

NAVAL POSTGRADUATE SCHOOL Monterey, California



Contextual Criticality of Knowledge-Flow Dynamics: The Tragedy of Friendly Fire

by

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ABSTRACT

Recent research has produced models that improve our ability to identify, describe and explain a diversity of knowledge-flow patterns that manifest themselves in various enterprises, which improves our efficacy in designing organizations and processes. But enterprises do not all operate in the same environmental context and current theory is relatively silent on contextual implications of knowledge flow. The research described in this technical report builds upon current theory to explicitly address the contextual implications of knowledge flow in terms of organization and process design. Using a recently developed, multidimensional model to characterize and delineate a variety of enterprise knowledge flows, we integrate key aspects of Coordination Theory and extend this model to address context. The use, utility and implications of this extended model are described through application to an extreme case in which knowledge flows are embedded within a hazardous, time-critical context with mortal consequences: a military “friendly fire” incident in Northern Iraq. The extreme nature of this application case provides revelatory insight into the contextual importance of knowledge-flow dynamics, and by using such an extreme case for application, we enhance the generalizability of our model to less extreme environments that are more commonly associated with non-military enterprises (e.g., corporations, governmental agencies).

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PREFACE

The authors of this technical report began their collaboration in an informal seminar focusing on organization design and analysis as well as knowledge management. The different frames of reference represented by the authors provided the basis for interesting and provocative discussions. This report is an overview of our overall approach. We anticipate our collaboration will continue and result in additional technical reports and journal articles in academic and professional journals.

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INTRODUCTION

Imagine that you are a knowledge worker, reporting as usual to your customary workplace, interacting in standard fashion with your regular group of coworkers, interfacing with the familiar set of tools and technologies associated with your workplace, and performing work tasks as part of your ordinary professional routine. Now imagine that, in the middle of this work environment and routine, as you are working and conversing with coworkers, you hear a noise, and suddenly, without warning, the whole work area explodes, and you and your coworkers are killed instantly. Does this sound far-fetched and unlikely in the context of your work environment? Welcome to the context of joint military operations.

Many scholars (e.g., Drucker 1995) assert that knowledge represents one of the very few sustainable sources of comparative advantage, and the practice of knowledge management (KM) takes the power of knowledge to the group, organization and even enterprise level (Davenport and Prusak 1998). Within the rubric of KM, current survey work identifies knowledge flow as a key area in need of additional research, indicating that there are "large gaps in the body of knowledge in this area" (Alavi and Leidner 2001, p. 126). If we accept that knowledge is even an entity that *can* flow (Brown and Duguid 1998), then understanding how to manage and enhance such flow is central to attaining and sustaining competitive advantage.

To facilitate such understanding, recent research on the phenomenology of knowledge flow (Nissen 2002) has produced models that improve the ability to identify, describe and explain a diversity of knowledge-flow patterns that manifest themselves in various enterprises—in the private and public sectors alike (e.g., businesses, corporations, governmental agencies, military units)—and this improves our efficacy in designing organizations and processes. But enterprises do not all operate in the same environment, and effective organization and process design must explicitly take into account the context of knowledge flows (Nissen et al. 2000). Unfortunately, current theory is relatively silent on contextual implications of knowledge flow.

The research described in this technical report builds upon current theory to explicitly address the contextual implications of knowledge flow in terms of organization and process design. Using a recently developed, multidimensional model to characterize and delineate a variety of enterprise knowledge flows, we integrate key aspects of Coordination Theory and extend this model to address context. The use, utility and implications of this extended model are described through application to an extreme case in which knowledge flows are embedded within a hazardous, time-critical context with mortal consequences: a military “friendly fire” incident in Northern Iraq. The extreme nature of this application case provides revelatory insight (Yin 1994) into the contextual importance of knowledge-flow dynamics, and by using such an extreme case for application, we enhance the generalizability of our model to less extreme environments that are more commonly associated with non-military enterprises (e.g., corporations, governmental agencies).

DYNAMIC KNOWLEDGE-FLOW MODEL

In this section, research is summarized to conceptualize a four-dimensional model of knowledge-flow dynamics. First there is a summary of the integration and extension of two well-known models from the literature. This model is then employed to characterize and delineate knowledge flows associated with a software project for illustration. In this report the usual data, information, knowledge distinctions are aggregated and called knowledge.

