SYNCHRONIZED COORDINATION LOOPS: A TYPOLOGY FOR THE ASSESSMENT OF JOINT ACTIVITY

THESIS

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ABSTRACT

Designing for effective coordination and collaboration in domains of distributed decision-making and decentralized control is a daunting challenge. In order to support such collaboration, it is necessary to look at modelling such systems from the perspective of coordination requirements by focusing on the functional relationships inherent in the joint cognitive work. Synchronized Coordination Loops are a proposed typology to assess joint activity in settings of distributed coordination to support team adaptability and control. As a typology for joint coordinated performance, Synchronized Coordination Loops present preliminary assessment capability based on four support functions of coordinated work: information flow, system observability, trust, and reciprocity. Joint coordinated activity can be analyzed in terms of these support functions across three classes of loops: horizontal collaboration within an echelon, vertical collaboration between echelons, and projective collaboration between technology bridged echelons and interpersonal platforms. These functions of coordination and classifications of loops fuse together to describe how roles, actors, and system functions can integrate to assist and enhance managed coordination in any organizational structure. Synchronized Coordination Loops have direct implications for the design and evaluation of systems to support joint coordination activity.

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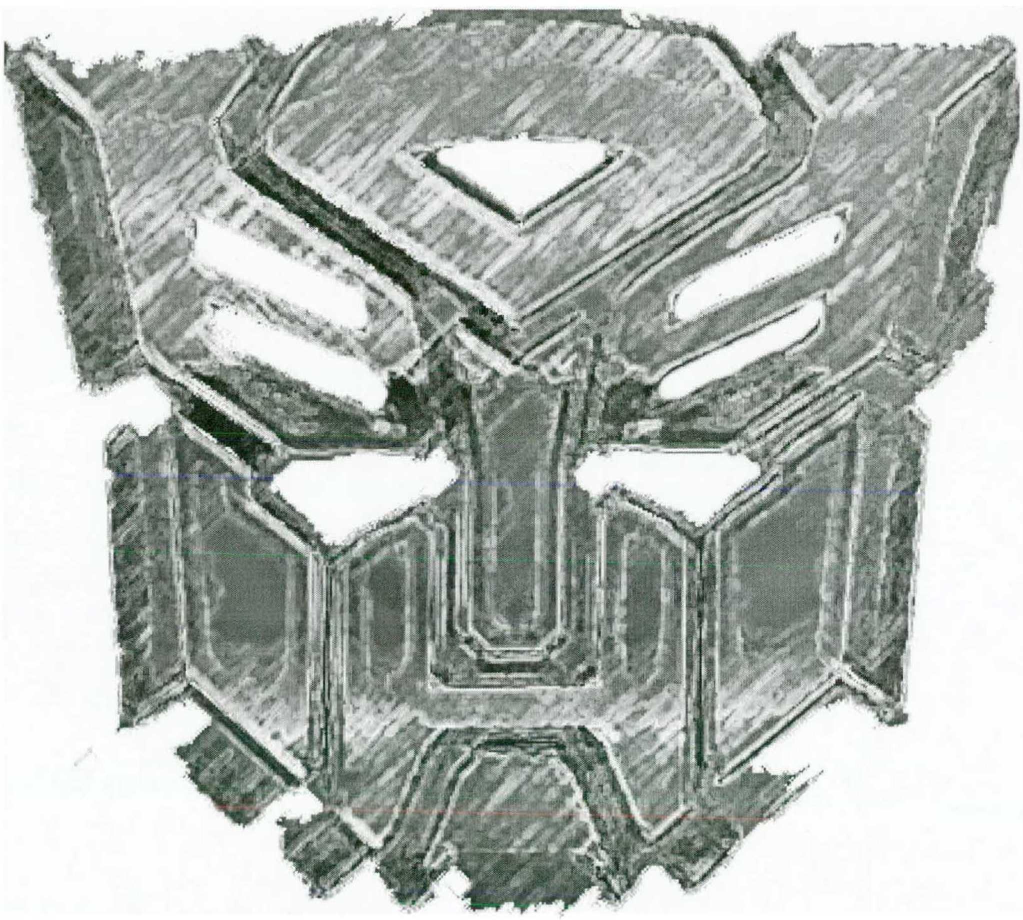

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INTRODUCTION

Synchronized Coordination Loops are a proposed typology for assessing the success of decentralized joint coordinated activity. Through identification of the dependencies working across actor boundaries, assessments of the level of coordination in the joint activity can be made. As the coordinating actors (the team) progress, adapt, or struggle to achieve their goals, they are forced to readjust their scope as events in the world create impasses or opportunities. Successful anticipation and exploitation around these impasses and opportunities relies on synchronization among the coordinated parties. Synchronized Coordination Loops (SCL) helps to identify support for the underlying requirements that must be satisfied to synchronize joint coordinated ventures. SCL support requirements are based on observations from urban fire department operations and the crisis management domain as a whole. The requirements that make joint coordinated activity synchronized, joint activity being defined simply and explicitly as multi-actor and agent work, provide promising new directions to leverage these requirements- information sharing, system observability, trust, and reciprocity - in the design of new tasks, new resources, and new organizational structures to effectively support and incorporate future net-centric operations.

To cooperate, actors both local and distributed communicate information regarding their perceived state of the world. This information influences the state of the group, preparing it for events and activities as the team follows, and modifies a plan. This information sharing is the first fundamental requirement to synchronize. Inherent in joint coordinated activities are cross dependencies influencing actors and their roles in the world. These cross dependencies are what make joint work interesting, as they highlight the fact that success in joint activity is more than each individual, each actor, doing their role. As each actor performing their role alone does not provide enough support to the higher, more over arching team goals it is evident that there is some form of collaboration, some addressing of the dependencies that reach beyond the scope of a single actor to create the need for synchronized coordination. Making these cross dependencies observable such that cooperators work together and not at cross purposes is the second fundamental requirement Synchronized Coordination Loops proposes for designing to support synchronized coordination.

Actors inherently assume their roles and training have been developed in such a way that in a "team" setting they are naturally working towards the best interest of the team by performing their routine actions, this exemplifies the third requirement: trust. When actors trust their role, and the roles of others on their team the fourth requirement for synchronizing coordination is the ability for teammates to anticipate their teammates and act accordingly – the notion of reciprocity. This anticipation hinges on knowledge of the adaptive capacity, the resources and capabilities of an actor that allows them to anticipate and respond to anomalies and opportunities in the world. Successful designs will assist in managing these possible actor role overlaps and disjoints, and the resulting adaptive capacity with the intention to balance the underlying costs of coordination relative to how roles develop as they progress along the plan towards the teams overarching goals through reciprocity.

Synchronization is used as a descriptor for the continuous mutual readjustment that must occur for joint coordinated activity to succeed. Information sharing, system observability, trust, and reciprocity form the fundamental requirements for the ability to synchronize coordination, identifying the needs in order to keep actors aware of the contingencies that affect the adaptive capacities of all those on the joint cognitive venture. Synchronization is not simply referring to a contingency plan, increased communication or connectivity, or 'proper role design', but the ability for actors distant from one another, in time, space, scope, etc., to craft a read of the situation with which to anticipate the demands on, or opportunities created by other actors you are synchronizing with. Based on the requirements for synchronized coordination, truly synchronized relationships between actors requires the foresight to alter one's scope based on how other synchronized parties are succeeding or struggling.

1.1 A Story

An anecdotal story heard while working with and observing a major metropolitan fire department provides a great example to begin to explore the nature of joint activity, and to explore the requirements for synchronized coordination first hand. Standard operating procedure for multiple companies responding to a fire dictates that the first engine ("pump") and first ladder ("truck") are to serve as first responders. The third company on the scene, be it ladder or engine, is to serve as the "fast truck" whose sole purpose for that fire is to monitor all available information channels for any emergencies which require a rescue of one of the fire fighters fighting the fire. While an extremely important role, it is also the least desired due to the intense attentional demands coupled with its "hurry up and wait" nature. It does not matter whether an engine or ladder truck is third on the scene, either can serve as this fast rescue team. Engines and ladders arriving after the fast truck has been established serve as backup, replacements for the initial responders when resources dictate they take a break from fighting the fire. It is worth noting that the fast truck does not get any backup, in all but the most extreme cases they retain that role for the entirety of the response.

In the situation that was presented, the first responders to the scene determined that the fire is in the basement of the house, and despite an access point from the front, the team decided that the back entrance and the route it provided to the basement was a better staging area for fighting the fire. Because they were the first engine on the scene, standard operating procedure dictates that they had "first rights" to the fire and any successive arrivals are to serve as the fast truck, and backup respectively. As the first engine proceeds to the basement, a second engine arrived. In this case standard procedures dictate the second engine should have served as the rescue truck, however the second engine proceeded to act as if they were the first on scene, and entered the building from the front. Like the true first responders, they deduced the fire was in the basement, and opened the front entry point, venting the fire and causing it to jump directly at the first team positioning themselves to the rear.

This story seeds both directly and indirectly identification of the requirements for not only coordinative activity, but also successful synchronization of the parties involved in such activity. The second engine arriving on the scene experienced some breakdown, whether in information flow or simple assessment of the situation it is clear they did not see the front opened which would indicate the first engine on scene was active inside the building, they did not receive word from their chief or chief's aid that they were indeed not the first on scene, did not observe chatter on the radio which would indicate a response operation already in progress, or even see the other truck already on scene, or some combination of these and/or other unknown factors. The lack of coordination between these two groups, which according to procedures *should* for all intents and purposes be working toward the same goal, results in a lack of understanding (in this case ignorance of who has initiative) that actually has the second team working at ends with the first. This is the definition of working at cross-purposes, the result of a lack of synchronization between the two respective teams. While this example will be revisited in more detail in chapter 2, it prompts the need for an initial description of the differences between the role of the firefighters who responded, and their respective chiefs.

1.2 The Sharp End & The Blunt End

In the previous story, it is clear "the ball was dropped" somewhere. Was it the individual team members' fault for not pausing or was it the chief's for not applying their authoritative power and calling them back? All complex systems have both a sharp, and a blunt end. The "sharp end" represents those actors with roles that cause them to directly touch the monitored process, who directly interact with the world working to achieve their current goal – the firefighters in this case. The "blunt end" represents those actors who are distant from the monitored process, but whose roles work to regulate and administrate the resources available to, and constraints on, the sharp end actors – the chief in this case. Connectivity between these two levels is required for coordination to have a chance to flourish. Just as communication is required between actors "in the thick of things" its required between the sharp and blunt ends as well – these channels are a requirement for any long term analysis, re-visioning, and re-planning to occur, as the resources, constraints, incentives, and demands managed by the blunt end shape the environment and influence the behavior of those actors at the sharp end (Cook 1998).

As coordination is the notion of working with others to fill the gaps necessary to exploit opportunities for success, creating pathways for reciprocity to occur allows for stronger bonds between the sharp and blunt ends, serving to keep the blunt end up to date on the processes the sharp end is working with to keep the available resources maximized, and the constraints minimized. The points of action for reciprocity are contingent and contextual - dependent on perspectives, perspectives that vary based on sharp/blunt location. Just as roles provide such necessary contingent contextual information, Synchronized Coordination Loops (SCLs) are proposed as a typology to identify and capitalize on it to empower the cross adaptations each actor implicitly makes by sharing this fundamental information explicitly with others "on the loop". The underlying methodology for SCLs includes contrasting the narrow (expert) view at the sharp end, a perspective focused on the work, with the (ideally) more global perspective of the blunt end to manage the requirements for synchronized coordinated activity. As goals are better supported by such role overlap, supporting the adaptive capacity and reciprocity cycle creates common resource pools for specialized roles to share while retaining unique capabilities, resources, and expertise. The resulting increased level of interpredictability and increased ability to notice timely anticipatory cues supports smooth coordination, creating a robust form of collaboration within a distributed system of mixed roles.

1.3 Requirements for Synchronized Coordinated Activity

Group formation is the initial step for any coordinated work, when a group begins to form individual actors each decide that it is more beneficial to work together as a cohesive unit. This catalyst for team formation has a few fundamental requirements to make the jump from a series of individuals to a team. Primarily, each member of the team needs to value the beliefs, goals, and intentions of the team above their own individual desires. This ensures a commitment to the team, which is another fundamental requirement to truly mesh as a group of aggregate actors. The acceptance that beliefs and goals will persist over time is also required, formulating the ability for the aggregation to share intentions and enabling the emergence of joint actions. This ability for joint intention and joint commitment is the glue that binds a team together (Cohen, 1991). Cohen and Levesque identify this important first step for successful joint activity, expecting actors to first form these future-directed joint intentions, and then continuing to act and cooperate over time by retaining those joint intentions. Where things get interesting is when new, unexpected, opportunities for cooperative interaction arise. Actors can commit to another actor's actions and persistent goals, this critical notion will be expanded upon later, but even at a first glance the ramifications for teamwork and cooperation are evident.

