and Shaw (2002) when the emphasis was on showing that organizational change in steel mills must be accompanied by changes in social networks. In this current paper on connective capital we go beyond the previous paper by modeling individual decisions to communicate in our theoretical model and in our new regressions on communications patterns.

contrast, Figures 4c and 4d for the lines with traditional HR practices reveal a much lower extent of within-crew interaction.[31] On Traditional line 2, between 10% to 15% of all possible within-crew ties exist in the four crews. Furthermore, out of 35 operators across the four crews at Traditional line 1, there are 20 workers who communicate with either no other crew workers or one other crew worker *on his own crew*. Similarly, on Traditional line 2, 67% of the crew operators across the four crews communicate with two or fewer fellow crew members. These network diagrams paint a clear picture – operators on the Traditional lines are doing their jobs on their own.

Figures 4a-4d display the amount of communication *between* crews and groups. Each network diagram shows eight nodes—one each for the four crews and for maintenance workers, foremen, management, and staff. High levels of inter-group interaction (indicated with bold lines) exist when at least 60 percent of all possible two-person links between the two groups exist.[32] Medium levels of interaction (indicated with thin lines) mean that between 36% and 59% of all possible two-person links across the two groups exist. Low levels of interaction (indicated with dashed lines) mean that no more than 35% of all possible ties across the two groups exist.

These results and the regression results below are consistent with hypothesis H1: These inter-group network diagrams show dramatically higher levels of communications between different crews and between operating crews and maintenance on the Team-Oriented lines compared to the Traditional lines. For Traditional line 1, the average of this cross-group communication percentage is 23.1%, and the range is from a low of 9% to a high of 42%. For Traditional line 2, the average cross-department communication percent for these five blue-collar worker groups is only 10%, ranging from a low of 0% to a high of only 19%. In contrast for the Team-Oriented lines, the average cross-crew percent among production and maintenance worker

[31] At Team-Oriented line 1, the average crew member communicates about operations issues with 86% fellow crew members on the A crew, 78% on the B crew, 90% on the C crew, and 61% on the D crew. For Team-Oriented line 2, the corresponding figures for the four crews are 76%, 86%, 70% and 73%. On traditional line 1, the A crew has the highest level of intra-crew interaction of any crew at either of the two traditional lines at 44% of all possible intra-crew ties, but this is only about half the level of communication for the IO line crews. For the other three crews at traditional line 1, an average crew member communicates with only 12% of his fellow crew members on the B crew, 19% on the C crew, and 16% on the D crew.

[32] We calculate this "average" level of inter-group interaction by first determining the number of possible worker-to-worker ties between any two groups. For example, the total number of possible two-person ties between the six-person A crew and the six-person B crew at IO line 1 is 36 ties. The actual number of two-person ties between the A and B crews divided by the 36 potential ties gives the percentage for the inter-group level of interaction for those two groups.

groups is 76.2% at Team-Oriented line 1 and 71.6% at Team-Oriented line 2. Across both of these lines, these cross-crew percentages range from a low of 53% (or, 11 percentage points above the maximum cross-crew percent at either traditional line) to a high of 90%. Communication among production workers on the same crew and among operators and maintenance workers on different crews is much more extensive in lines with Team-Oriented HR practices than it is in lines with Traditional HR practices.

Summary Statistics on Human Capital and Connective Capital under Different HR Practices

In this section, we test Hypothesis 2a and find that the typical measure of workers human capital are uncorrelated with connective capital. Table 1 presents summary statistics on typical human capital measures and measures of workers' connective capital. The typical human capital measures of education and tenure are displayed in rows 1 through 4. A workers' connective capital is measured three different ways. Row 5 measures connective capital by calculating the percent of all workers in the line with whom the given worker has a direct "tie." In terms of the parameters of the section 2 model, this is the percent of all cc_{ij}'s that equal one for worker i, or:

$$\text{Connective Capital “Tie\%”}_i \equiv (\text{CC Tie\%})_i \equiv \sum_{j\neq i}^{N} cc_{ij} / N$$

Because steel lines have slightly different numbers of employees, we normalize the tie percent statistic by the overall size of the steel line (N). Rows 6 and 7 measure connective capital by weighting each workers' communications link by the skill levels of the workers in the link:[33] in row 6, links are weighted be the workers' years of education and in row 7, links are weighted by the the total number of years of tenure of co-workers or:

$$\text{“Aggregate” Connective Capital}_i \equiv CC_i \equiv \sum_{j\neq i}^{N} cc_{ij} HC_j$$

[33] The section II model defines a worker's connective capital ($\mathbf{CC}_i$) as a vector of cc_{ij}*HC_j elements. One can interpret this "aggregate connective capital" measure as the value of $\boldsymbol{\delta}'\mathbf{CC}$ when we set the $\boldsymbol{\delta}$ vector, which measures the value of problem solving, equal to one.

where cc_{ij} equals one if worker i communicates with worker j and zero otherwise, and HC_j is measured alternatively by the number of years of experience or education of worker j. These connective capital measures formed with human capital links as weights are aims to measure the quality of knowledge passed between workers.

The results show that workers in Team-Oriented lines have much higher levels of connective capital than do Traditional HR lines, when connective capital is measured in any of the ways displayed in rows 5, 6, or 7 of Table 1. In complete contrast, there is absolutely no difference in the means or distributions of education and tenure in the Team-Oriented versus Traditional HR lines. Using the typical measures of human capital (education and tenure) we see no apparent differences in skills on these lines. But the much higher degree of connective capital in Team-Oriented lines suggests workers are tapping into each others' knowledge to solve operating problems, and thus suggests these are teams of experts. If a workers could solve his problem alone, with out the help of other workers with different expert knowledge, he would not make the effort in these mills to contact other employees on the steel line. Like the network diagrams in Figures 3 and 4, these summary statistics also support hypothesis 1 that connective capital and information sharing among workers is higher when firms adopt HR practices that promote teamwork.

Regression Estimates of the Determinants Connections Among Workers

In this section we discuss regression results that confirm Hypothesis #1: connective capital is higher on Team-oriented lines and when we control for worker characterized of education tenure and occupation.[34]

On average, workers in Team-Oriented lines are connected with 17.5% more of their line workforce than are workers in traditional lines, based on a regression of workers' connective capital (measured as the tie percent) as a function of the Team-Oriented dummy variable and four occupation dummies as control variables (Table 2, column 1).[35] When the dummy for Team-Oriented HR is interacted with different occupational groups, the results are the same:

[34] See also Gant, Ichniowski, and Shaw (2002) for these regression results when examining organizational change in steel mills.

[35] The sample is stacked by frequency of contact (strong or daily ties; moderate or weekly ties; and weak or monthly ties) and by topic of contact (related to operations, to customers, or to work routines); thus the data set includes nine observations per worker in the "all ties" columns, and three observations in the "strong ties" columns. We include dummies for all four occupation groups but omit the constant term from the regression.

workers in all occupational groups have significantly more connective capital in Team-Oriented lines (column 2). More specifically, the largest percentage differential is for foremen and then production workers, and the smallest in magnitude for managers. Team-Oriented HR practices elevate the connective capital of operating workers more than managers. These regressions displayed connective capital measures for all frequencies of communications (daily, weekly, and monthly). When connective capital is measured for each of these frequencies, the results are the same, except that there is no difference in the amount of management communications between Team-Oriented lines and Traditional HR lines: managers are always communicating with workers on a daily basis in all the lines.[36]

In Table 3, we re-estimate these regressions but add controls for the workers' human capital, as measured by education and tenure. The sample size in the Table 3 regressions is lower than the Table 2 sample size due to missing data on the individuals' education and tenure. The basic patterns remain the same: the estimated effect of Team-Oriented HR practices on each worker's connective capital is independent of the effects of typical human capital variables in these workforces.