Model Integration

Drawing from Nissen (2002), the two models from the literature are called the Spiral Model and the Life Cycle Model. They are both well known and widely cited, so their principal elements are only briefly summarized here. The Spiral Model is described by Nonaka (1994), and it employs two dimensions to characterize knowledge as it flows through the enterprise: *epistemological* and *ontological*. As delineated in Figure 1, Nonaka uses interaction between these dimensions as the principal means for describing knowledge flow, which is characterized by a "spiral" dynamic through four enterprise processes: 1) socialization, 2) externalization, 3) combination, and 4) internalization.

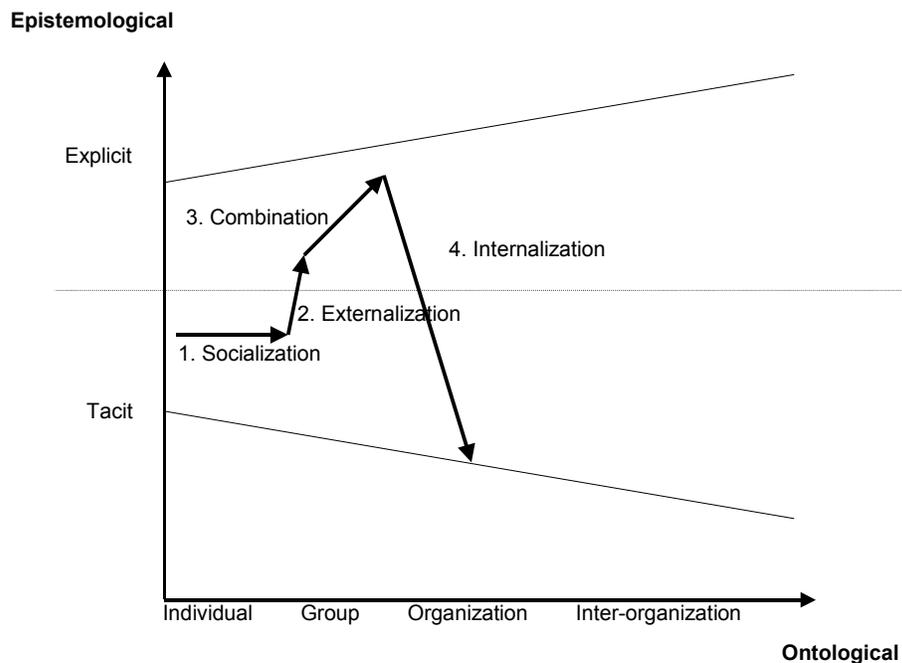


Figure 1. Spiral Model (Adapted from Nonaka 1994)

Briefly, socialization denotes members of a team sharing experiences and perspectives, much as one anticipates through communities of practice. Externalization denotes the use of metaphors through dialog that leads to articulation of tacit knowledge and its

subsequent formalization to make it concrete and explicit. Combination denotes coordination between different groups in the organization—along with documentation of existing knowledge—to combine new, intra-team concepts with other, explicit knowledge in the organization. Internalization denotes diverse members in the organization applying the combined knowledge from above—often through trial and error—and in turn translating such knowledge into tacit form at the organization level.

The Life Cycle Model represents an amalgamation of several knowledge-flow conceptualizations described in the literature (e.g., Despres and Chauvel 1999, Gartner Group 1999, Davenport and Prusak 1998, Nissen 1999) that employ the concept *life cycle*. The life cycle concept is the subject of textbook discussion in terms of IS design (e.g., Fertuk 1992), and it has been used to describe the sequence of activities associated with business process re-engineering (Guha et al. 1994, Kettinger et al. 1995). In the present context, the Life Cycle Model includes six discrete phases of knowledge as it flows through the enterprise: 1) creation, 2) organization, 3) formalization, 4) dissemination, 5) application, and 6) evolution (Nissen et al. 2000). Note that in the organization design literature each phase is a separate task to be performed. The word “phase” connotes a sense of the overall process.

Briefly, the creation phase begins the life cycle, as new knowledge is generated within an enterprise. The second phase pertains to the organization, mapping or bundling of knowledge. Phase three addresses mechanisms for making knowledge formal or explicit, and the fourth phase concerns the ability to share or distribute knowledge in the enterprise. Knowledge application for problem solving or decision making in the organization constitutes Phase five, and a sixth phase is included to cover knowledge refinement and evolution, which reflects organizational learning through time.

Clearly, these two models share a number of common ideas. For instance, both the Spiral Model and Life Cycle Model conceptualize knowledge passing through various stages as it flows through the enterprise (e.g., socialization, externalization), and both models imply directionality (e.g., socialization precedes externalization, creation precedes organization). Also, both models describe mechanisms for iteration (e.g., knowledge-flow processes and phases can be repeated in cycles), and both models focus on characterizing the dynamics of knowledge flow.