The essence of joint activity is mutual action. Information needs to be mutually accessible to all actors on the team, ranging from the state of the world to progress and status of the goals shared by the team. If an actor comes to believe that a goal is impossible it is imperative they communicate this with the rest of the team. Actors who deem a goal impossible naturally give up the goal and move on, which can become troublesome for the team as a whole if the team does not collectively give up and move on as well. Joint activity has inherent implications for the individual commitments that must be made relative to the other actors on the team. These commitments require the belief that each actor's actions are part of and depend on the group's effort as a whole (Cohen, 1991) and as such, it is the collection of these commitments to successful team work that formulate the basis for any analysis of coordinated activity.

The importance of these cross commitments that form the dynamic dependencies in joint activity was identified briefly in the anecdotal story, but in order to flesh out what it means to be synchronized there must first be a definition of coordinated activity. Fundamentally, Synchronized Coordination Loops serve as an assessment of joint activity based on four aspects of coordination and collaboration: information sharing, system observability, trust, and reciprocity. Synchronized Coordination Loops focus on these support requirements for managing coordination with intent to be better able to adapt and transition across different forms of adaptive capacity. Just as coordination in the interaction between multiple collaborating parties, any proper support for modeling or designing for coordination needs to focus on not only the requirements for coordination to occur, but the interactions between those requirements that keep the coordinated activity going. Based on observations and analysis of previous work Synchronized Coordination Loops are based on the interplay of the four specific support requirements for coordination.

1.3.1 Information Flow

Information flow serves as the backbone for coordinated activity in any context. Actors must transition and balance both strategic and tactical perspectives while up against the inherent time-sensitivities in a dynamic and changing world, supporting assured and trusted data flow is of critical importance. Organizational approaches seen in hierarchical organizations, such as military and information analysis domains, often address this need by either forming new ways or resorting to work-arounds in order to integrate existing "stovepipes" of information that were previously unconnected. These connections and couplings across information channels need to occur at every possible level - not just at the beginning or end of the process - otherwise is simply changing the orientation of the stove-pipes, rather than bridging the pre-existing gaps. Proper information flow fundamentally supports controlled information exchange opportunities at every practical level, such that communication reaches an optimal "sweet spot" between the two of extremes where either no single entity is sharing anything or where information availability is not equal to all parties involved. To do this system designers must capitalize on artifacts created doing normal work that others can use to help construct and re-conceptualize the global picture in order to achieve a coherent perspective of the world. These artifacts can be funneled back downstream to influence information collection or funneled upstream for dispersion across actors and other potential organizations to serve as a catalyst for reciprocity.

In a series of micro-world experiments Dickson, McLennan and Omodei found that procedural verbalization, that is when local actors verbalize the bases of their decisions and decision-making process, perform their tasks significantly worse (on average) then actors who do not (Dickson, 2000). They proposed that such performance degradation is a result from decision actions being delayed by the verbalization; systematic shifts in focal attention to more readily verbalizable yet less performance relative features of the task; and attentional resources being withdrawn from real-time task performance in order to generate verbal explanation of the bases for their decisions (Dickson, 2000). With the current infusion of technology into the emergency response domain it is a daunting task to keep everyone up to date on not only what goals local actors are currently working towards, but also how they are achieving those goals. This research is just one piece highlighting the importance of supporting the ability for this update information to be shared passively along horizontal and vertical loops. Additionally it is important to remember that as advances in communications technology make it easier for remote supervisors to project themselves into the local scene it does not mean there needs to be continuous contact between local actor and projected supervisor. Dickson et al. use the example of an emergency power plant shutdown, but the point remains true for any emergency in every domain – when local actors, who are trying to respond to the emergency, are continuously interrogated on the basis for their decisions they are at risk for performance degradation due to the greater attentional demands implied by the requirement to verbalize all of their thoughts and actions. The interplay between information flow and trust comes to the forefront in this example, due to the level of trust required for a distant stakeholder to "shut up and let a local actor [me] work". The benefits for supporting the ability for local actors to passively push relevant information such as progress, mental strain, and overload to other members on all loops to prevent the need for this concurrent procedural verbalization, and the risks of performance degradation that come with it.

To support synchronization, the ability to anticipate and mutually readjust based on changes in the world; information flow must be more than simply a given radio frequency that is shared among all actors who need to participate in joint activity. There are essentially three kinds of information sharing that require support: active, passive, and directed. Active information sharing encompasses the typical channels of communication, speaking over a radio and hoping whoever needs the message is listening. In the previous story, an example of active information sharing would have been if the second engine had asked if anyone else was on scene when they arrived, they would have been actively trying to information share, whether or not anyone was listening would be a matter of passive information sharing. Passive information sharing, touched on slightly thus far and in more detail in chapter 5, includes collecting information to read and make judgment calls about the situation. In the previous story an example of passive information exchange would have been if the second engine to arrive had noticed the other engine already on the scene and used this to question entering the building from the front. Direct information sharing is just what one would think, conversations and information being directly passed along to the necessary parties, examples in the story have would have been dispatch sending a direct communication to the second engine letting them know another engine had already arrived on the scene.

1.3.2 System Observability

Just as actors can passively push information, they need to be able to pull information as well. Observability has been defined by Woods (2006) as the ability to infer the details of a process through feedback from both the work domain and the independent agents and actors "behind the scenes". Increasing actors' awareness of the flow of information, to "walk" on the bridges formed by positive information flow, increases insight into the cognitive load of other involved actors both horizontally and vertically – it not only tells actors what they can and can not pull, but also what and where they should push information. For example, in the intelligence analysis domain observability of collection assets as well as other analyst teams assists analysts with "putting the pieces of the puzzle together", resulting in new collaborative opportunities for analysts to add additional information and potentially multiple contexts to a problem another analyst is working on. The signal to noise ratio in information operations is extremely high – most often all of the information analysts have is "good information". While analysts may already have access to the information they need, they just do not know it. Observability is the bridge across information spaces such that analysts can combine their respective pieces of the puzzle along with supporting the foresight to realize they have pieces to contribute.

Observability into a process of system creates opportunities for actors to develop and maintain common ground. This forms the fundamental framework for trust and reciprocal bonds – without the ability to observe the cognitive load of others on a team one cannot accurately and effectively assist teammates in their goal space. When system observability and reciprocity are considered, and equally prioritized in the design process designs can capitalize on this cognitive load information to help transition “right place at the right time” events from a seemingly lucky happenstance occurrence to more of a reliable event. Actors within a team will be able to more accurately anticipate the needs of each other, and be able to provide support before support is even requested (or known it is even needed), which naturally helps to build trust within coordinated groups.

1.3.3 Trust

Trust in any environment is critical, and even more so when dealing with distributed work systems. While collaborative bonds can tentatively form without trust, for any form of long lasting collaboration to succeed trust must be established within all levels and between all echelons (when hierarchies exist) in a system. If there are doubts as to how information is shared, used, or protected when dealing with systems where information needs to be synthesized across multiple echelons and from many different potentially relevant sources, the chance of defections occurring is high and thus collaborative activities will not succeed. It is one of the fundamental requirements for common ground, let alone collaboration, that collaborators deem each other competent. If collaborators do not trust that their group mates can handle the tasks ahead then they have already stopped collaborating and have headed down the path to defection.

In order to capitalize on the benefits of a large collaborative system it is imperative to preserve the inherent unique perspectives and capabilities enabled by diversity of the system. Successful collaborative activity achieves goals that could not be accomplished by a single perspective. The additional perspectives afforded by a 'team' must be preserved which opens up new opportunities for accruing acute knowledge. When trust is high, this knowledge is not exclusively of the world around the team, but includes the space inside it – that is, knowledge of the cognitive load of those working within and around. This 'internal awareness' resulting from increased observability serves to strengthen bonds and increase opportunities for information sharing, and in the process of evolving these rapports the possibilities for reciprocation develop.

1.3.4 Reciprocity

Social motivation and social orientation research have found that people have a predisposition toward cooperating when it is evident coordination is going to be a long-term event. Long-term coordination opportunities appear worth investing in based on individual self-interest due to the ability to maximize work on those interests. In a Prisoner's Dilemma task where trust, and sense of control were independent variables used to judge the rationale behind the desire to coordinate Ostrom et al. (2003) found that people inherently "have a belief that mutual cooperation is generally a gainful strategy for all parties; and thus participants cooperate insofar as they think their partner will do so as well."(Ostrom, 2003) This immediately brings the importance of persisting coordination to the forefront. Coordination that exists in the long-term creates more opportunities for partners to "cooperate" with each other and reciprocate those opportunities – this ability to anticipate reciprocity results in a greater vested interest in maintaining coordinative bonds, and as such, creates the opportunities for coordinative synchronization, which will be covered shortly.

Long-term coordination based on the common ingredients seen in social dilemmas, such as the Prisoner's Dilemma, imply benefits resulting from keeping one's promises and performing actions with short term individual costs but long term benefits net benefits for the group. These behaviors, that is being a 'promise keeper' or 'team player', result in a new status within the team dynamic – that of being 'trustworthy'. Individuals achieving this 'trustworthy' status are a requirement for reciprocation-based coordination. In order to succeed, team members must know that positive actions will be rewarded, and that negative actions and defections will be punished accordingly. In an evolutionary context, actors with reputations for being trustworthy increase the fitness of reciprocity in a team environment, pushing reciprocation toward 'the norm' in terms of acceptable action (Ostrom, 2003).

It is not enough for actors to be 'trustworthy' unfortunately. For successful joint coordinated activity to blossom, other actors in the team need to be able to anticipate and judge who will be 'trustworthy', this needs to be *observable* (further example of the interplay between requirements). Ostrom presents 'trustworthy' judgments as a reaction to observed actions of an actor on a team – it is specifically not used to predict an actor's appropriateness on a team desiring successful coordination. While there is merit in using the label as a reward to distinguish people to team with in the future opportunities, success in *time critical* ventures demands that joint activity succeeds efficiently on the first attempt if it shall succeed at all. As such, a fundamental requirement for such successful joint activity is supporting the interpredictability and observability of participants' attitudes and actions to catalyze reciprocity (Klein, 2000). Anticipation is the cornerstone of successful joint ventures, and to anticipate there must be a level of understanding.

Initially developed by Clark and Brennan, Common Ground is such a functional state of understanding between team members. Common Ground has been further developed by Klein et al. (2000) in the context of multi-agent joint collaborative work to include this level of anticipation and interpredictability through "the pertinent knowledge, beliefs and assumptions that are shared among the involved parties". Inherent in this ability to predict and respond to the actions of other local actors is the assumption that they have formed a mutual 'Basic Compact'; an unspoken agreement that all involved parties will work to facilitate coordination and prevent possible breakdowns. More often than not there is a temporal dependency in this compact, where actors will strive to maintain common ground only while a perceived common goal exists. As individual perceptions may vary across teams of actors they may begin to defect from the coordinated group. As an example, if two people are heatedly arguing across a room it does not necessarily mean that either individual has defected and broken the Basic Compact. As long as there is still mutual goal alignment between the individuals involved they can still be committed to the Basic Compact, and thusly jointly pursuing high-level long-term goals despite possible short-term surface disagreements. It is extremely important to note that common ground is a continual process with constant work and coordination demands necessary to achieve mutual understanding and to share pertinent knowledge and beliefs. This allows actors to work independently while retaining the ability to not only anticipate and react to changes, but to repair faulty decisions and assumptions when detected.

Maintaining common ground is dependent on the notion of a 'basic compact.' The compact is essentially the tacit agreement "if you sacrifice a bit and I sacrifice a bit" then together there will be goal-space alignment. Reciprocity in Synchronized Coordination Loops uses this overlap between actors that would initially spawn common ground, but without either having to sacrifice part of their goal-space. Reciprocity develops through trust and observability, and is perpetuated through the natural inertia reciprocation garners in cooperative groups. Once trust is established and the reciprocity engine is rolling, actions based on an understanding of the scope of other involved actors on the team allows for actors to adopt exocentric goals, which are still supported and accepted as possible by the other actors on the loop. This persistent coordination fusion allows for situations where an actor is able to receive assistance to achieve their individual goal despite it being outside the goal space of the team - with the intention to return the "favor" and act outside their immediate interest to help achieve another goal at some other juncture. By putting function and flow at the forefront of the coordinated activity rather than immediate gratification of one actor's own goals, synchronized activity centers on mutually adapting and reciprocating to achieve multiple goals more efficiently, rather than on temporary ad-hoc formations to achieve a singular goal.