Overall, patterns in the worker communication data demonstrate the HR environments have large and powerful effects on the extent of worker communication and interaction. Workers have more connective capital in lines with Team-Oriented HR practices compared to virtually identical finishing lines that operate under Traditional HR practices. These data also show that connective capital is very distinct from human capital – workers with equivalent tenure or education have very different connective capital depending largely on the nature of the HR practices adopted by the lines. Typical human capital measures like tenure and education are not good predictors of connective capital and are not likely to measure underlying expert skills.

D. Who Talks to Whom?

Lastly, we test Hypotheses 2a and 2b using data on who talks to whom. The data set for Table 4 is the set of communications from all possible worker pairs in all the lines. When there is a communication between a given pair of workers, then the dummy dependent variable, Tie, equals one. If the workers do not have a communication connection, the dependent variable for

[36] We also estimate regressions in which we omit observations in IO lines with very large numbers of ties to test whether the positive IO effect is driven by the higher communications for a subset of the workforce. Even eliminating these outliers in IO lines, we find that the IO effect is very positive for all groups of workers.

that pair equals zero. We separate the data sets into the Team-Oriented communications (column 1) and the Traditional HR communications (column 2).[37]

In Team-Oriented lines, there is some evidence that experts communicate more (Hypotheses 2a) and that physical proximity matters (Hypothesis 2b). Communications are higher within the occupation groups – within manager-manager pairs, operator-operator pairs, and within maintenance-maintenance pairs.[38] These communications could reflect higher comfort levels for workers talking with the own kind. But more specifically, they show that within occupation groups, workers communicate with each other because they believe each worker has different expert knowledge (Hypothesis 2a): if the worker could solve his operating problem alone, he would not communicate. Plant visits to observe problem-solving in the steel mill lines, and interviews, confirmed this interpretation.

Physical proximity also raises communications (Hypothesis 2b): maintenance workers communicate with each other the most because they work out of a base "shop" in a part of the mill. All other workers are located at different points along the production line.

Turning to the regressions for Traditional HR lines, virtually no one talks to each other. The level of the coefficients on the job class types are much smaller than for Team-Oriented lines. Operators do not appear to be considered as experts with knowledge to share. Maintenance workers also do not communicate with each other – they just take orders from above. One variable that is more significant is tenure: tenure groups seem to stick together. The older workers on the line are more likely to talk to each other (measured by the "both senior" dummy variable).

In sum, we show that operators and maintenance workers talk more to each other on Team-Oriented lines. Apparently, they value their expert skills despite the apparent homogeneity of their occupational titles. Workers on Traditional lines are also likely to have expert skills, but the HR practices of Traditional HR lines do not support the sharing of information to solve problems.

---

[37] For the Team-Oriented results of column 1, the sample size is small because we drop the line that does not have jobs designated "supervisor" but instead uses team leaders among the operators. When looking at detailed communications pairs, we aimed for very homogeneous measures of occupation.

[38] The omitted occupation pair is maintenance-manager, because these workers need to communicate to maintain the capital on the line.

These results also show that economists do not have reasonable measures of the "expert skills" of employees. Job class does not measure expert knowledge. The individual workers on the line do know who to turn to when faced with a problem, but our data does not measure such expert knowledge. This is not just true of data on steel mills, but all data sets where we use occupation as a measure of knowledge.

E. Linking Connective Capital to Productivity

The theoretical model proposes that connective capital will raise the productivity of workers when problem solving is valued. At the beginning of Section II, we refer to the previous work showing that Team-Oriented lines have significantly higher productivity than Traditional lines for 36 steel mills (Ichniowski, Shaw and Prennushi, 1997). We return to seven of these mills in this paper surveying individual workers' communications. In this subset, seven mills is too few mills to test whether connective capital raises productivity (because productivity is measured at the mill level not the worker level). However, because these mills are drawn from the larger sample, we do know that Team-Oriented lines are much more productive than Traditional HR lines, and the clearly higher levels of connective capital to solve operative problems is a likely explanation for the higher productivity of Team environments.[39]

III. Conclusion

Firms nowadays are likely to be using problem-solving extensively to produce output. In manufacturing, gone are the days when most workers only stood on a production line and manually fitted together products; now they also solve production problems together. Knowledge workers, as in the software industry or other professional service industries, will spend a portion of their time solving co-workers problems. One piece of evidence that firms are now comprised of problem solvers comes from Autor, Levy, and Murnane (2003). They show, using detailed occupational task data for individuals over the last thirty years, that virtually all growth in labor demand has been for workers who do "non-routine cognitive tasks" – i.e., problem solving.

[39] For an explanation of why many mills don't adopt Team practices due to the high transformation costs, see Ichniowski and Shaw (1999).

We posit that much of this problem solving occurs through knowledge sharing among experts. That is, firms are more likely to be comprised of different "experts" who must share information to solve problems. Firms are not composed of generalists who know it all and work alone. This creates a new form of capital that workers and firms invest in, called connective capital. Each worker's individual connective capital is the skills he taps into among his co-workers. There are two reasons why this notion of connective capital is of interest. First, it defines a new production function that goes beyond traditional models (such as Cobb-Douglas). Connective capital specifies how workers are complements and produce higher output when working together: connective capital defines firms as teams of complementary workers. Second, firms that value problem solving must invest in connective capital HR practices that support the development of connective capital. Individuals constantly make decisions about how to spend their time since the output from connective capital is team based; individual workers have too little incentive to share knowledge when co-workers ask for help solving problems. Firms can increase sharing by creating a culture of "norms" of sharing: as in any group output, all share more, and all collectively reach a higher level of pay and performance. Our data from steel mills supports this proposition: mills with an active set of Team-oriented HR practices aimed at producing a culture of sharing have higher levels of information sharing among operators.

In sum, the model of connective capital that we develop in this paper is ultimately a model about teamwork in large group settings. Connective capital shares many features with related group-based notion of social capital. Like social capital, connective capital can only occur in groups. It generates externalities since sharing ideas and knowledge among workers is more beneficial to the entire group than to the individual. Cooperative knowledge sharing behavior can spread within the group as workers observe patterns of sharing behavior that the firm has encouraged through norms of sharing. Therefore, connective capital is a knowledge-based variant of social capital that provides one reason why individuals in groups can be smarter and more productive than they are working on their own. In short, connective capital represents a way to leverage the value of individual human capital and increase the returns from human capital for both workers and firms.

References

Agrawal, Ajay, Iain Cockburn and John McHale, (September 2003). "Gone but not Forgotten: Labor Flows, Knowledge Spillover, and Social Capital," NBER Working Paper #9950.

Akerlof, George and Rachel Kranton, 2005. "Identity and the Economics of Organizations," *Journal of Economic Perspectives,* vol. 19, no. 1, 9-32.

Aoki, Masahiko (1986), "Horizontal vs. Vertical Information Structure of the Firm," *American Economic Review*, vol. 76, (December), pp. 971-983. 3. 2003.

Aral Sinan, Marshall W. Van Alstyne, (March 2008), "Networks, Information & Social Capital," Working Paper, Social Science Research Network.

Autor, David, Frank Levy, and Richard Murnane, 2003. "The Skill Content of Recent Technological Change: an Empirical Investigation," *Quarterly Journal of Economics.* 118(4): 1279-1333.

Bandiera's Oriana, Iwan Barankay, Imran Rasul, (forthcoming) "Social Capital in the Workplace: Evidence on its Formation and Consequences," *Labour Economics.*

Bandiera's Oriana, Iwan Barankay, Imran Rasul, Aug 2005 "Social Preferences and the Response to Incentives: Evidence from Personnel Data," *Quarterly Journal of Economics.*

Berg, Peter, Eileen Appelbaum, Thomas Bailey, and Arne L. Kalleberg (1997) "The Performance Effects of Modular Production in the Apparel Industry," *Industrial Relations,* vol. 35 (July), pp. 356-373.