The first step of integrating these models is to augment the two variables of the Spiral Model (i.e., *epistemological*, *ontological*) through incorporation of the Life Cycle variable. This incorporation increases the number of model variables to three. It can be represented in a vector space. The incorporation of the Life Cycle variable permits the tracing of the spiral flow of knowledge across various life cycle phases. The second step is to extend this integrated model by incorporating the dimension *time*. This extension increases the model’s variables to four, and permits the description of the dynamics, the time path, and knowledge flow. For instance, it is possible to trace the flow time of knowledge as it spirals along the life cycle. The third step is to clarify the language used. Because Nonaka’s terminology for the variables (reflected in Figure 1) can lead to confusion (e.g., with respect to use of the terms *epistemological* and *ontological*), the

term *explicitness* is substituted for *epistemological* and the term *reach* is substituted for *ontological* in the integrated model. With these three steps, the resulting four-variable model preserves—and indeed subsumes—both the Spiral Model and Life Cycle Model, and it provides the basis for a richer understanding. The integrated model is used to guide an understanding to the friendly fire incident.

Model Illustration

The model has four variables. To illustrate the model using three variable pictures, one of the variables must be held constant. The first variable held constant is time. Time is modeled as a sequence of discrete time periods. In the first discussion, time is fixed at some time period and the other variables are discussed. Then a multi-period model is considered.

Again drawing heavily from Nissen (2002), a few, notional, knowledge-flow vectors are noted in Figure 2 for illustrating and classifying various dynamic patterns of knowledge as it flows through the enterprise. Consider, for instance, the simple, linear flow labeled “P&P”. It depicts the manner in which most enterprises inform and train employees through the use of policies and procedures: explicit documents and guidelines that individuals in the organization are expected to memorize, refer to and observe. As another instance, the cyclical flow of knowledge described by the amalgamated KM life cycle model from above, depicted and labeled in the figure, reflects a more-complex dynamic than its “P&P” counterpart. As depicted, this latter flow delineates a cycle of knowledge creation, distribution and evolution within a workgroup, for example.

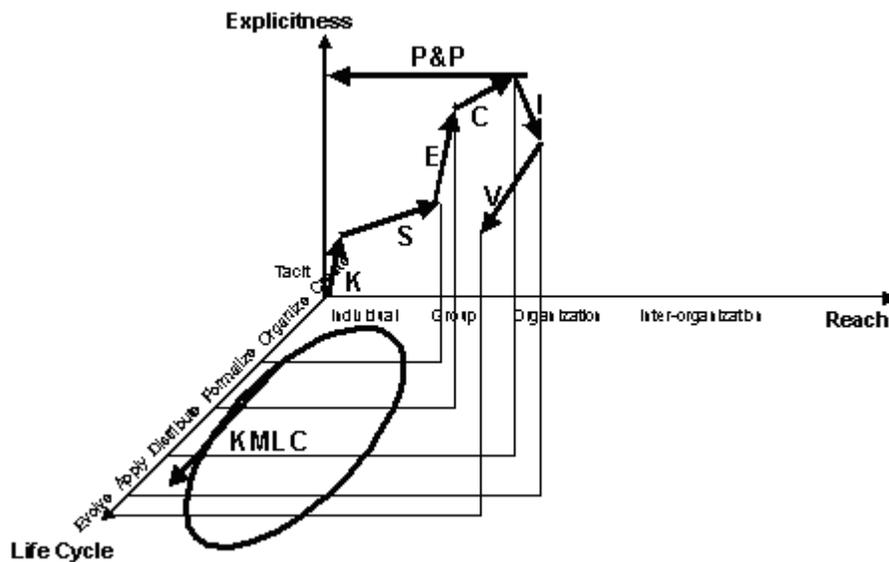


Figure 2. Extended Model with Knowledge Flows

Further, Nonaka's dynamic theory of knowledge flow can also be delineated in this space by the curvilinear vector sequence **K-S-E-C-I**, corresponding to the processes of knowledge creation, socialization, externalization, combination, and internalization, respectively. In Figure 2 notes that the **K-S-E-C-I** sequence involves all the phases of life cycle (note that it is a 3-D representation). Thus the integrated model subsumes the one proposed by Nonaka, and it reveals a somewhat-complex dynamic as knowledge flows along the life cycle. Moreover, examination of this space suggests also including the *refinement* vector (i.e., **V**), which is not part of Nonaka's theory but represents a key element of the empirically derived, Life Cycle Model (e.g., key to knowledge evolution). Refinement is the evolutionary detailing and adjustment of knowledge. Clearly, a great many other flows and patterns can be depicted in this manner. Preliminary results from fieldwork (Nissen 2001 for research agenda) suggest that this three variable subset of the model (represented as a vector-space) is very useful in depicting and visualizing knowledge flows in an empirical investigation into the phenomenology of knowledge flow.