The cross dependencies evident in coordinative functions mandates synchronizing actors to respond to them. As demands in the world are dynamic, changing to reflect the perturbations, any consideration for analysis, planning or for design of joint coordinative systems must be dynamic as well, requiring synchronization between actors. Urban firefighting crisis management needs this level of, and exemplifies the need for, synchronized coordination. The story indicates a very first glimpse at the cross dependencies in the work: engines/chiefs/individual actors needing to communicate actively, passively, and directly with each other at any given time during a response, which creates need for cross dependencies joint activity. To avoid breakdowns it is clear there needs to be synchronization, which is dependent on the requirements previously identified, and to support these dependencies requires functional insight into the domain's goals and scopes, as presented in chapter 5. The basis for the Synchronized Coordination Loops is having observed people attempt to do synchronized joint activity, particularly in urban firefighting, coupled with a functional abstraction network created for the urban firefighting domain. Synchronized Coordination Loops are presented to help people understand why coordination is difficult through establishment of the requirements that must be met in order to synchronize to achieve successful joint coordinative activity in dynamic situations.

CHAPTER 2

SYNCHRONIZED COORDINATION LOOP TYPOLOGY

While each characterization of Synchronized Coordination Loops will be discussed in depth in this chapter, some initial context can be garnered from reviewing the anecdotal story introduced in the first chapter. A brief introduction to the three classes of loops is as follows: horizontal loops contain actors in the same echelon, sharing the same, or similar, goals; vertical loops are loops crossing immediate echelon boundaries, usually containing roles of authority; finally, projective loops cross enable an actor to retain the benefits and perspective inherent in their horizontal and/or vertical loops, yet participate in other distant loops. Distant in this sense is not limited to geographic location or the temporal dimension, but includes being distant in scope, role, and/or goals. Projective loops project an actor's perspective where it normally would or could not reach, enabling a greater opportunity for reciprocity.

In the introductory story, each engine has their own horizontal loop – each team of firefighters represents a unique horizontal loop during the fire response. While this horizontal loop is emergent from living, working, and training together, it is not the only horizontal loop found in the response. Each team's unique horizontal loop is actually nested within a larger horizontal loop, containing all of the engines and ladders responding to this incident. Each chief and their respective engine team represent the vertical loops in this example, as the chief holds a broader scope for the response and an increased level of decision making authority not present in the horizontal loops. So revisiting the introductory story, there are two horizontal loops present (one for each engine that responded), a third horizontal loop that links both unique horizontal loops together, and a fourth horizontal loop existing between the two chiefs on the scene. The breakdown in communication that resulted in the second engine loop entering from the house could have been for a plethora of reasons. There could have been a breakdown in information sharing between the local chiefs, or between the first team on the scene and the arriving second, both cases representing a breakdown in horizontal loops. There could have been a breakdown between the second chief determining that his engine was to take the rescue role and communicating that to his team, representing a breakdown in the vertical loop.

2.1 Synchronized Coordination: The Flavor of Loops

Specifically, Synchronized Coordination Loops (SCL) is an initial typology of joint activity developed to include fundamental coordination support functions. This preliminary framework focuses on the interactions between the factors and actors that jumpstart coordination in order to achieve the necessary levels of coordination with the necessary and available actors more effectively than simply providing communications. Synchronized Coordination Loops expand upon previous measures and constructs that allow specification of the requirements of distributed work. The work has identified three initial loop classifications based on communication within teams of actors (horizontal loops), communication across levels of control (vertical loops) and the ability to incorporate new technology into the scene to assist perception and action capabilities (projective loops), addressing the ever-changing nature of coordinated activities.

The three classes of coordinative patterns provide constructs that allow us to specify requirements of distributed work and systematically characterize many different complex systems in which to test effective coordination and collaboration. Each coordination loop is a collection of groups formed in anticipation or in reaction to an event or series of events. These events are domain driven and can range anywhere from simple information gathering to coping with unexpected surprises in the field. By quickly describing and defining the loops here, we capture the dynamics that constitute skill across a variety of coordinative capabilities. Capturing the dynamic nature of the cross dependencies is required to support synchronization, and the nature of the three classes as presented indicates how they work together to keep pace with escalations and cascading events.

Fundamental to the description of joint coordinated activity in terms of Synchronized Coordination Loops is the notion of an echelon. While it is difficult to define what is an echelon without falling into traditional hierarchical command and authority descriptions, the definition on which the Synchronized Coordination Loop typology is based on is: echelons have a scope/field of view used to shape the decision making process with which actors use to act in the world. Just as the differences between transitioning from sharp to blunt end include a reevaluation of priority and goal scope, moving higher across echelons provides a broader scope for an actor's goals and level of authority. As such, echelons and thus Synchronized Coordination Loops can nest within themselves, creating situations where, as previously discussed, a broader horizontal loop can contain several smaller horizontal loops.

2.2 Horizontal Loops

Specifically, horizontal loops are defined as relationships between actors existing on parallel echelons on the joint activity. Horizontal loops share the same authority and similar scopes, roles, and functional goals in a theater of mixed operations. Coordination is defined on a horizontal loop by the groups (be they mixed, practice-oriented or adhoc, homogenous or heterogeneous) that work together within a similar scope and scale. Horizontal loops can cover the interactions between actors both within and across group boundaries, which results in nesting as horizontal loops cover the varying goal scopes in the scene. Working on these loops, teams can form groups, shift and reform coordinative relationships (such as search and rescue personnel, robots and unmanned vehicles entering into an area of interest) to identify threats, discover injured parties, and move survivors to decontamination or aid stations. For example, if a group is conducting a robot operation for IED (improvised explosive device) disposal, emphasis is placed on the disposal task. As the scope and focus of secondary and tertiary tasks shift, there may be a goal adjustment that leverages a new functional demand for securing the safety of the robot operator. One can have separate horizontal loop structures carrying out independent work in any operation (i.e. law enforcement and fire personnel rarely work together on the individual level, despite working together as organizations) but our goal is to move beyond simply the teams that work together in order to describe coordination writ large and be inclusive of roles and functions that are not always acknowledged in analysis, planning, and training (such as victims in an emergency that can adapt, have communications, and will act of their own volition).

2.3 Vertical Loops

Vertical loops are relationships supporting coordination connections and changes that act across echelons. While most simply this is a communication or modification of plans across levels, the overarching functional goal of vertical loops is to provide a more blunt end perspective, enabling a more efficient and effective reframing/vision perspective on the state of both the world, and the plan the horizontal loops are working to enact. Speaking in terms of echelons to describe the vertical component implies formal hierarchies, however, many systems are relatively informal and do not have such rigid hierarchies. Search and rescue is often quite informal in terms of authority and yet contains vertical loops. Different domains have adopted and utilize different command systems (i.e. Incident Command System, Command and Control) that attempt to be flexible enough to adapt to changing situations. For this reason we have defined vertical loops in terms of changes in levels as descriptors acknowledging that in any of these systems there may not be sharp delineations, and levels may always be either partial or local as they dynamically change to keep pace with the events in the world.

While vertical loops are not explicitly "command" loops, typical chain of command hierarchies are the easiest, and most prevalent, example of the cross echelon perspective taking that makes up the essence of vertical loops. An interesting example of the interplay and nesting that can occur between horizontal and vertical loops can be seen during rescue operations, when rescuers come across groups of self-sufficient victims. A group of victims who have come together to both find and rescue other possible victims, and to extricate themselves from the situation will likely interact with rescuers on a more horizontal level, exchanging information and possibly assisting in parts of the rescue, in spite of the vertical level of authority textbook procedures would indicate for how rescuers should handle victims.

2.4 Projective Loops

Keeping in terms of echelons, projective loops are relationships providing an envisioning of the perspective/scope of a specific echelon without actually forcing an actor onto that echelon. This makes projective loops interesting because it enables the management of both local and distant roles in various echelons; managing generalist role with the insight of a specialist's perspective or introducing blunt end more directly into the sharp. Advances in communications and robotic technologies allow distant parties to project themselves and their roles into distant scenes through the sensing and action capabilities of remote automated systems (Woods, 2004). While projective loops existed previous to this technological bloom, the new implications and resources provided by technology are what have driven the need to explore projective loops. Robotic resources that allow for people out of scene to utilize technology in theater to project their intent back into the scene is just one such example of the increase in projective loops. Imagine a robot as part of a disaster response rescue team. There is a critical need for medical care but it is normal procedure that doctors are not allowed in the hot zone. We can envision using the robotic platform while coordinating horizontally with rescue personnel to also serve as a surrogate where distant medical parties can project through sensors on the robot to have a virtual presence in the hot zone. Instead of waiting for reports from the field or for victims to start arriving, medical expertise can now be projected ahead to start the assessment processes, make triage decisions, and evaluate needs before people start moving out. Projective loops provide the capacity to move the decision making into the area of interest, in this case the hot zone. Instead of waiting for the need to meet the resources, these systems have the potential to project the resources to the need. In any functionally coupled system, one needs to first project to figure out what the need is with this scope one then needs to figure out how and when to take the needs to the resource.

It is important to note that projective loops are not limited to the incorporation of new technology to project distant actors into the local scene. The distant-local projection is in terms of information gathering, and while it can take the form of cameras unmanned semi-autonomous vehicle, human interpersonal interactions can also be projective loops, which can lead to instanced where loops can be projective *and* either horizontal or vertical. Take interactions between the media and the police department for example. A press release made by the police to the media would constitute communications across the horizontal loop on the agency level, but if a reporter has a relationship with an officer they may be able to garner more specific information than was included in the press release. That specific exchange and the insight it garnered would be considered a projective loop. A military commander issuing orders to a squad is a vertical loop; the same commander sharing the details of those orders with another commander would be a horizontal loop. If orders were issued via a UAV the loop could be considered projective. An interesting twist though, is when the commander shares the details with another commander who is actually a spy for the opposition – the commander thinks he is sharing across a horizontal loop, while the loop would be projective from the spy's position. This twist also identifies the varying degree to which loops can be nested within each other. It is quite common, and even likely, for horizontal loops to exist nested within other horizontal loops due to the fact that individuals who share one scope along an echelon are likely to share others. Vertical loops are less likely to be nested, as that would require an individual's authority and perspective to be narrowed across the echelon they are crossing, and projective loops have the least amount of nesting, although cases of using technology to use technology to project into the desired scene are sure to exist.

2.5 Completing the Loop

The important caveat is, while the classifications of loops are more concrete, their application is flexible and dependent on perspective. This means there is an inherent danger in the use of projective loops, namely the pitfall of getting stuck/fixated in a lower echelon. This entails not only losing the benefits of unstable environment. The simple fact that the "amount" of information that can be absorbed, used or otherwise processed, varies according to expertise (relative to the situation), the manner in which it is presented, and the competing demands of the given situation. This variation in the capacity for actors to absorb and adapt information as the environment changes and connectivity is fluctuating creates a fundamental need for the ability for actors to support each other in the decision-making process, rather than solely relying on information to trickle down through possibly unreliable channels. A synchronization focus is vitally important to provide support for these impromptu joint decision making situations that arise from the dynamic nature of the work by allowing the propagation of information despite disturbances in connectivity – being on a synchronized loop means that just because connectivity is down does not mean communication and action need to halt. The benefits lie in the overlap of knowledge that is available when knowledge is shared in synchrony- presenting actors with the ability to step away from their perspective and see how the same, or related, information was interpreted by the other perspectives on the loop. Synchronized Coordination Loops address this important facet with reciprocity, where other actors on the loop have the ability to act (in this case push information) based on their knowledge of the perspective of others in the team, without having to abandon or even step out of their own perspective.

In the spirit of Rasmussen (1994), SCLs are prototype event-sensitive descriptions based on abstraction into functional relationships of joint activity. They provide categorization from which to look at and describe agent (actor), artifact, and event interaction in an environment based on functional analysis (M. Voshell, personal communication, May 28, 2008). The reflections on observations that fused to form the notion of Synchronized Coordination Loops highlight the importance of providing support by helping actors capitalize on the experience that culminates as teams achieve a goal. Synchronized Coordination Loops identify this need to assist teams in bringing that experience with them as they move on to the next goal, the next task, the next response.

This temporal dimension and future orientation distinguishes Synchronized Coordination Loops from artifacts such as Voice Loops and organizational strategies such as Hastily Formed Networks. Voice Loops and Hastily Formed Networks are used/created in response to anomaly, whereas Synchronized Coordination Loops are future oriented, seeking to anticipate what the next coordinative demands will be. Going beyond the simple limitations of connectivity, loops foster coordinative support through interpersonal relationships and increased judgment capabilities of the cognitive load and adaptive capacity of present, and almost more importantly, future teammates. This top-down management of coordination, the ability to gauge whether a new actor should join an existing loop not based on current goals, but in anticipation of future impasses or opportunities for exploitation, is lacking in hastily formed networks. While this level of "experience capture" and application is existent in Voice Loops, it is more an emergent property than one of the initial goals for the support system. With appropriate knowledge and experience an actor can apply anticipate which Voice Loop to listen or speak on at a given time to more efficiently achieve their goals, but this experience and knowledge is not readily available to new participants on a loop. This forces a "catch up" period before said actor is really synchronized with the rest of the loop, and clearly distinguishes experts from novices within the system. The predictive power inherent in Synchronized Coordination Loops bridges this experience gap through support based on knowledge of the functional goals of the system. Synchronizing in such a fashion helps novice actors be at the "right place at the right time" similar to their expert counterparts.