Black, Sandra and Lynch, Lisa (2001) "How to Compete: The Impact of Workplace Practices and Information Technology on Productivity," *Review of Economics and Statistics,* vol. 83, no. 3, pp. 434-45..

Bolton, Patrick and Mathias Dewatripont. (1994) "The Firm as a Communication Network," *Quarterly Journal of Economics,* vol 109, no. 4, (November) pp. 809-839.

Boning, W. Brent, Casey Ichniowski, and Kathryn Shaw (2007), "Opportunity Counts: Teams and the Effectiveness of Production Incentives" *Journal of Labor Economics*. 25: 613-650.

Borgatti, Everett, and Freeman (1996), "UCINET IV Version 1.64 Reference Manual," Analytic Technologies Natick, MA.

Burt, Ronald, (2005). *Brokerage and Closure: An Introduction to Social Capital*. Oxford, England: Oxford University Press.

Burt, Ronald, (forthcoming). "Second-Hand Brokerage: Evidence on the Importance of Local Structure for Managers, Bankers, and Analysts," *Academy of Management Journal*.

Cappelli, Peter and David Neumark (2001) "Do High-Performance Work Practices Improve Establishment-Level Outcomes?" *Industrial and Labor Relations Review*, July, vol. 54, no. 4, pp. 737-75.

Charles, Kerwin and Patrick Kline, (July 2002). "Relational Costs and the Production of Social Capital: Evidence from Carpooling," NBER Working Paper #9041.

Coleman, J.S., (1988). "Social Capital in the Creation of Human Capital," *American Journal of Sociology,* 94, 95-120.

Costa, Dora and Matthew Kahn, (December 2001). "Cowards and Heroes: Group Loyalty in the American Civil War," NBER Working Paper #8627.

Costa, Dora and Matthew Kahn, (December 2005). "Surviving Andersonville: The Benefits of Social Networks in POW Camps," NBER Working Paper #11825.

Costa, Dora and Matthew Kahn, (forthcoming). "Deserters, Social Norms, and Migration," *Journal of Law and Economics*.

Dunlop, John T., and David Weil (1997) Diffusion and Performance of Modular Production in the U.S. Apparel Industry," *Industrial Relations,* vol. 35 (July), pp. 334-355.

Durlauf, Steven and Marcel Fafchamps, (2004). "Social Capital," NBER Working Paper #10485.

Gant, Jon, Casey Ichniowski, and Kathryn Shaw (2002). "Social Capital and Organizational change in High-Involvement and Traditional Work Organizations." *Journal of Economics and Management Strategy,* Summer, 11 (2): 289-328.

Garicano, Luis, (October 2000). "Hierarchies and the Organization of Knowledge in Production," *Journal of Political Economy,* 108(5): 874-904.

Garicano, Luis and Thomas Hubbard, (July 2006). "The Return to Knowledge Hierarchies," Working Paper.

Geanakoplos, J. and Paul Milgrom, (1991) "A Theory of Hierarchies Based on Limited Managerial Attention," *Journal of the Japanese and International Economies,* pp. 205-225.

Gil Richard, Wesley Hartmann, (2007). "Airing Your Dirty Laundry: Vertical Integration, Reputational Capital and Social Networks" Stanford University, Working Paper.

Gant, Jon, Casey Ichniowski, and Kathryn Shaw, (2002). "Social Capital and Organizational Change in High-Involvement and Traditional Work Organizations," *Journal of Economics and Management Science,* Summer 11 (2): 289-328.

Glaeser, Edward L., David Laibson, and Bruce Sacerdote. (2002) "An Economic Approach to Social Capital," *Economic Journal,* v112(483,Nov), pp. 437-458.

Golden, Claudia and Lawrence Katz, (Spring 1999). "Human Capital and Social Capital: The Rise of Secondary Schooling in America," *Journal of Interdisciplinary History*, 29: 683-723.

Griliches, Zvi (1980) "Returns to Research and Development Expenditures in the Private Sector," in W. Kendrick and B. Vaccara, ed., *New Developments in Productivity Measurement,* vol. 44, Studies in Income and Wealth, Chicago; University of Chicago Press. pp. 419-54.

Heliwell, John and Haifang Huang, (November 2005), “How's the Job? Well-Being and Social Capital in the Workplace”, *Working Paper* NBER no 11759.

Huselid, Mark (1995) “The Impact of Human Resource Management Practices on Turnover, Productivity, and Corporate Financial Performance,” *Academy of Management Journal*, vol. 38, pp. 635-672.

Ichniowski, Casey, Kathryn Shaw, and Giovanna Prennushi (1997) “The Effects of Human Resource Management Practices on Productivity: A Study of Steel Finishing Lines,” *American Economic Review*, vol. 87, pp. 291-313.

Ioannides, I.M. and L.D. Loury, (2004). “Job Information Networks, Neighborhood Effects, and Inequality,” *Journal of Economic Literature*, 42(4), 1056-1093.

Jackson, Matthew, (2005). “The Economics of Networks,” Working paper, California Institute of Technology.

Jackson, Matthew (forthcoming), “*Social and Economic Networks*”, Princeton University Press.

Jackson Matthew, and Bisin Benhabib (forthcoming),“Social Networks in Economics," *Handbook of Social Economics*.

Jackson Matthew, James E. Rauch, (2007), “The Study of Social Networks In Economics," in *The Missing Links: Formation and Decay of Economic Networks,* edited by James E.Rauch, Russell Sage Foundation.

Jackson, Matthew and Hugo Sonnenschein, forthcoming. “Overcoming Incentive Constraints by Linking Decisions,” *Econometrica*.

Kalnins Arturs and Wilbur Chung, (2006), “Social Capital, Geography, and Survival: Gujarati Immigrant Entrepreneurs in the U.S. Lodging Industry,” *Management Science* 52(2): 233-247.

Kandel, Eugene and Edward Lazear (1992) "Peer Pressure and Partnerships" *Journal of Political Economy*, vol. 100, pp. 801-817.

Keren, M. and D. Levhari, (1979) “The Optimum Span of Control in a Pure Hierarchy,” *Management Science*, vol 40, pp. 1162-1172.

Knack, S., and P. Keefer (1997) "Does Social Capital Have an Economic Payoff? A Cross-Country Investigation," *Quarterly Journal of Economics*, vol. 112(4), pp. 1251-1288.

Lazear, Edward, “Globalization and the Market for Team-mates” *Economic Journal:* 104: 454 (1999): 15-40.

Lazear, Edward P. (2004) "Balanced Skills And Entrepreneurship," *American Economic Review*, v.94 (2,May), 208-211.

Lazear, Edward P and Kathryn Shaw, (Fall 2007), “Personnel Economics: The Economist’s View of Human Resources,” *Journal of Economic Perspectives*, 21 (4): 91-114.

Leana, Carrie and Harry Van Buren, III, (1999) "Organizational Social Capital and Employment Practices", *Academy of Management Review*, vol. 34, no. 3, pp. 538-555.

Leana, Carrie and Fritz Pil (2006) "Social Capital and Organizational Performance: Evidence from Urban Public Schools," *Organization Science*, 13(3): 1-14.

MacDuffie, John Paul (1995) "Human Resource Bundles and Manufacturing Performance: Organizational Logic and Flexible Production Systems in the World Auto Industry," *Industrial and Labor Relations Review*, vol. 48, pp. 197-221.

MacLeod, Bentley (1987), "Behavior and the Organization of the Firm," *Journal of Comparative Economics*,11: 207-220).

MacLeod, Bentley (1988), "Equity, Efficiency, and Incentives in Cooperative Teams," *Advances in the Analysis of Participatory and Labor Managed Firms, 3*: 5-23.

Manski, Charles, (2000). "Economic Analysis of Social Interactions," *Journal of Economic Perspectives*, vol. 14, no. 3, 115-136.

Marshall, Alfred (1965) *Principles of Economics* (Macmillan, London).

Mas, Alexandre and Enrico Moretti (2009), "Peers at Work," *American Economic Review*, September, 99(1): 112-145.

Nahapiet, Janine and Sumantra Ghoshal (1998) "Social Capital, Intellectual Capital, and the Organizational Advantage," *Academy of Management Review*, vol. 23, no. 2, pp. 242-266.

Reagans Ray and Ezra W. Zuckerman, (July-August 2001), "Networks, Diversity, and Productivity: The Social Capital of Corporate R&D Teams" *Organization Science*, 12(4): 502-517.

Sabatini Fabio, (August 2005), "Does Social Capital Improve Labour Productivity in Small and Medium Enterprises?"Working Paper, Social Science Research Network.

Singh, Param Vir, Tan, Yong and Mookerjee, Vijay, (April 2008), "Network Effects: The Influence of Structural Social Capital on Open Source Project Success," Working Paper. Social Science Research Network.

Yli-Renko, H. K., Autio, E., Sapienza, H. (2001)." Social Capital, Knowledge Acquisition, and Knowledge Exploitation in Young Technology-Based Firms". *Strategic Management Journal*, 22, 529-613.

Appendix A: Comparative Statics

This appendix derives the conclusions of Section I.C.

For point 1:

$$\frac{\partial B_{ij}}{\partial\left(t\alpha_j HC_j\right)} = \frac{R}{N} < 0$$

so B_{ij} is decreasing in $t\alpha_j HC_j$, therefore $P_r(cc_{ij}=1)$ is decreasing in $t\alpha_j HC_j$.

For point 2:

$$\frac{\partial B_{ij}}{\partial \delta_{ij}} = \frac{R}{N} dHC_j > 0$$

So B_{ij} is increasing in δ_{ij} and hence $Pr(cc_{ij}=1)$ is increasing in δ_{ij}.

For point 3, recall that

$$\begin{aligned} P_r\left(cc_{ij} = 1\right) &= F^A\left(B_{ij} P_{ji}\right) F^S\left(B_{ij}\right) \\ &= F^A\left[B_{ij} F^S\left(B_{ij}\right)\right] F^S\left(B_{ij}\right) \end{aligned}$$

Therefore $P_r\left(cc_{ij} = 1\right)$ is increasing in B_{ij}, and cc_{ij} is increasing in all factors that increase B_{ij} for

$$\begin{aligned} B_{ij} &= \frac{R}{N} \cdot \left[d\delta_{ij} HC_j - t\left(\alpha_i HC_i + \alpha_j HC_j\right)\right] \\ &= \frac{R}{N} \cdot \left[\left(d\delta_{ij} - t\alpha_j\right) HC_j - t\alpha_i HC_i\right] \end{aligned}$$

So that:

$$\frac{\partial B_{ij}}{\partial HC_j} = \frac{R}{N} \cdot \left(d\delta_{ij} - t\alpha_j\right)$$

Therefore, when $d\delta_{ij} > t\alpha_j$, B_{ij} is increasing in HC_j. Hence communication is more common when $d\delta_{ij} > t\alpha_j$.

Note that $d\delta_{ij} > t\alpha_j$ is not a real restriction because for a communication to be profitable for the firm in the first place, we must have $B_{ij} > 0$, and this implies that $(d\delta_{ij} - t\alpha_j)HC_j$ and $t\alpha_i HC_i$ from its definition.

Appendix B - Summary of Communication Survey Questions

Here is a summary of the questions that are included in the communication survey. The survey is relatively easy to fill out and takes between 10-15 minutes. The survey is organized with one question per page. The rest of the page contains the names of all of the employees. Beside each employee name are three check boxes indicating the frequency of communication. Each respondent will be asked to read each question and place a check mark by the name of each employee's name that meet the question's criteria.

For example, below is a brief illustration of one page from the survey.

With whom do you typically communicate?

Please check as many names as may be appropriate.

	Daily	Weekly	Monthly or less		Daily	Weekly	Monthly or less
Adams, Fred	[ ]	[ ]	[ ]	Hurley, Stanley	[ ]	[ ]	[ ]
Christopheson, Bill	[ ]	[ ]	[ ]	Marshall, Jim	[ ]	[ ]	[ ]
Haynes, Lester	[ ]	[ ]	[ ]	Smith, Don	[ ]	[ ]	[ ]
Lieman, Mary	[ ]	[ ]	[ ]	Norville, David Jr.	[ ]	[ ]	[ ]
Jordan, Barb	[ ]	[ ]	[ ]	Ostertag, John	[ ]	[ ]	[ ]
Childs, Tim	[ ]	[ ]	[ ]	Patton, Mike	[ ]	[ ]	[ ]

The survey questions include:

1. With whom do you typically communicate?
2. Who do you communicate with about operational issues?
3. Who do you communicate with about safety issues?
4. Who do you communicate with about quality issues?
5. Who do you communicate with about maintenance issues?
6. Who do you communicate with about customer issues?
7. Who do you communicate with about supplier issues?
8. Who do you communicate with about job related routines that you have developed?
9. Who do you communicate with about the performance of the company issues?
10. Who are you dependent on for critical information in doing your job?
11. Who is dependent on you for critical information in doing their job?
12. How much training would you need to fill-in for the following employees
13. With whom would you feel comfortable filling-in for you?

All of the surveys will be handed out by the research team along with an envelope. The respondents will be instructed to return the survey in this envelope and seal it to members of the research team. This will help to protect the confidentiality of the responses.

Table 1

Mean Values Human Capital Variables and Connective Capital Indicators

Measure of Human Capital or Connective Capital	Type of HR Practices: Traditional	Team-Oriented
Human Capital		
1. Years of Schooling	13.26	13.22
2. Percent High School Grad or Less	56%	59%
3. Percent with Some College Degree	17%	20%
4. Years of Tenure at Plant	13.67	11.86
Connective Capital Indicators[a]		
5. Connective Capital Tie % (Percent of Other Workers that Focal Worker Has Ties With)	.117 (.161)	.387 (.275)
6. Aggregate Connective Capital, person i (Sum of Tie * Years of Schooling[b])	340.9 (152.3)	664.7 (133.3)
7. Aggregate Connective Capital, person i (Sum of Tie * Years of Tenure[b])	298.8 (349.5)	535.4 (228.3)

See the variable definitions in Section IIC.
a- Standard deviations in parentheses
b-Lines 6 and 7 present the average value (and standard deviation) for a statistic that sums the total number of years of the given human capital measure among workers with whom the focal worker has a tie.

Table 2

Determinants of Connective Capital Tie%

Dependent Variable = (No. of Ties)$_i$/(N_{plant})

	Connective Capital Tie%			
	All Ties		Strong Ties	Weak Ties
	(1)	(2)	(3)	(4)
Production Workers	.092 (6.28)	.091 (10.88)	.062 (8.12)	.067 (6.58)
Managers	.078 (4.39)	.103 (6.30)	.071 (6.41)	.061 (4.03)
Non-Production Staff	.053 (5.34)	.064 (4.21)	.055 (3.78)	.039 (2.08)
Foremen/Team Leaders	.149 (4.51)	.084 (2.59)	.052 (1.98)	.047 (1.92)
Team-Oriented HRM Practices (TEAM HR)	.175 (15.18)			
Production Workers*TEAM HR		.199 (13.47)	.118 (5.57)	.169 (9.65)
Managers*TEAM HR		.151 (5.44)	.023 (1.50)	.201 (5.96)
Non-production Staff*TEAM HR		.176 (7.65)	.114 (3.19)	.163 (7.42)
Foremen/Team Leader*TEAM HR		.283 (5.55)	.205 (4.31)	.253 (3.80)
R^2	0.49	0.50	0.37	0.55
N	5688	5688	1896	1896

<u>Table Notes</u>:

All Ties refers to the daily, weekly, and monthly communications. Strong ties refer only to daily communications. There are also three separate observations for each of three different communication topics. Thus, samples for "all ties" models contain 9 observations per employee and samples for strong ties models have 3 observations per employee. Models include controls for type of communication topic and frequency of communication.