CHAPTER 3

TECHNICAL CONSIDERATIONS FOR SUCCESSFUL COORDINATION

A basic failure seen in joint coordinated activity is the inability to properly revise a plan. The problems with a mindset in which an actor or group of actors continues doing what they are currently doing despite the fact that the world has changed are only compounded when actors need to anticipate the needs and decisions of the others they are jointly coupled with. Fragmentation is the variation on this basic failure that results from the inability to take into account the actions and decisions of those with whom an actor is supposed to be coordinating. Fragmentation is the notion that an actor will keep doing what makes sense to them without taking into account what is happening to the other existing coordinating actors as all work toward achieving the same goal(s). An actor can act rationally for their perceived situation, but their mental model of the world is skewed or incomplete, and as such actually results in said actor working at ends with other actors they think they are coordinating with effectively. When scope is limited in such a way, it is easy for each actor to work to achieve their immediate goal(s) rather than the long term goal(s) shared by the team without even knowing they are at ends with their team. The first step in designing to prevent this coordination breakdown is assisting actors with seeing beyond their current sub function, either directly on their horizontal loop or through assistance along vertical and projective loops. Assessing the success of this aid relies on identifying the actor-role coupling, and using this knowledge to boost the level of adaptive capacity among joint coordinated actors.

3.1 The Importance of Actor-Role Coupling

The first step toward increasing an actor's understanding of the others on their loop is to facilitate understanding of the ways their respective roles interact. It is no longer enough to end support for coordination at the "enable" stage of setting up joint activity. It is clear there are significant challenges that extend to building effective support systems, as well as analyzing and assessing the success of them. As coordinated activity evolves, future designs will need to consider more than the individual actors or their roles. Designs need to go a further step and support the fusion of the two. The level of coordination between actors, their common dependencies and opportunities to adapt, and their functional roles in a system are equally important and successful designs will need to support this coupling.

Figure 3.1 describes these possible individual actor and role couplings and how they may manifest in the world. Going from the upper left and working down to the right: the first coupling in the upper left shows how actors can be tasked to roles they are not optimally suited to, and if they are not synchronized with the other actors they are functionally supposed to breakdowns and failures are likely to occur. When actors are not suited to their current role, but are synchronized and coordinating (the second coupling image) with their teammates the burden of not being functionally optimal is diffused throughout the team and the benefits of coordination allows the team to succeed. The most common coupling is the third image, when actors are suited to their tasked role, but not synchronized or coordinating. In this image, both actors could be optimal for their roles, but the first actor (represented by the triangle) is not "snug" in his role, and as such is susceptible to breakdowns and failure. Due to the lack of synchronization between the two actors, the second actor, the hexagon, has minimal knowledge of the state of the first actor and is unable to anticipate when the first actor will require help (assuming the first actor even recognizes they need such assistance). When actors are suited to their roles and synchronized in their coordination there is still a high likelihood for achieving the desired goals even if one of the actors is not completely on the correct path to achieving said goals (the fourth coupling). In this case, synchronization makes success likely due to the ability for the second actor to anticipate the first actor's need for assistance and provide help before the first actor even needs to ask. Finally the fifth coupling on the bottom right represents the ideal case, where actors are not only suited for their roles but also coordinating and synchronizing with each other.

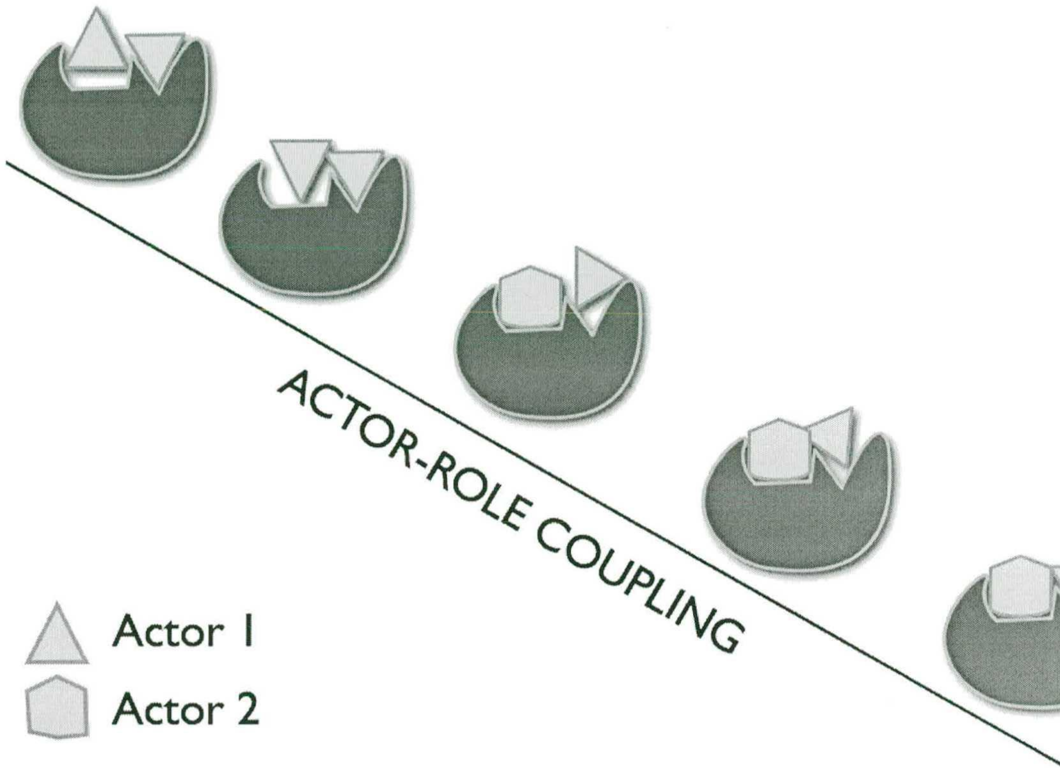

Figure 3.1: A representation of the possible coupling between actors and between the roles they are tasked with filling. The shapes represent individual actors on a larger team, while the gray "base" in which they are trying to fit represents the possible roles. How tightly an actor can couple with their specific role is based on their "shape" (capabilities), and the "hole" (requirements) of the role they are trying to match. How tightly an actor is coupled with their role, and what help other actors can provide is determined by their respective adaptive capacity.

Designing for successful coordination is more than ensuring a specific level of synchronization; it is having the ability having the ability to judge the adaptive capacity of those in your group, horizontally and vertically, and using that information to feed reciprocity. Anticipating when someone on your team will require assistance and being able to act appropriately to keep them stable in the face of disrupting events is a more accurate measure of successful coordination than a numerical measure of synchronization. The ability to judge the cognitive load of your teammates, and use this to evenly distribute tasks is another example of maintaining a resilient joint coordinated system. Supporting such knowledge sharing and providing opportunities for one actor to assist another, before the other is in so much trouble that they need to allocate resources asking for help, or even worse, don't recognize that they are in trouble at all, is the next step to supporting local and distributed joint cognitive activity.

3.2 Evolution of Coordination

With multiple actors linking together, each trying to anticipate the needs and goals of one another, it is tempting to reduce the description of such a system to terms of supervisory control processes. While supervisory control processes are inherent in domains of managed coordination such as military command and control and emergency incident command, these are but two specific examples of the broader mechanisms at play. On a more global scale, overcoming the costs of coordination is parallel to how enzymes catalyze work in organic systems.

Enzymes in organic systems do not make the impossible possible; they make already existing processes more efficient. By reducing the activation for a biological process enzymes dramatically increase the rate at which those processes can occur, and that should be the goal for successfully designing to support coordinated activity. Synchronized Coordination Loops were developed to highlight the aspects of coordination that require support in order to more efficiently overcome the costs of coordination. As described in Figure 3.2, the next step in improving coordinated activity lies in the ability to support for rapidly, and efficiently, creating coordinative bonds.

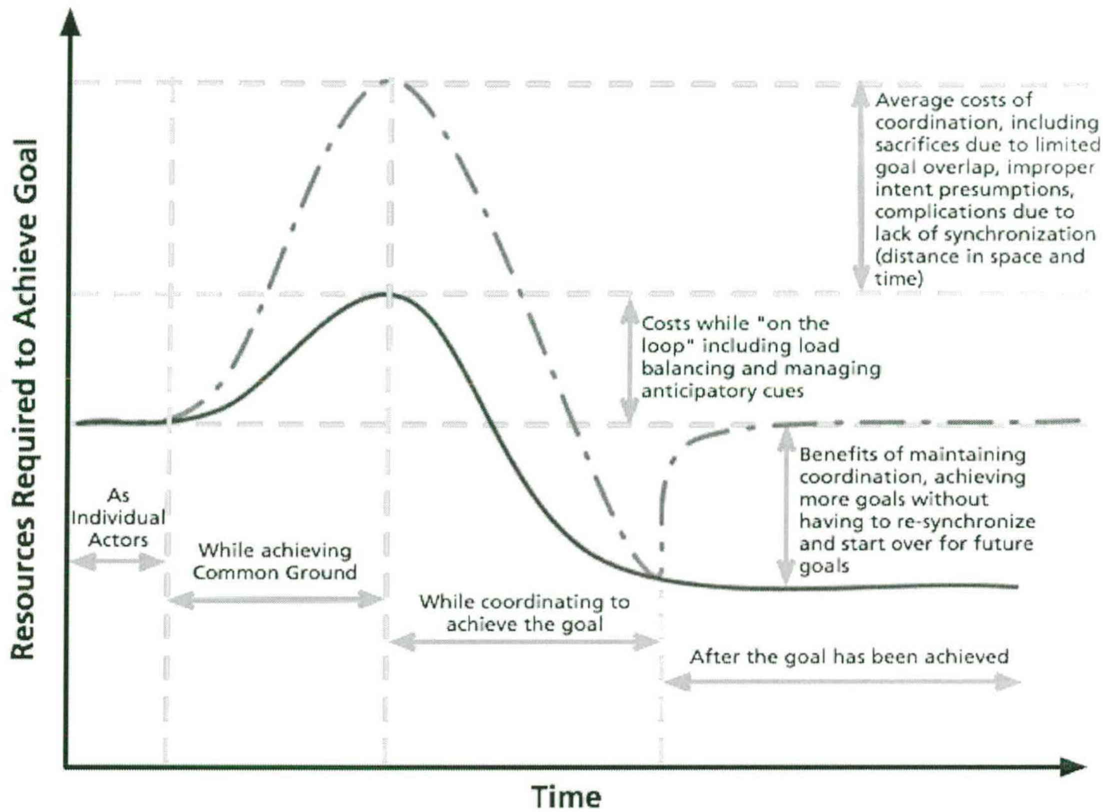

Figure 3.2: A descriptive representation of the differences between ad-hoc one time coordinative efforts, and the benefits of striving to maintain coordinative bonds through Synchronized Coordination Loop theory. The (red) dotted line represents ad-hoc or single-goal coordinative efforts, while the (blue) solid line represents coordination based on any of the Synchronized Coordination Loops.

3.3 Adaptive Capacity

Once a team has formed, and it is evident the group will persist, how the actions of the team come together forms the next stage of judging whether or not a group is successfully coordinating. The ability to measure the level of interactions between members of the team differentiates successful coordination from simply having a large pool of friends and contacts that have been acquired and maintained over time. While loops support and encourage the formation of such a resource pool from successful collaborative ventures, the distinction between such "hibernating" coordination and active coordinating parties needs to be made. A group's adaptive capacity is a measurement on which to base such distinctions. Our notion of adaptive capacity stems from the Woods definition of being able to anticipate change and adapt while being grounded in resilience (Woods, 2006).

An experienced team, in terms of working together, is more readily aware of its cognitive load and as such, is better able to manage adaptive capacities of all members of the team to retain all the benefits of a small group while monitoring the balance between a wide distribution of attention and specific focus on high priority tasks without requiring actors falling into a singular role. While long-term collaborating members still retain some ability to anticipate what may or may not be useful in a general sense, highly active collaborative bonds have a more acute sense. This sense is akin to capitalizing on the increased awareness resulting from observability and adaptive capacity information, and affords a pre-attentive vision for group members, reducing fixation by helping them to notice things that should change their focus without explicitly having to commit all of their attentional resources on detection.

The prevention of 'gimbal lock' on Apollo 13 is a seldom-told example capturing a team's successful ability to resist fixation and still anticipate anomalies despite a situation of information overload. After the infamous "Houston, we have a problem" call that started the crisis, mission controllers were initially faced with a loss of pressure in the oxygen tanks on the spacecraft. The possibility for gimbal lock (a state in which the spacecraft essentially loses the ability to determine its position in space, rending navigation systems useless) was acted on within six minutes of detection. The controllers on the mission management team were able to balance trying to decipher the "unbelievable screens" showing oxygen tank status in front of them with continuing to monitor the other systems on the spacecraft for potential failures. Instead of approaching each crisis in turn and spending crucial response time deliberating the authenticity of the "errors" the controllers were able to pool their attentional resources to continually revise their model of the world and maintain a state of action. This coordinated pooling of attention assisted them to manage each current problem and, almost more importantly, *anticipate* what could quickly become an issue, all while trying to diagnose how best to bring the spacecraft and crew home. This event and others like it throughout the response culminated in what is generally considered a successful rescue operation, the controllers had a joint commitment to a goal and shared cognitive resources to accomplish it – successful coordinative behavior.