Standard errors are adjusted for worker-specific clustering; t-statistics are in parentheses.

Table 3
Determinants of Connective Capital Tie% in Models with Controls for Workers' Human Capital
Dependent Variable = (No. of Ties)$_i$/(N_{plant})

	Connective Capital Tie%		
	All Ties (1)	**Strong Ties (2)**	**Weak Ties (3)**
Production Workers*TEAM HR	.211 (11.22)	.096 (4.76)	.198 (8.12)
Managers*TEAM HR	.282 (7.89)	.098 (3.52)	.296 (5.65)
Non-production Staff*TEAM HR	.260 (8.31)	.160 (2.87)	.250 (7.90)
Foremen/Team Leader*TEAM HR	.323 (9.80)	.238 (5.59)	.289 (4.46)
Age – Operators	.0003 (0.25)	-.0025 (-1.80)	.0017 (0.91)
Non-operators	-.0040 (-3.18)	-.0043 (-2.14)	-.0034 (-2.58)
Tenure – Operators	.0016 (1.11)	.0021 (1.66)	.0009 (0.49)
Non-operators	.0038 (2.45)	-.0011 (-1.16)	.0068 (2.73)
Education – Operators	.0050 (0.61)	.012 (1.92)	-.003 (-0.25)
Non-operators	.021 (2.07)	.032 (2.12)	.007 (0.61)
$(Education)^2$ – Operators	-.0001 (-0.38)	-.0004 (-1.51)	.0001 (0.21)
Non-operators	-.0007 (-1.45)	-.0013 (-1.81)	-.00003 (-0.06)
R^2	0.54	0.41	0.60
N	2657	885	889

Table Notes:

Strong Ties refers to the sample of daily communications; Weak Ties refers to the sample of monthly communications; All Ties refers to the daily, weekly, and monthly communications. There are 3 observations per employee for each tie frequency for each of three different communication topics.

Standard errors are adjusted for worker-specific clustering; t-statistics are in parentheses. Also included are controls for type of communication topic and, in the “all ties” model, frequency of communication.

Table 4

Who Talks to Whom: The Probability of Communication for Pairs of Workers

Dependent Variable: Tie =1 if Communication Between Worker (i,j) Pair
Tie =0 if No Communication

	Team HR Lines (1) strong ties	Traditional HR Lines (2) strong ties
Mean of Dependent Variable	0.368	0.075
Independent Variables		
Occupations		
1. Operator-Operator	0.311	-0.109
	(4.12)	(-3.20)
2. Manager-Manager	0.326	-0.053
	(2.52)	(-1.16)
3. Operator-Manager	0.291	-0.077
	(3.76)	(-2.60)
4. Staff-Manager	0.122	-0.064
	(1.50)	(-2.02)
5. Staff-Staff	0.154	-0.082
	(2.21)	(-2.25)
6. Staff-Operator	0.173	-0.093
	(2.46)	(-2.68)
7. Staff-Maintenance	0.095	-0.032
	(1.20)	(-0.95)
8. Operator-Maintenance	0.125	-0.070
	(1.86)	(-2.38)
9. Maintenance-Maintenance	0.471	0.038
	(4.47)	(0.82)
10. Supervisor-Supervisor	--------	-0.041
		(-0.70)
11. Supervisor-Staff	--------	-0.032
		(-0.78)
12. Supervisor-Operator	--------	-0.063
		(-1.64)
13. Supervisor-Maintenance	--------	0.008
		(0.18)

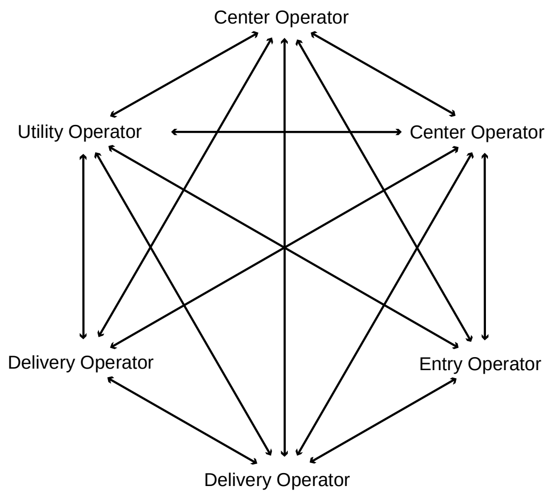
14. Manager-Maintenance	Omitted dummy variable	
Education		
15. Both High School	0.189	-0.010
	(3.58)	(-0.59)
16. Both Post High School	0.055	-0.001
	(1.20)	(-0.08)
17. Both College	-0.008	0.19
	(-0.16)	(0.90)
18. HS-Post High School	0.143	-0.009
	(4.09)	(-0.68)
19. HS – College	-0.075	0.009
	(-1.47)	(0.59)
20. Post High School-College		
Age		
21. Matching Age	0.020	0.005
	(1.09)	(0.94)
Tenure		
22. Both New	-0.063	0.045
	(-1.32)	(2.35)
23. Both Average	-0.037	-0.019
	(-0.63)	(-1.87)
24. Both Senior	0.058	0.147
	(0.72)	(4.34)
25. New- Average	-0.044	-0.009
	(-1.14)	(-0.81)
26. New- Senior	-0.153	0.031
	(-3.18)	(2.31)
27. Average- Senior	Omitted dummy variable	
R^2	0.09	0.05
N	3893	12549

Table Note: The omitted categories for categorical variables above are manager-maintenance for occupations; post high school-college for education, average- senior for tenure, and non-matching age for age.

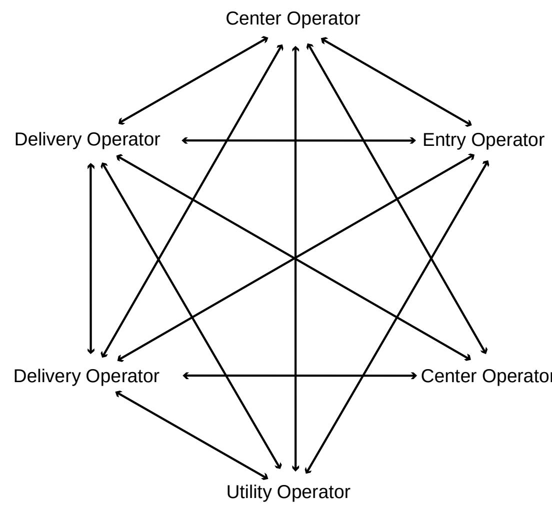
Table 5
Means of Selected Variables in Sample of Worker Communications Pairs

	Mean	
Variable	*Team Oriented*	*Traditional*
Strong Ties	.368	.075
Weak Ties	.302	.052
Both HS	.329	.328
Both Post HS	.222	.230
Both College	.078	.040
HS- Post HS	.219	.301
HS- College	.276	.190
Both New	.427	.143
New- Average	.292	.333
New- Senior	.140	.139
Both Average	.101	.189
Both Senior	.012	.048

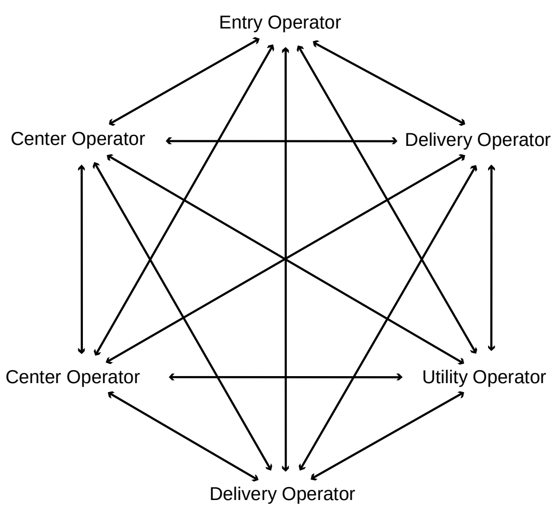
Figure 3a - intra-crew Communication Interactions for IO Line 1



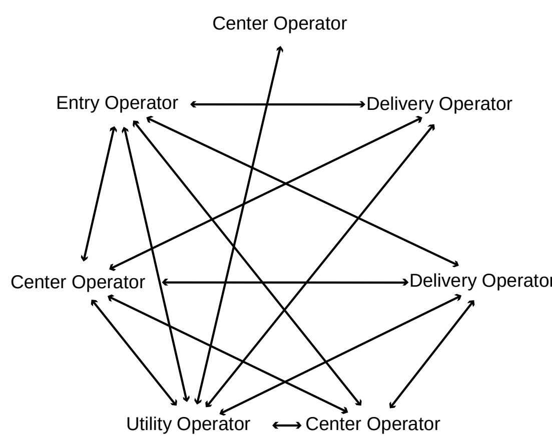
Crew A



Crew B

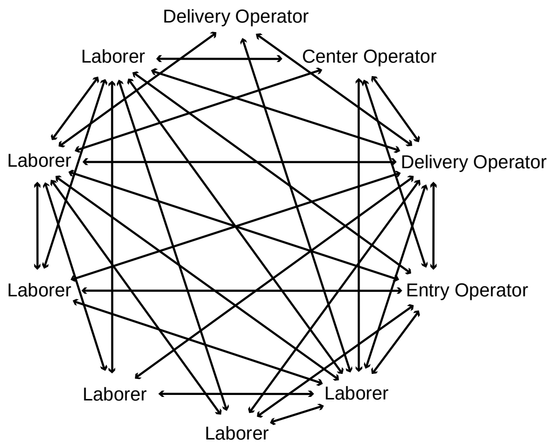


Crew C

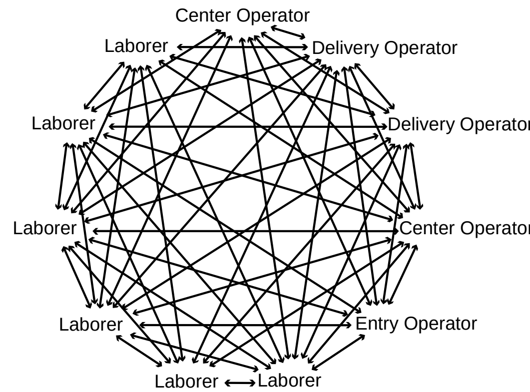


Crew D

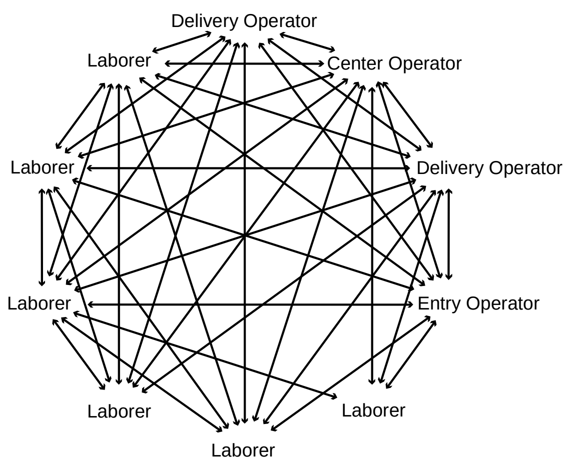
Figure 3b - intra-crew Communication Interactions for IO Line 2



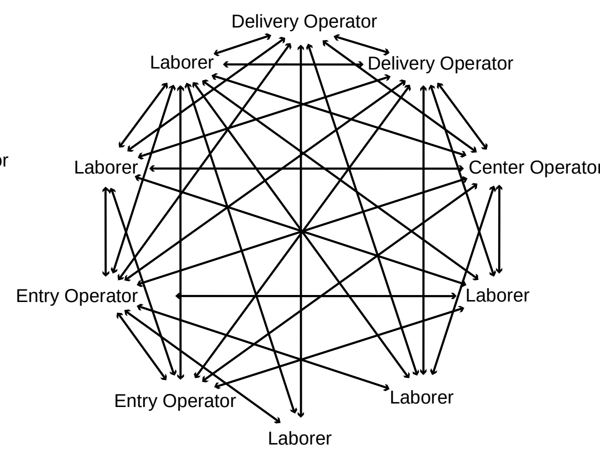
Crew A



Crew B

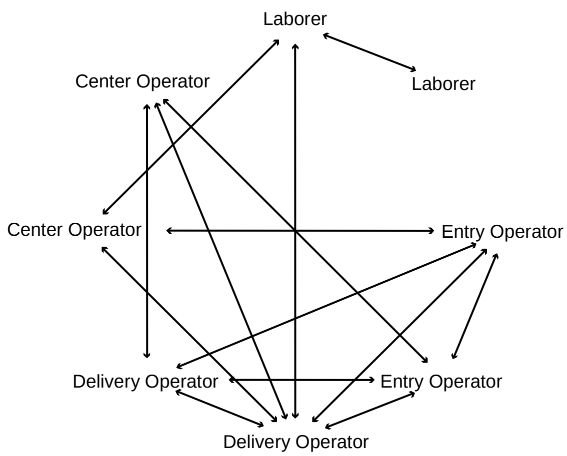


Crew C

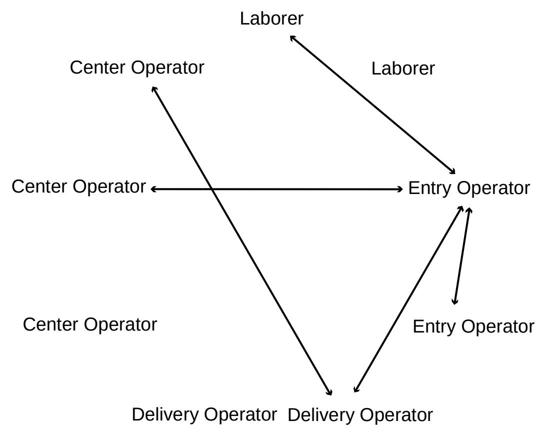


Crew D

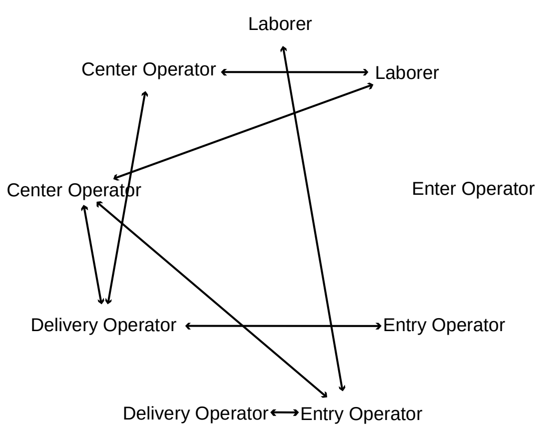
Figure 3c - intra-crew Communication Interactions for CO Line 1