Being *synchronized* on a coordination loop is the result of adequately allowing groups to share and adopt joint commitments and intentions. To step back this reiterates the inherent importance of being *able* to share and adopt commitments and intentions. Cohen and Levesque identified the ability for actors to commit to the actions of another actor in their modeling of teamwork (Cohen, 1991), stating that such a commitment requires the assisting actor to have mutual knowledge and beliefs the same as the initial actor. However, a common problem in coordinated activity is the inability for team members to realize a current path is incorrect, or that a current goal is impossible to achieve. "When a member of a team finds out a goal is impossible, the team as a whole must again give up the goal, but *the team does not necessarily know enough to do so*." (Cohen, 1991) Going beyond fixation, this shows how even at the most basic level knowledge propagation is paramount to the success of a team. Shared knowledge can easily become difficult when team dynamics deviate from normal operation such as when teams lose direct communication. If one actor realizes a goal is impossible and cannot share that information with others in the team, coordination has failed. Synchronization in such coordination is fundamental towards ensuring critical information (such as when to abandon a goal) is propagated throughout a team regardless of its experience or activity, allowing actors to *pull* critical relevant information to themselves while also allowing other actors to *push* information to them.

Using such information sharing is critical in ensuring actors do not end up working at cross-purposes because one subgroup has abandoned a goal and another has not. Preventing this fragmentation through increased observability leads supports maximizing the adaptive capacity of the team, which inherently leads to increased reciprocity, and ideally an increased flow of more relevant information. Rather than waiting for information to come to them, actors are able to point out and share (directed information sharing) information with each other, providing clues and insight into their current scope, which other actors on the team can listen in on (passive information sharing) and use to make judgments about what information they have that could be useful to the initial actor resulting in a cycle of increased opportunity for reciprocity.

This adaptive-capacity reciprocity cycle is fundamental in the achievement of synchronized coordinated loop activity. As coordinated activity succeeds and flourishes, actors adapt to changes both inside their team and in the world around them in meaningful ways. Its important to note synchronized loop activity is more than just achieving common ground. While the concepts of Synchronized Coordination Loops and common ground are both based on mutual knowledge, common ground forming bridges based on knowledge already in existence, SCLs go a step further to help foster the creation of *new* knowledge shared by all participating actors. Synchronized Coordination Loops help create a foundation for the *creation* of mutual knowledge, but most of all both SCLs and common ground are an ongoing processes that must be maintained by assisting actors to anticipate anomalies, avoiding surprise and exploiting opportunities.

3.4 Observations at King's Plaza

The scenario briefly described here relates an overview of a full-scale joint training exercise conducted by a major urban fire department and is a collection of first hand observations by the author, expanding on Voshell et al. (2008). This scenario simulated a mass casualty terrorist event, taking place late evening at an urban shopping mall and movie theater complex, and perfectly illustrates some of the breakdowns than can occur when the requirements for synchronized coordination are not met. The majority of the exercise took place in the movie theater area, and due to the scale of simulated destruction the exercise incorporated division level and below fire departments collaborating with specialized units (HAZMAT), emergency medical personnel, and police. Being able to capture multiple points of view around situations in parallel is a key strategy in conducting these observations (for a variation see Trent, et al. 2006). Four observers were placed in critical "information-rich" areas on the exercise grounds including the incident's command post, and various positions situated throughout the area of tactical operations. The observation team coordinated using phone text messaging as well as quick physical travel while listening in on the tactical and command radio channels. Observers used these modalities to cross-cue anticipatory information to one another when the opportunities presented themselves so as to concentrate resources to track the participants' responses to the observed communication and planned initiations of key events.

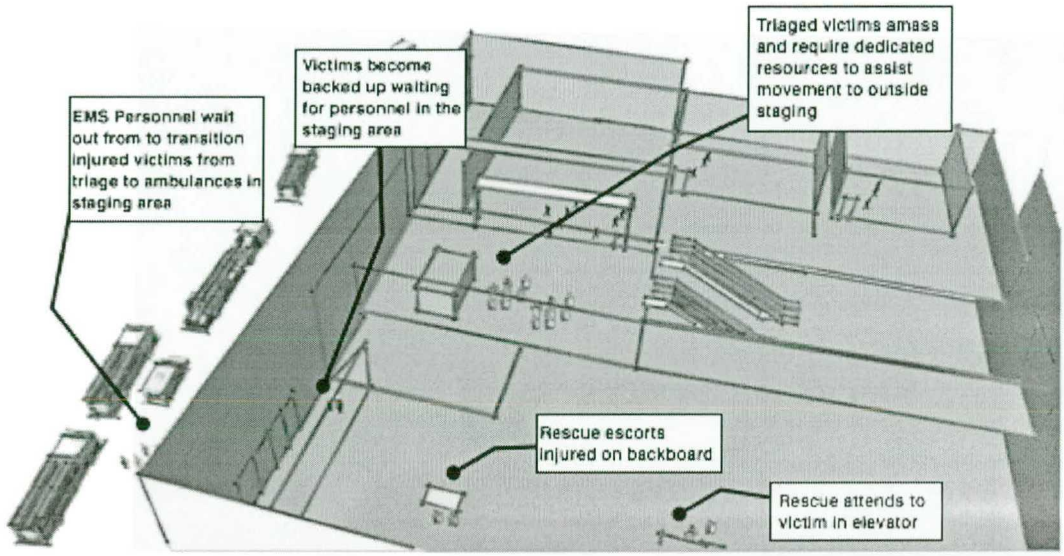

Figure 3.3: A layout of the training exercise in the mall-movie theater complex. Triage was on the second floor at the top of the two escalators, victims were escorted either down the escalators or down the elevators before being taken outside, from where they were taken to the ambulance staging area. Adapted from Prue et. al. (2008).

A process trace was performed and reported elsewhere (Voshell, 2008). The current work entails reflection on the cognitive challenges and adaptations observed in the form of sources of disruption and opportunities for exploitation. The exercise represented a 'rapidly escalating' series of consequences and events based on a simulated terrorist event. As the observer in the middle of tactical operations these observations are first hand, examining how the interactions between ground units played out as the overall response scaled up with specific focus on information and 'victim' handoffs between echelons and the department units (fire and medical). A high level of trust horizontally across departments was observed. As 'victims' were moved through the response, when a 'victim' was first identified they were tagged with a triage marker that remained with the 'victim' throughout. Interestingly, problems occurred in the simulation when revisions in the triage-tag diagnosis were required- either due to the state of the 'victim' changing, or due to the 'victim' being handed off from a first-responder fire fighter to the EMS personnel in charge of moving the 'victim' to a hospital. This lack of revision signifies either a breakdown in the horizontal loop bridging fire and EMS personnel, and/or in the vertical loop between the care provider and the 'victim'.

Observations point to the horizontal problems as the cause of the breakdown, as when 'victim's were handled by care providers they were all aware of the 'victim's' current and potentially future states. The horizontal loop is identified as the source of the breakdown as the fire responders displayed little awareness of the load on the EMS personnel working the ambulance staging area, despite having working communication connectivity in the form of radio contact that could be used while moving 'victims' from the triage area to the outside ambulance staging area. EMS personnel frequently were forced to transition from periods of 'no victim traffic' to periods of 'too many victims', which resulted in 'victims' being left unattended for extended periods of time. 'Victim's were observed being unattended in two separate scenarios: when personnel were busy with other victims and when staging personnel did not realize 'victims' "were still coming" from triage. At one point the observer controllers in the simulation observed the rough transition handoff between triage and staging. They explicitly told the 'victims' who were left unattended in the ambulance staging area to flop around on the ground and "start to die, then if they [EMS] don't come over just lay still, because you're now dead". This exemplifies how lack of team-awareness on the horizontal level creates opportunities for surprise and lowers the robustness of the coordinated response as a whole, especially as it attempts to scale up with an incident.

The fragmentation in this example is clear between the triage and outside ambulance staging area. Both areas were doing their respective jobs, triage was channeling victims to the staging area, as they should have been, and staging was distributing those victims to various hospitals in the area, as they should have been. However, the lack of information flow and observability between their two scopes undermined their respective ability to achieve success. The overarching goal of victim management was failed due to the lack of awareness of the load at each station. Triage did not adapt their plan either because they were unaware of the state of the ambulance staging area, and/or unaware of the implications their current plan was having on their distant coordinating party. Triage had little knowledge of the state of ambulance staging and this lack of identification of staging's current adaptive capacity resulted in the backup breakdowns that were observed. This fundamental breakdown within the horizontal loop between triage and staging further exemplifies the need to support not only state-based awareness among coordinating parties, but also the ability to prevent and avoid situations of fragmentation through understanding the implications of their current and proposed actions.

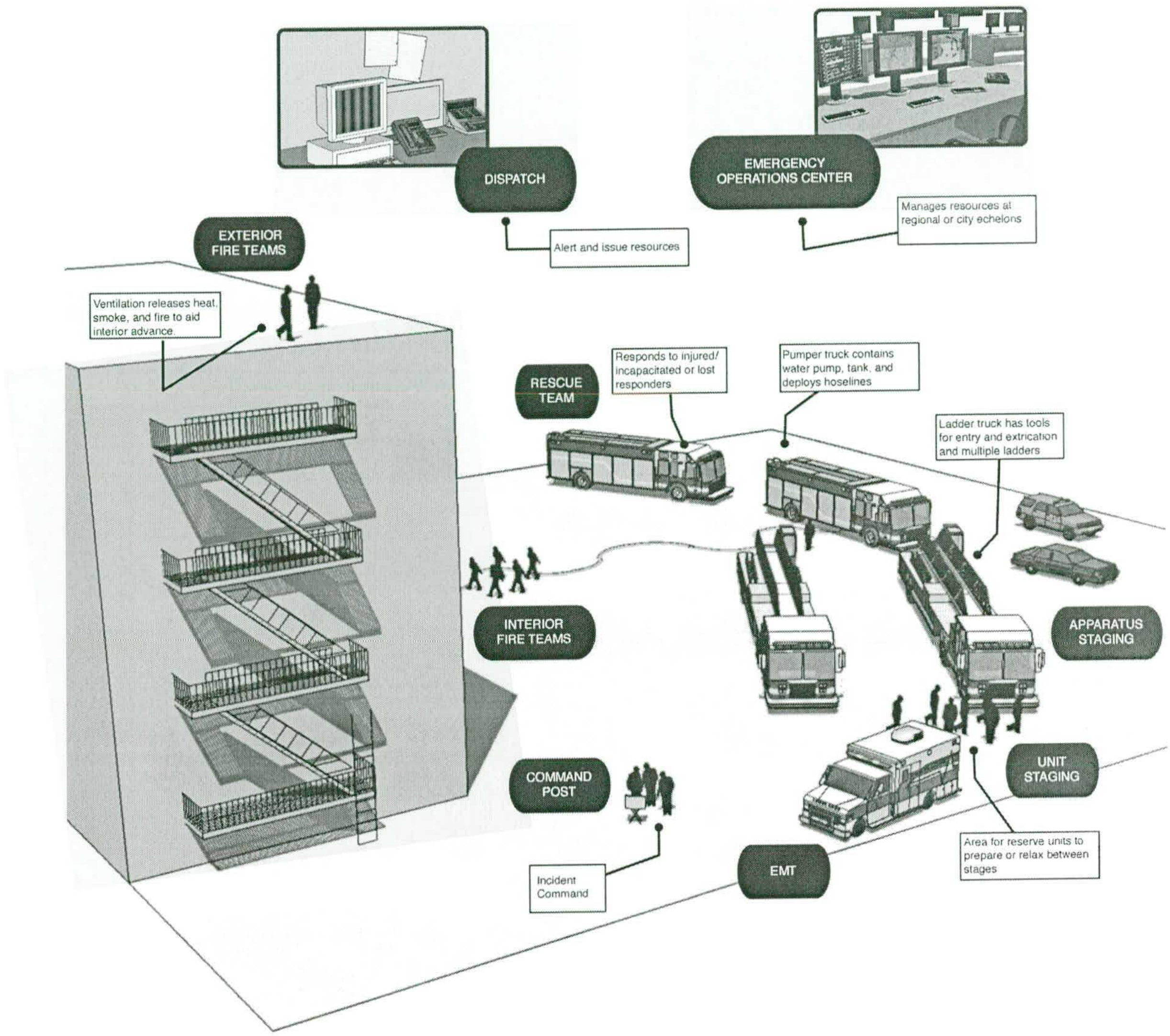

Figure 3.4: A sample representation of the units and resources involved with an incident as it scales up in the emergency response domain. Illustration adapted from Trent et al. (2008).

CHAPTER 4

OBSERVATIONS IN OTHER DOMAINS

Present in this chapter is one concrete artifact (Voice Loops), one case in the middle (Hastily Formed Networks), and one more conceptual example (Commander's Intent), which all worked to inspire the classes and requirements present in the Synchronized Coordination Loop typology. As each example touches on some of the requirements for synchronizing coordination and none captures them all in practice, these examples are collected to serve as context for the future possibilities of the proposed Synchronization Coordination Loop typology – as a means of assessment for managed coordinated activity, and catalyst for potential redesigns. Distributed teams inherently include varying functional roles based on the technical aspects of the anomaly they are responding to. It is important to note responses are not strictly relegated to a specific physical place. A response entails the distributed nature of control between multiple coordinating functional roles as threats emerge and the flow of activity changes (Watts, 2007). Just as highlighted previously, goals are better supported by role overlap and supporting the adaptive capacity and reciprocity cycle creates common resource pools for specialized roles to share while retaining unique capabilities, resources, and expertise. The resulting increased level of interpredictability and increased ability to notice timely anticipatory cues supports smooth coordination, creating a robust form of collaboration within a distributed system of mixed roles. Identifying the methods and requirements for support in previous iterations of coordination provides a baseline for the future, functional basis present in Synchronized Coordination Loops

4.1 Voice Loops

Voice-loops are an illustration of a coordination support artifact that emerged from studies of NASA mission control. "Voice loops" have been previously described as a robust form of collaborative communication (Patterson, 1999), but they do not extend further than that in terms of supporting collaborative activity. For example, voice loops enabled those on the loop to observe necessary information, but there is no feedback regarding what they should deem 'necessary'. Experience helps determine what is important, but there exists the possibility that things will be important "down the road" and thus missed when listening in on a voice loop. Access to information existing in other communities helps reduce uncertainty in the anomaly response (Watts, 1996). However, there is still a need for synchronization in the information sharing. Just being forced to act (and listen) in unison does not help information "pop out" to the listeners of a voice loop any more than if they were listening individually. Voice loop benefits lie in the overlap of knowledge that is available when knowledge is shared in synchrony- allowing actors to see the perspective of others on the loop, and how it should affect their own perspective.

4.2 Hastily Formed Networks

It is important to note the differences between Voice Loop assisted coordination, and the coordination that is claimed to be emergent from 'hastily formed networks' or 'HFNs' (Denning, 2006). While some loops may only be used in given situations, they inherently resist "disbanding" as HFNs are created to do. Voice Loops provide support by helping actors capitalize on the experience that culminates as teams achieve a goal and assist them in bringing that experience with them as they move on to the next goal, the next task, the next response, responding as each consecutive problem arises. The single goal support of hastily formed networks causes them to suffer from similar problems to ones they claim to address, namely an over reliance on immediate communication connectivity and an inability to synchronize with the inclusion of new actors and agencies as a response scales up. A hastily formed network does not foster the connections and linkages to be formed between actors that are required to provide a means for successful coordination. Simply adding additional technological methods for communication does not guarantee that actors will share information across them, let alone realize they share similar goals beyond the obvious.

Hastily formed networks offer no long-term coordinative benefits, providing no support for the incorporation of new actors and agencies into the network: an actor is either on the network at its formation or they are not on it at all. Attempts to add a new party to a hastily formed network result in the same confusion and shock that resulted in regression to old ingrained habits detrimental to the ability to collaborate that prompted the need for the network in the first place. Proper support of coordinated activity needs to assist the ability to synchronize actors to better anticipate anomalies and exploit opportunities regardless of what the anomalies and opportunities are. Coordinative networks such as hastily formed networks that are formed strictly from policy decisions are not flexible enough to allow actors to synchronize with each other to adapt as circumstances change.

4.3 Commander's Intent

Military command and control can be described as an orchestration of supervisory control systems. Coordination in command and control settings normally occurs through the use of predetermined plans and procedures to forge mutual knowledge. These plans and procedures can be underspecified and thus brittle when a local actor is confronted with an unanticipated situation. While grounding helps local actors coordinate together in scene when presented with impasses or surprises outside of their scope, local actors must adapt plans, tactics, techniques, and procedures to the situation based on their understanding of the remote supervisor's intent. Actors in-scene must look vertically for insight to maintain the higher level goals in the face of a changing and potentially hostile environment (Shattuck, 1997). As coordination is founded on mutual knowledge, it makes sense to frame intent as a mutual assumption for constructing a basis for action (Shattuck & Woods, 1997). There needs to be an emphasis on the ability to project this vertical intent across echelons and form a distributed coordinated team to help reduce problems that occur because the supervisor's plan, high level goals, and the current scope of a local actor may become disjointed and require common grounding to better deal with the changing situation in the world.

Intent is the means by which the remote supervisor can impart his or her presence to local actors, to assist local actors in responding the same way the supervisor would. Shattuck and Woods (1997) investigated commander's intent in a simulation where four battalions, with four company commanders each, responded to anomalies and found that company commanders who were successful in matching their battalion commander's intent were able to determine the system status and were able to coordinate their activities with commanders of adjacent units prior to taking any action. The unsuccessful company commanders generally did not refer to the battalion commander's statement of intent. They had a low tolerance for situational uncertainty, not acting until the where given more information, and in some instances not even incorporating new information into their mental model of the system. When a major, unanticipated event occurred on an adjacent part of the battlefield, these commanders would not deviate from their assigned mission, even though the event jeopardized the higher-order goals of the system. From this research it is clear that just as goals and commitments to a team persist over time, so must support for coordinated activity. The projection of intent illustrates just how important a role synchronization plays.

CHAPTER 5

CONCLUSIONS AND IMPLICATIONS FOR EMERGENCY RESPONSE

Similar to military operations, emergency response organizations face similar time critical operational pressures. In the high tempo world of emergency response, organizations are dependant on flexible yet synchronized responses to anomalous and uncertain situations. It is often not sufficient for local actors to simply follow the original plan; the plan must evolve and adapt to reflect changes in the world that must occur at the correct time and place as well as in the relation to the actions of the other actors in the system. To model such dynamic decisions and actions it is necessary to look at them from the perspective of coordination and reciprocity requirements to capture how actors are reducing uncertainty, achieving common ground, and projecting intent to meet the particular goals of the response. Synchronized Coordination Loops capture how to aid and maintain this organizational awareness, (Oomes, 2006) and support continued communication within and across echelons - propagating intent information to support and encourage individuals to reciprocate not only within, but also between groups.

Emergency response has three general goals: save lives, stabilize the incident, and preserve the surrounding property and infrastructure. Environmental pressures and the emergency response organizations themselves can quickly confound these goals in complex and escalating incidents (Peffer, 2008). Individual response organizations are diverse, hierarchical, and often form multiple command centers when incidents develop. The resulting time-phased resource staging can produce multiple groups vying for control rather than being solely concerned with the emergency at hand. As incidents grow, it is difficult for the scope of the response to appropriately scale with this growth due to these factors (the time-critical nature of the events, the emergent multi-disciplinary nature of the ad-hoc organization, and the multi-layered nature of a large emergency response organization). Oomes and Neef (Oomes, 2005) acknowledge the need for an information system that supports the proper build-up of an emergency response organization, starting with the smallest possible unit and remaining effective and useful throughout the entire process, aiding the organization shape itself into the most appropriate form at the correct time. Synchronized Coordination Loops are instrumental in being able to describe how to support the needs and goals of rapidly evolving organizations in highly dynamic environments (Voshell, 2007).

Passive information gathering and sharing in all loop classifications has the potential to be used by all emergency response organizations in concert. Emergency response is multi-disciplinary: firefighting services, emergency medical services, police, government agencies, the media, and the victims themselves are all possible horizontal parties interested in how the response is growing, and the connections and linkages between them provide opportunities for projective information sharing. These multiple parties all have some means to project themselves into the local scenes of the responders, capitalizing on these different methods enables projective loops to be a resilient source of feedback for decision making, providing varying perspectives on a given situation. However, just because the ability to exist to project into other horizontal and vertical perspectives it does not necessarily imply that it is clear when to use this projective access. A low scale example of this comes from the 9/11 Commission (2004), when policemen in the North Tower were informed by radio communication that the South Tower had collapsed and were ordered to evacuate the North Tower immediately. On their descent they encountered a group of firefighters, to whom the policemen communicated their evacuation orders. Despite the advice, "some of these firefighters essentially refused to take orders from cops" and they remained in their location. The lack of trust, and limited observability of the local parties possibly could have been circumvented by either fire or police command if they had been aware of the exchange between the two parties.

There were also situations where helicopters in the area were listening in on both police and fire radios. They could disambiguate which agency was which, providing what information, and could hear the evacuation orders that were issued but they had no idea that they could, or even should, pass the information along to those not on the immediate receiving end. These strong examples showcase the dangers of stove-piping information within an organization. In organizations and specialized systems it is common for broad decision-making authority, and the resulting communications, to only exist in only the vertical. In the emergency response domain this vertical information ownership results in incidents like the interaction between the fire and police responders, where the firefighters did not receive the information along their vertical loop and thus disregarded it coming from the horizontal loop they had with the police.

In professional sporting events it is common practice for a "most valuable player" or a "man of the match" to be declared at the end of the match. Typically this award goes to whichever player scored the most points, or which goal tender prevented points from being scored, but how do you determine the most valuable player of a match that ends in a tie? In football (the soccer kind) matches in normal league play can end in a draw, if neither teams scores points, other aspects of the game must be judged in order to distinguish which team, or player, played "better" than the other. Having to describe a match that ended in a tie to someone who was unable to watch first hand draws an immediate parallel to trying to describe synchronized coordinated activity. It is easy to point out the great successes and great failures, but to analyze the gray area in between requires a metric. Sports use various statistics to make these judgments of success or failure in the gray area: assists, steals, blocks, shots all help the assessment. So what are "statistics" to measure coordinative activity? Accuracy of mental models, perceived versus actual progress toward a goal, levels of trust and reciprocity, and functional partial-decompositions are starting points for analyzing coordinated behavior in its gray area, where the team is unsure if it is on the path towards success, or the path toward failure. It is important to note the difficulty of these judgments- it is commonplace for actors who have changed their behavior to support successful collaboration, that is to say they are "doing things right", to be sure that they have done anything at all. Increasing awareness of the level of coordination between actors through identification of these "synchronized coordination statistics" is a requirement for successful designs to support coordinated activity in the future. Synchronized Coordination Loops identify the requirements for synchronized activity to be information sharing, system observability, trust, and reciprocity, and using these four requirements, propose the three classes of loops themselves as the "statistics" on which analysis can determine if coordination was, or will be, successful.

5.1 Scaling Up – Aligning Mental Models in Organizations

Actors assist each other based off of mental models of what the current tasks, and goals, are for both themselves and the organization as a whole – as there is no such thing as a cognitive vacuum. Sharing this information and updating each other of perceived changes to the model results in a more robust, and resilient organizational structure. The resilience present in structure is emergent from the lack of reliance on a centralized source for all information regarding the state of the response, and thus reducing the risks inherent in having a single collection of data that can fail. The drawback to this sort of response organization is the extra amount of work it entails, in the heat of a response actors will not necessarily have time to constantly update and inform other distant observers of their status explicitly. This additional work requirement, coupled with the time critical nature of response organization suggests that a more passive means for information sharing is the best option to pursue.

Assisting information sharing through passive collection of artifacts that can be viewed, rather than created, when the actor has time creates a truly more resilient method of cooperative activity, and that is what we propose with synchronized coordination loops – especially in terms of the projective loop. The ability for actors to have their current state of progress to their respective functional goals passively mapped and recorded allows other agents to make informed judgments and decisions to support the working actor without having to wait for the actor to request the assistance. A simple example of this would be the ability for a battalion, or deputy chief's aid to monitor the oxygen level of all the firefighters in a building coupled with how long it took the firefighters to reach the fire, and thus how long it should take them to get out of the area. In this case combining information collected passively, the amount of oxygen and time to enter/exit, provides insight into how much oxygen would be required to safely exit the building. This allows the incident commander to anticipate problems and make decisions regarding when the treatment power of the responders (the oxygen allowing them to fight the fire) is running low and requires a swap to occur, instead of being forced to wait and base the judgment on when to rotate units based either on experience (which varies) or on a reaction to the alarm bell indicating a potentially dangerous situation has already occurred.

Passive information sharing from the loop typology applied in this situation allows actors to align their mental models of the world with each other without having to be actively aware, or attempting to do so. Scaling up the scope of passive information sharing, we can look at the way responses are organized overall and how this alignment process can, and should, apply to organizations as a whole.