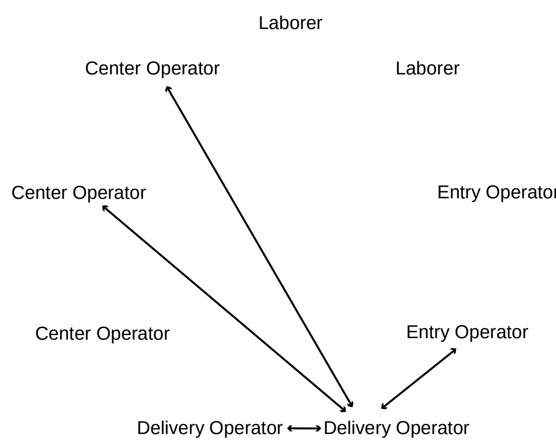
Crew A



Crew B

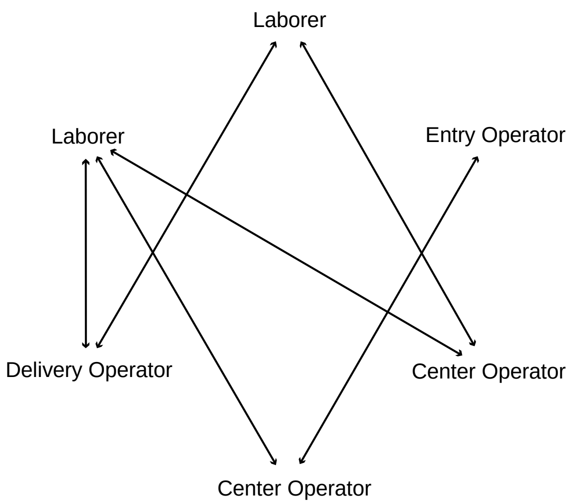


Crew C

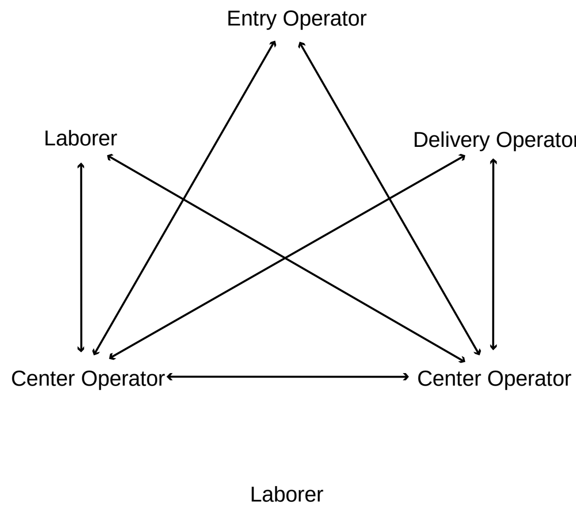


Crew D

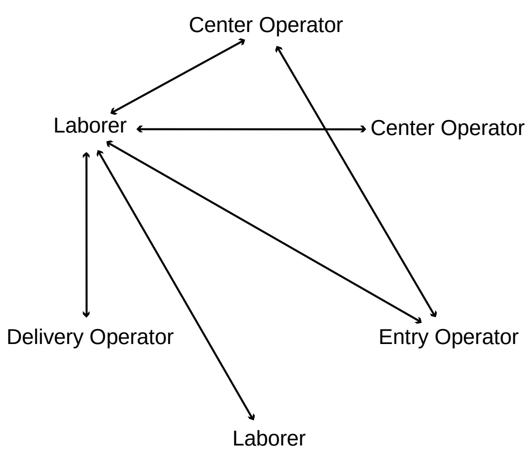
Figure 3d - intra-crew Communication Interactions for CO Line 2



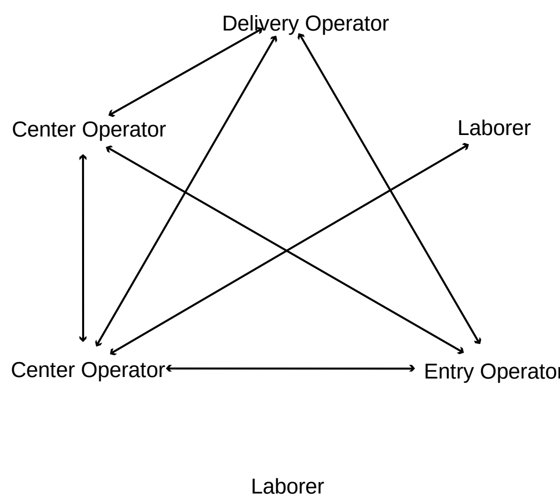
Crew A



Crew B

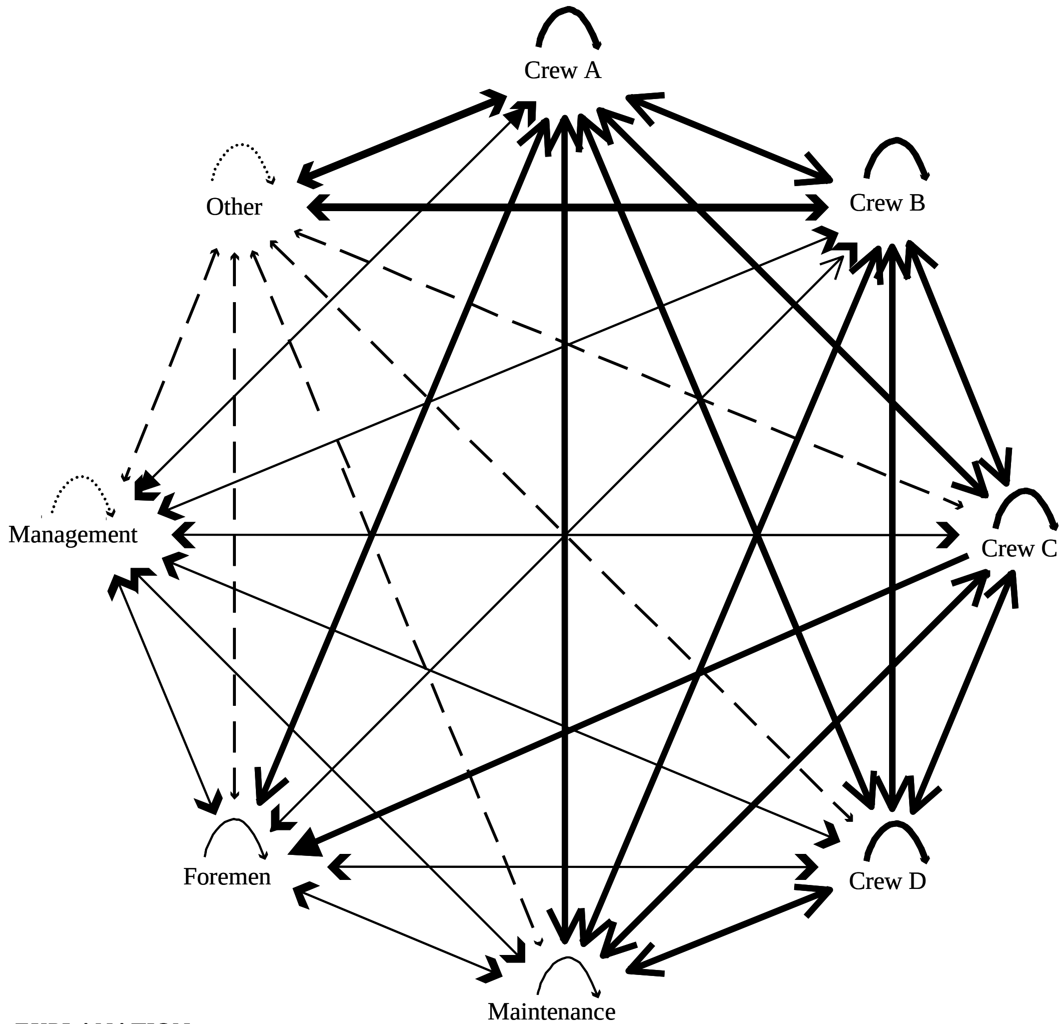


Crew C



Crew D

Figure 4a – Inter-group Communication Interactions for IO Line 1



EXPLANATION

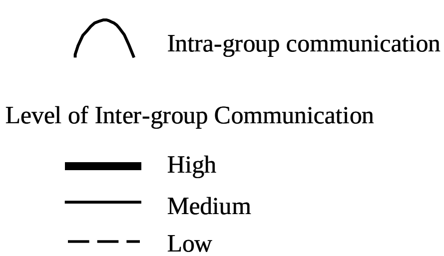
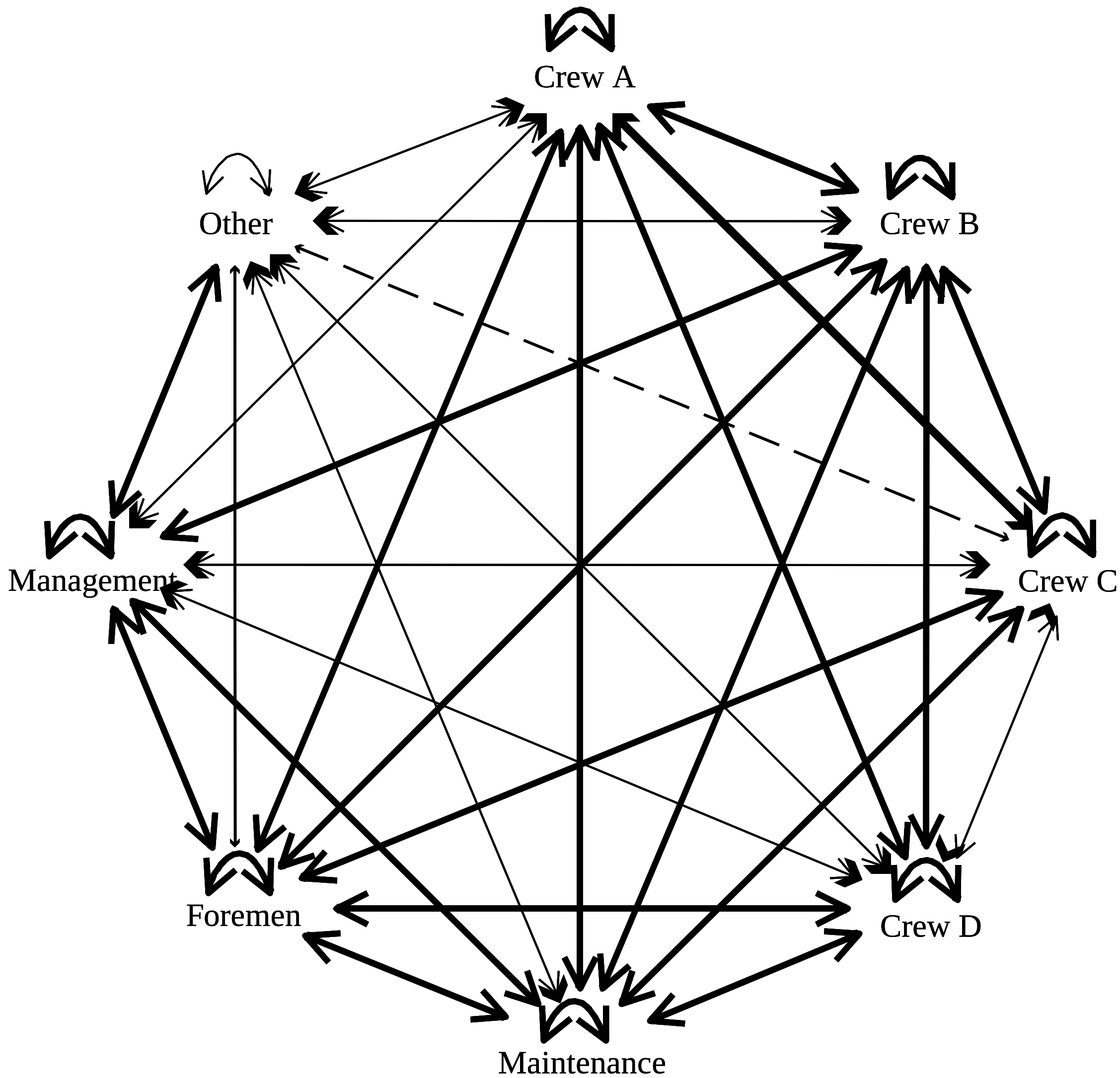


Figure 4b – Inter-group Communication Interactions for IO Line 2



EXPLANATION

Intra-group communication

Level of Inter-group Communication

High
Medium
Low

Figure 4c - Inter-group Communication Interactions for CO Line 1

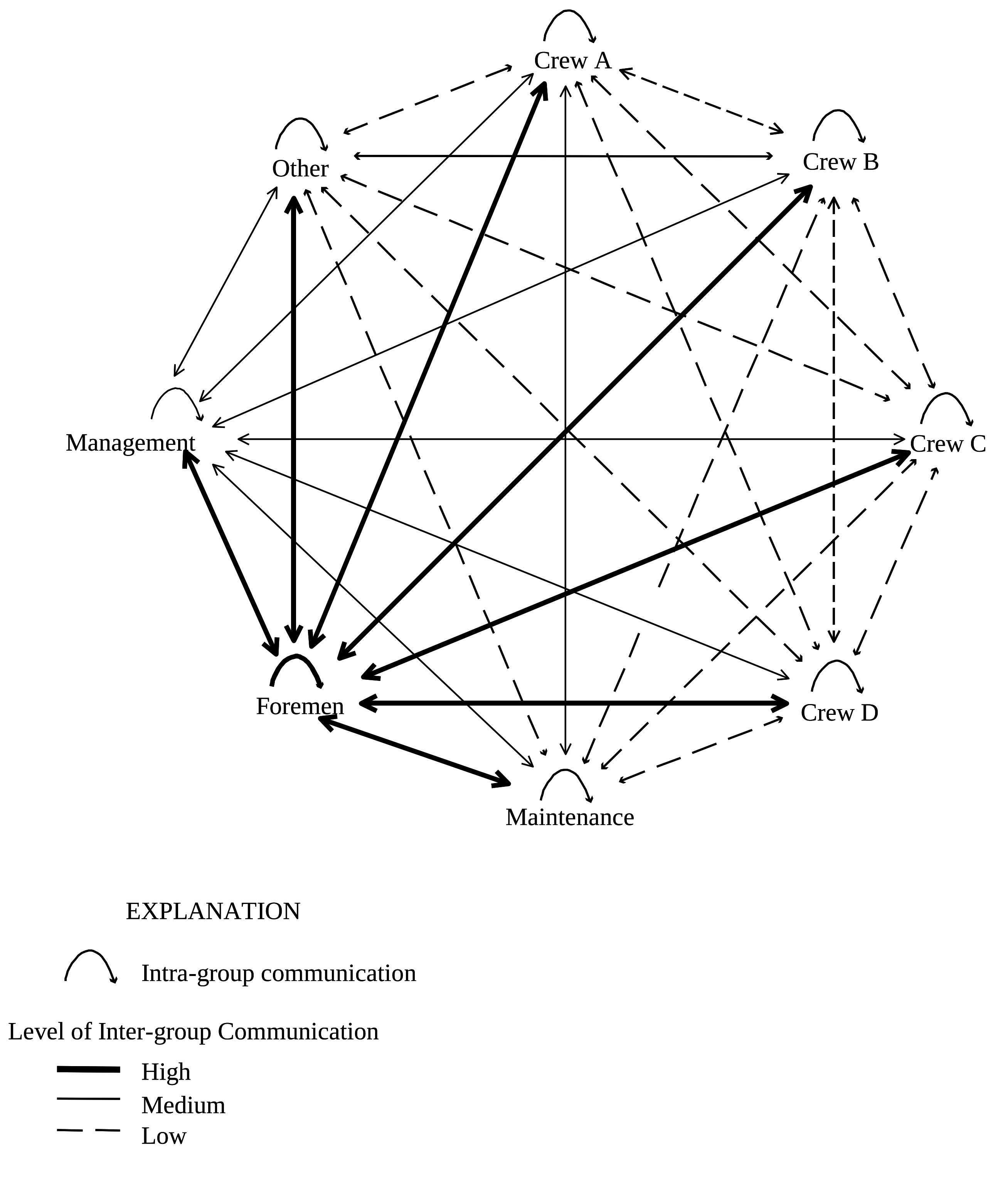


Figure 4d – Inter-group Communication Interactions for CO Line 2