Fire response utilizes a National Incident Management System based on the Incident Command System in which they boil their comprehensive management structure and organizational design down into four components assisting one command section. The four components are the planning section, the operations section, the logistics section, and the finance and administration section. This organizational breakdown by function is a step in the right direction, but occurs at too high a level to be optimally effective. Responses handled in this manner grow modularly, only filling the functions that are needed to manage the emergency at minimum cost, often resulting in minimum effectiveness (Oomes, 2005). While this type of modular approach allows greater flexibility when building an emergency response organization, it suffers from being in a state of perpetual reaction – that is to say, it lacks the tools and ability to anticipate changes and build up *before* the demand for a specific module exceeds its current capacity.

The current sections are each responsible for handling specific aspects of the response in an attempt to push and distribute the ability to command, "lower down the chain". While this is a step in the correct direction, the current method does not change much beyond increasing the need for coordinative support by creating 5 individual chains of command who may, or may not, be coordinating critical information with each other. To get these modular sections to coordinate in synchrony support needs to come in the form of re-designing to support the overlap between their respective goals. Rather than beginning to build up the logistics section to reallocate resources *after* the planning section has detected an anomaly, logistics should receive feedback on what planning is monitoring so as to take on a more anticipatory role, allocating resources to both create and exploit opportunities all while reducing the chance and ramification of impasses. All four sections are a perfect example of where integration based on designing for information flow, system observability, trust, and reciprocity in their goal spaces would support coordinated activity by assisting dispersed actors and agencies with building up into a cohesive coordinated unit.

5.2 Accuracy in Judging Coordination: Measures of Progress and Timing

"If the world could be completely objective and predictable, there might be little need to monitor the progress of the multiple efforts involved in a joint activity." (Feltovich, 2008) As Feltovich notes, the world is neither completely objective, nor is it predictable, so one can assume that some measurement of progress is required for any assessment of the success of joint coordinated activities. The notion of progress itself implies a future-looking perspective, as progress requires information about the current state and desired state within a specific timeframe. Fortunately this synchronizes well, no pun intended, with the future-centric support of the Synchronized Coordination Loop framework.

In any coordinated activity the coordination actors are constantly probing the situation, actively and passively, in order to revise their perspective of their environment. Synchronized Coordination Loops highlight the need for increasing support of more passive probes, as a means of information sharing as previously discusses, but this increase in passive probing can be capitalized on as a means to analyze progress as well. As people join to engage in coordinated activity more complex forms of probes naturally emerge to cover the increasing range of roles and scopes. People naturally attempt to judge the progress of those they are collaborating with, “especially with regard to interdependent aspects of that work.” (Feltovich, 2008) However, when technology is added to the mix normal attempts at probing for progress assessment can fail – which is of critical importance due to the increasing reliance on projective loops as a means to bolster coordination between distant and local actors. It is commonplace for autonomous agents to be working in complete obscurity from the actors they are supposed to be collaborating with. Judgments of progress require high-level reflective judgments that machine agents are unable to accurately make at the current technological progress, however, that does not mean that the information required to make those judgments is necessarily different from what their human counterparts require. Machines can readily provide extremely extensive and detailed accounts of their current state and their current ability to perform, they can also recite their desired state easily enough, and they time with which they have to reach that state – so why is it argued, and observed that machine agents cannot provide an accurate estimation of progress? Because they lack awareness of the effects the ever-changing world around them is having on their path to their desired state.

Progress is a quality that needs to be measured to judge the success of coordinated activity, but is there something more basic, something underlying that is fundamentally more important? As stated, to measure progress one needs a current state, a desired state, and a time in which to reach the desire state. Progress itself is simply a measure of change – a relationship between a current state, a desired state, and the time it takes to travel between the two, and in mathematics this is called a derivative. Derivatives measure the *rate* of change; as such time is the most critical dimension along which progress is assessed. Timeframes determine the margin of error that can be accommodated before a goal becomes either impossible or irrelevant, and thus needs to be abandoned by a coordinating team. Time determines the scale along which deviations from the intended plan can be judged (falling behind, or being ahead of schedule for example). Success or failure of a collaborative venture is determined along the temporal dimension.

Synchronized Coordination Loops are a proposed assessment framework analyzing the requirements for more effective coordination through persistence of the coordinative bonds that make coordinated activity more beneficial than individual actions. Persistence of those coordinative resources is the key, and as such, the length of the coordination, that is to say the time during which it exists, needs to be measured to determine the success or failure of the team. There are temporal costs to successful coordination: it takes time to build trust, time to setup and enable channels along which information can flow, and there must be enough time for opportunities for reciprocity to emerge.

Achieving a single goal in a limited time can be considered a success in terms of accomplishing the desired goal, but if the time during which collaboration was able to exist is limited was the collaboration itself really *successful*? What about the scenario where no goals are achieved, yet collaboration is maintained; is that a success because collaboration persists despite failing to achieve any of the team's goals, or does a lack of goal accomplishment make it a failure? It is clear the success of a coordinative venture cannot be accurately measured simply in terms of how many goals are achieved, or how long team members have been working together.

While accomplishing goals is a requirement for success from a stakeholder's perspective, determining success by disregarding the time it takes to form the bonds that enabled goal achievement and the benefits afforded by having persistent collaboration is not a true measure of whether coordination was successful. As Axelrod notes, "the foundation of cooperation is not really trust, but the durability of the relationship" (1984).

The fundamental first step in judging successful coordination is realizing the distinction between successful accomplishments and successful coordination - measuring not only what the team accomplishes, but also how long the team itself is able to exist. Analyzing this ability for a team to aspire to goals and attempt to exist long enough to achieve them is inherent in the Synchronized Coordination Loop typology. Aspirations in this sense are defined by how much of a goal space both an individual and a team can achieve given the scope of the current plan. There must be a balance between the degrees of realism and aspiration when developing a plan. Reciprocity, however, as a requirement or synchronizing coordination affords an increased overlap between what is a realistic goal scope, and what aspirations the team may have – allowing individual aspirations within the team to be achieved, without forcing the team to compromise any of the overarching high level goals. In these terms, aspiring and achieving more than was built into the plan is definitely a successful measure of synchronized coordination.

5.3 FAN – A Tentative Cognitive Model of Work

The final piece of the puzzle in formulating and judging successful coordination is consideration of the fundamental functional requirements of the activities in question. Knowledge of these fundamental functional links allows identification of the various tiers of cross dependencies inherent in the work. Traditionally there has been little examination of how the functional requirements for coordinated activity can be used to design support systems for distributed coordinated activity. This results in a lack of support for adaptive capacity, and what little support is present existing unfounded in the cross dependencies that create the requirements for said adaptive capability. Synchronized Coordination Loops can describe joint activity in supervisory control settings through such required functional analysis to provide insight into how to balance the functional goals of the system with those of the team, and thus anticipate the cross-dependencies and possible breakdowns that can occur.

As mentioned previously, simply adding connectivity does not address these fundamental requirements and does not guarantee successful team coordination. Coordination improvements based on metrics is the next step in order to go beyond current models of simply increasing communication and connectivity in an attempt to resolve the challenges of coordinated joint activity. Working with Resilient Cognitive Solutions (Peffer, 2008) we have developed initial metrics for analyzing coordinated work on the functional level based on a Functional Abstraction Network of the emergency response domain.

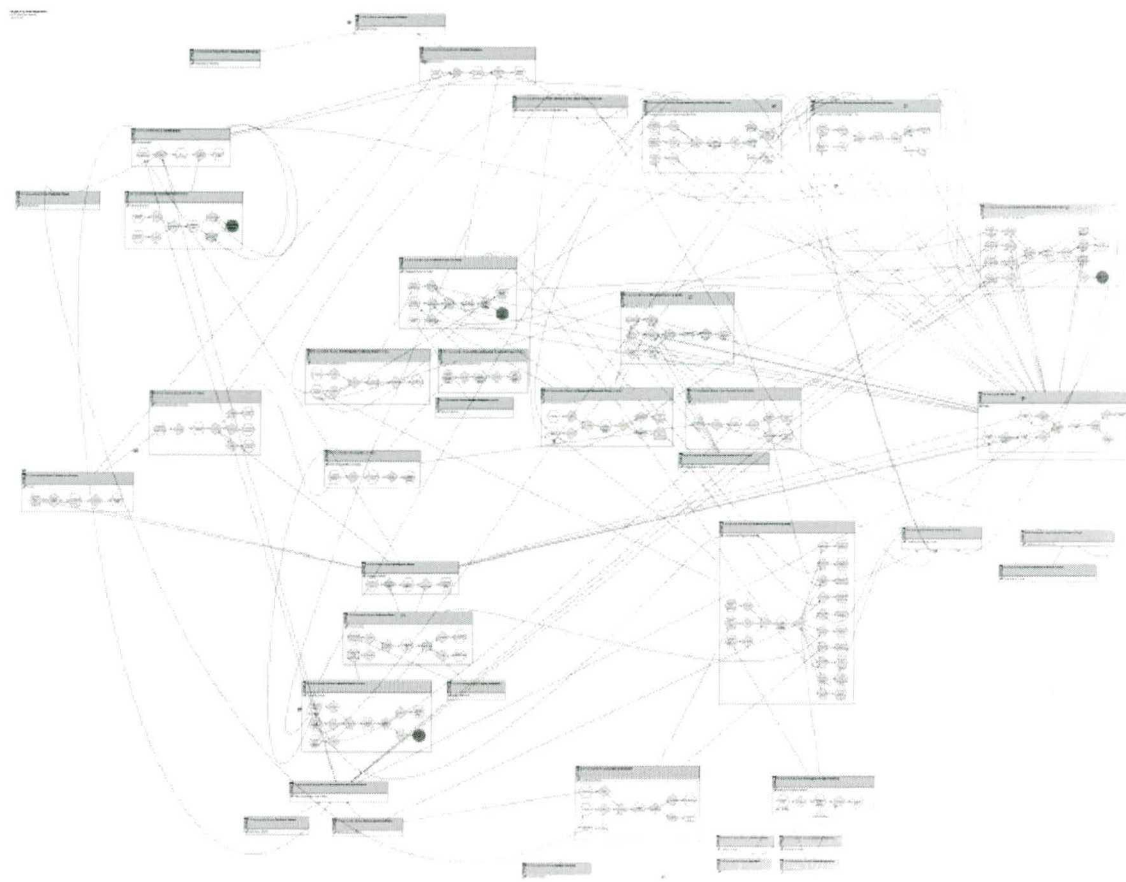

Figure 5.1: The Functional Abstraction Network for the Fire Response domain. A Full sized version can be found in Peffer (2007)

This Functional Abstraction Network was developed to initially explore functionally modeling an emergency rescue domain. The Functional Abstraction Network, or FAN, is a map of the goals and processes that must be achieved in order to accomplish an objective in a specific domain of work. The large boxes that incorporate the initial mapping are Goal-Process Nodes, nodes that form the network that come together to form the FAN. Goal-Process Nodes, GPNs, define the goals that must be achieved and the decision-making processes that are associated with each goal in the work domain. Within each GPN are the cognitive work requirements, CWRs, and information relationship requirements, IRRs, required for the specific goal. Cognitive work requirements represent the pieces of cognitive work that must be executed in order to achieve a particular goal in the desired domain, and are derived from the GPNs that compromise the FAN as a whole. Information relationship requirements are a step down the chain from CWRs, representing the information necessary to accomplish the CWRs needed to accomplish the over arching goal (Peffer, 2008). Using the FAN to capture domain concepts and relationships that define the problem-space of the domain ensures that any insight garnered takes into account not only possible goal, actor, and demand relationships, but the decision maker's perspective as well. Examining the cognitive work requirements is a way to identify the cognitive demands and decision tasks that arise and require support in a domain, while identifying the information relationship requirements helps support successful execution of possible points for collaboration through information sharing.

When organizational roles intersect links between the goals of the domain new demands are created. Identifying these emergent intersections creates the opportunity to understand the specific costs of coordination those roles have for achieving those goals. Judgments of how well roles are coordinating their efforts around those goals and measures of how and what pertinent knowledge is being shared are examples of metric insights that can be garnered from such identification. One such metric insight focuses on the relationship in organizational structure between how many supporting functions exist for any given work function and how many roles overlap at that given functional node. This is an excellent starting point for information regarding which roles work together to support which functional goals of the system. Take the path management node:

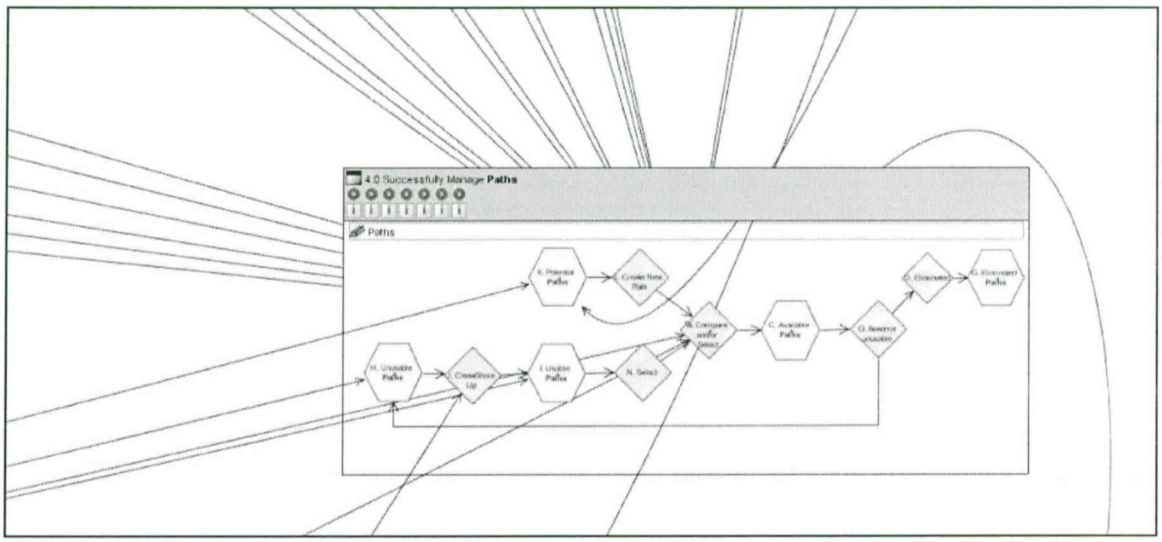

Figure 5.2: A focus on the Manage Paths GPN of the FAN.

There are twenty-one nodes that Path Management supports, while it itself is only supported by six. The greater the ratio between the number of nodes a node supports and is supported by, supporting:supported, the more balancing of demands that that goal is under at any given time. A high number of supporting nodes is a direct measure of how many other goals are dependant on this one goal for success, and these links between supported nodes express the dependencies and critical relationships between goals and functions. Twenty-one other goals in the emergency rescue domain are reliant on path management at some point in time for successful operations to occur. To identify cross dependencies this supporting:supported metric shows that there are twenty-one goals across which cross-dependencies exist, and can indirectly result in actors working at cross purposes. When you overlay roles on top of this partial functional decomposition it becomes even more complex in terms of demands on the node in question. However, adding roles also adds the ability for actors to coordinate their actions through increasing the number of goals that can be achieved and aspired to. Meeting the requirements for synchronizing this coordination by providing an understanding of the other roles that require this specific GPN for success allows for actors to temporarily alleviate the pressure they are placing on the GPN. This allows achieve aspirations that where not necessarily assumed to be in the plan, and others in turn can reciprocate this behavior, either at the same node or at a different functional node in the network, propagating increased chances for various successes through the organization. Organizing the roles and their requirements around this functional goal-needs structure rather than organizing around just pre-defined tasks ensures opportunities for increased collaboration, reciprocity, and support for the decision-making perspective.

Synchronized coordination is more than just identifying and supporting a single goal for a team to complete before it dissolves. Making actors aware of which other actors are pursing the same goal(s) is the first step in advancing opportunities for reciprocation, and thus more persistent coordinative bonds. Such tight goal-process coordination based in reciprocity, observability, trust, and information flow supports decision making across all levels by reducing misunderstandings that can lead to defection. If actors understand why given paths are unavailable to them they are more likely to be willing to accept other seemingly unclear decisions, and through proper loops they can share their process and demand information which can result in less effort and resources set aside solely for double checking and second guessing supporters and collaborators. If roles are overlapping on a node and yet not interacting in the actual process, observers and designers have a new area for exploration, analysis, and planning. Should the actors be bridged in the actual process? How have they adapted to accomplish the work despite the disparity in what we would expect functionally, and how can that expertise be exploited? It is clear such disjoints between functional overlap and role overlap provide ample starting points for process improvement, even for something as simple as identifying possible sources of information that would provide useful to a role or goal space.

Additionally, asymmetries between the amount of supporting a functional goal is receiving and how many other goals said function is supporting provides a useful metric for identifying possible choke points in the system. Due to the costs of coordinated activity Peffer describes a scenario where functions that "are characterized by a large difference between the number of support versus supported links", referring to a state in the world in which one would expect varying coordination breakdowns – fixation, shaky handoffs of information, and incorrect interpretations of intent, for example.

5.4 Implications for Design

Proper support for coordinated activities connects actors who share overlap in either functional or role spaces as situations develop and change. These points of overlap define cross-role dependencies. Looking at synchronization as the fundamental unit of analysis for coordinated activity provides an awareness for the differences between how different actors, different echelons, even how the process, all envision achieving specific goals. The foresight garnered from identifying these dependencies and overlaps leads to increased ability to judge which goals in an organization are functionally brittle, and identifying where breakdowns such as fragmentation can occur. Knowledge of this goal diversity, and the dependencies that cross it results in useful insight for the creation of design seeds to support synchronized coordination. The foresight garnered from the functional partial decomposition allows proactive, anticipatory actions to be taken without having to wait for accidents to catalyze change within a system. Improving training through better expertise capturing, and helping resource management and re-tasking are just two examples of areas which can benefit from the Synchronized Coordination Loop typology's approach.

As previously discussed, more often than not support for joint coordinated activity comes simply in the form of indiscriminately increased connectivity between actors, which does not support all of the requirements for synchronization. Information flow can incorporate a need for increased connectivity, but as evident in the training exercise at King's Plaza simply putting everyone on the same radio frequency does not guarantee coordination, let alone of the successful variety. Just as any coordination requires more than a single actor, support for coordination requires more than just a focus on a single aspect of collaboration.

Attempts at coordinative support that simply look at the distributed nature of the actors in the system often result in trying to shorten those distances. Trying to identify and adapt to the inherent cross dependencies is the correct approach to take for support coordinative work; although attempting to do so without attempting to understand *why* the cross dependencies exist is a faulty method. To truly support actors working in synchrony with little to no risk of devolving into working at cross-purposes systems must be setup to display these dynamic connections. Instead of asking what technology can be thrown at actors to get them to successful collaborate, the initial question that should be asked is what demands are being addressed by the current system's layout? This is the primary goal of Cognitive Systems Engineering, to understand the inherent demands and problems of the work in question.

Using a Functional Abstraction Network, based on observations, as the backbone for support is one such approach for performing an applied cognitive work perspective to developing and designing support tools and systems. Taking into consideration the four major requirements for synchronized coordination, and coupling that knowledge with the functional insights regarding cross-dependencies afforded by the FAN, is exactly what is captured in the Synchronized Coordination Loop typology. Identifying which goals are central in an actor's focus allows for the related goals to be tiered off. Separating goals into differing tiers based on the functional relationships allows actors to see at least the first level (functional) cross-dependencies for their current goal. Making actors aware of these static functional relationships is the first step toward providing a display to increase awareness of the dynamic cross-dependencies which can ultimately lead to coordination breakdowns when ignore. Designing a display for such awareness he next step to take with the Synchronized Coordination Loop typology: aiming to prevent coordination breakdowns by making actors aware of not only their current scope but the scopes of all related parties as they join and leave loops.

The Synchronized Coordination Loop typology captures the overlap and intersections between actors, their roles, and the functional goals of the system. Means to identify an actor's progress towards achieving a goal not only given their individual scope, but the scope of others working towards the same goal is driven by the requirements for synchronization. These requirements are fundamental, if not flat out required, for achieving the high level understanding that is required to synchronize decentralized joint coordinated activity. Investing in these requirements, opportunities for information flow, the perceived and actual level of observability between actors, the level of trust, and overall reciprocation is the next step in the design for resilient coordinative (net-centric) systems.

LIST OF REFERENCES

9/11 Commission Report, Final Report of the National Commission on Terrorist Attacks Upon the United States (2004). Washington, DC: U.S. Government Printing Office.

Axelrod, A. (1984). *The Evolution of Cooperation*. Basic Books: New York.

Clark, H. H. & Brennan, S. E. (1991). Grounding in communication. In L. B. Resnick, J. M. Levine & S. D. Teasley (Eds.), *Perspectives on socially shared cognition*. Washington D.C.: American Psychological Association

Cohen, P. R. & Levesque, H. J. (1991). Teamwork. *Nous*, 25, 487-512.

Cook, R. I., Woods, D. D. and Miller, C. (1998). *A Tale of Two Stories: Contrasting Views on Patient Safety*. National Patient Safety Foundation, Chicago IL, April 1998. (available at www.npsf.org).

Denning, P. J. (2006). Hastily Formed Networks. *Communications of the ACM*, 49(4), 15-21.

Dickson, J., McLennan, J., & Omodei, M. (2000). Effects of Concurrent Verbalization on a Time-Critical, Dynamic Decision-Making Task. *Journal of General Psychology*. 127(2), 217-228.

Feltovich, P. J., Bradshaw, J. M., Clancey, W. J., Johnson, M., & Bunch, L. (2008). Progress Appraisal as an Element of Coordination in Human and Machine Joint Activity. *Engineering Societies in the Agents' World VIII*. Heidelberg Germany.

Gunawan, L. T., Voshell, M., Oomes, A. H. J., & Woods, D. D. (2007). Envisioning Collaboration at a Distance for the Evacuation of Walking Wounded. *Proceedings of the Fourth International ISCRAM Conference*. Delft.

Hollnagel, E. & Woods, D.D. (2005). Joint Cognitive Systems: Foundations of Cognitive Systems Engineering. Taylor & Francis.

Klein, G., Armstrong, A., Woods, D. D., & Gokulachandra, M. (2000). Being on the Same Cognitive Wavelength: Common Ground in Coordinative Activity. *Cognitive Wavelength: The Role of Common Ground in Distributed Replanning*. Prepared for AFRL/HECA, Wright Patterson AFB.

Klein, G., Feltovich, P., Bradshaw, J. M. and Woods, D. D. (2005). Common Ground and Coordination in Joint Activity. In W. Rouse and K. Boff (Ed.). *Organizational Simulation*, Wiley, pp. 139--178.

Oomes, A., & Neef, R. (2005). Scaling-up Support for Emergency Response Organizations. *In proceedings of the 2nd International ISCRAM Conference*, Brussels. Belgium.

Ostrom, E., & Walker, J. (2003). *Trust and Reciprocity: Interdisciplinary Lessons from Experimental Research.* Russel Sage Foundation: New York.

Patterson, E. S., Watts-Perotti, J., & Woods, D. D. (1999). Voice loops as coordination aids in space shuttle mission control. *Computer Supported Collaborative Work,* 8, pp. 353-371.

Peffer, J. (2007). D1 Functional Analysis Report for the Emergency Management Domain. [White Paper]. Retrieved from Ohio State University's Cognitive Systems Engineering Lab: http://csel.eng.ohio-state.edu/projects/fdny/fans/d1joint.pdf

Peffer, J., Tittle, J., Elm, W. C., Voshell, M., Prue, B., & Woods. D. D. (2008). How Costly is Your C2 Coordination? Assessing the coordination requirements within Command and Control. *(submitted for publication). Proceedings of the 13th International Command and Control Resarch and Technology Symposium*, Bellevue, WA.

Prue, B., Voshell, M., Woods, D. D., Peffer, J., Tittle, J., & Elm, W. C. (2008). Synchronized coordination loops: A model for assessing distributed teamwork. Paper presented at the RTO HFM Workshop on "Adaptability in Coalition Teamwork" held in Copenhagen, Denmark, 2008. Published in RTO-MP- HFM-142.

Rasmussen, J., Pejtersen, A.M., & Goodstein, L.P. (1994). *Cognitive systems engineering.* New York: Wiley

Shattuck, L. & Woods, D. D. (1997). Communication of intent in Military Command and Control Systems. *In C. McCann & R. Pigeau (Eds), The human in command: Exploring the modern military experience.* New York: Plenum.

Voshell, M. & Oomes, A. H. J. (2006). Coordinating Shared Perspectives in Robot Assisted Search and Rescue. *In Proceedings of ISCRAM 2006.*

Voshell, M., Trent, S., Prue, B., & Fern, L. (2008). Cultivating Resilience in Urban Fire Fighting: supporting skill acquisition through scenario design. *(submitted for publication). Proceedings of the HFES 52 Symposium*, New York, NY.

Voshell, M., Woods, D. D., Prue, B., & Fern, L. (2007). Coordination Loops: A New Unit of Analysis for Distributed Work. *Proceedings of the Eighth International NDM Conference (Eds. K. Mosier & U. Fischer), Pacific Grove, CA.*

Watts-Perotti, J. and Woods, D. D. (2007). How Anomaly Response is Distributed Across Functionally Distinct Teams in Space Shuttle Mission Control. *Journal of Cognitive Engineering and Decision Making*, 1(4), 405-433.

Woods, D. D. & Hollnagel, E. (2006). Joint Cognitive Systems: Patterns in Cognitive Systems Engineering. Boca Raton, FL: Taylor & Francis Group.

Woods, D. D. (2006) Essential Characteristics of Resilience. In E. Hollnagel, D. D. Woods, N. Leveson (Eds), *Resilience Engineering: Concepts and Precepts.* Brookfield, VT: Ashgate Publishing 21-34