The discussion now turns to illustrating time as a multi-period sequence. In a multi-period model, the variables as shown in Figure 2 are repeated for each period. This is illustrated in Figure 2A. Now, each phase of the life cycle can occur in different time periods, with some phase(s) extending over several time periods. The same idea extends to the **K-S-E-C-I-V** sequence. To ease the exposition in this technical report, time will be discussed and illustrated in a much simpler manner. Consider the life cycle of a knowledge process. On average a knowledge process has a mean time to complete one cycle. The mean time of complete one cycle is a surrogate used for illustrating a multi-period model. Analysis of the mean time to complete one cycle for an organizational task (e.g. software development) is used to characterize the order-of-magnitude differences of knowledge flow times associated with the knowledge needed to perform a particular organizational task.

For instance, if we take some highly explicit knowledge—say a printed document describing how to install a major software application on one's desktop personal computer—then this flow of knowledge can conceivably be completed in a matter of hours, as a literate person needs only to read the instructions before being able to effectively install the software. We plot this first instance of knowledge flow (i.e., "S/W installation") in the figure, which delineates its three-dimensional classification as: 1) highly explicit knowledge, 2) involving only one person in terms of reach, 3) with flow time on the order of hours.

Notice a distinction in this example between the flow of work (i.e., installing software) and the complementary flow of knowledge (i.e., understanding installation instructions) that enables such work to be effected. Thus, in diagrams such as Figure 3, we are explicitly delineating the knowledge-flow processes that drive knowledge required to perform workflow processes.

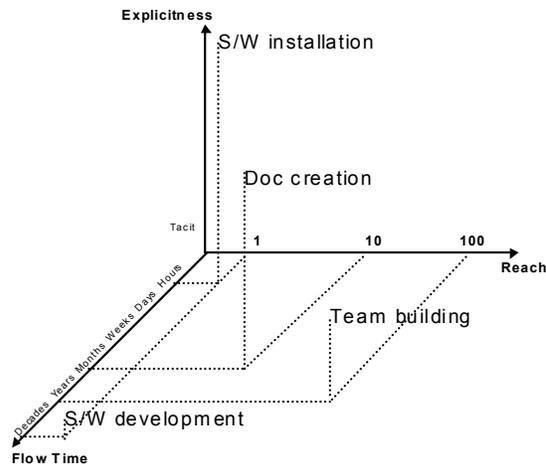


Figure 3. Knowledge Flows with Time Dimension

As another instance, let's take this same document and consider the flow associated with its creation. Presumably, the authors of a software-installation document would be knowledgeable about the corresponding software application, as well as how to write effective installation instructions. And depending on how extensive and complex such an application is, understanding its installation idiosyncrasies could take several months to effect, even though writing the instructions themselves could probably be accomplished in a matter of weeks. Here again, we differentiate between the flow of work (i.e., writing installation instructions; requiring weeks) and the corresponding flow of knowledge (i.e., understanding software-installation idiosyncrasies; requiring months) that enables such work to be performed effectively.

Notice also, the mean time to complete a cycle, the flow time associated with knowledge required to develop the installation document (e.g., months) is one or more orders of magnitude longer than the complementary flow time associated with an individual understanding how to install the software (e.g., hours). This second knowledge flow (i.e., "Doc creation") is plotted in the figure, as it represents moderately explicit knowledge (e.g., some tacit knowledge is required to understand the software), involving a group of people (e.g., 10) in terms of reach (e.g., assuming that people from several different organizations are required to develop the instructions), and requiring months for the knowledge to complete its flow.

As a third instance, consider development of the software application itself. Again depending upon the extensiveness and complexity, a comparatively long period of time

could be required for people to acquire the levels of software-engineering knowledge and experience necessary for its development. Consider that the software architects and engineers must complete several years of college and acquire numerous years of software experience before acquiring the knowledge and experience required to develop a major software product. In some cases, a decade or more may be necessary for the requisite knowledge to complete its flow and enable someone to develop the software application.

This third instance (i.e., “S/W development”) is plotted in the figure showing the knowledge required to develop software is relatively tacit when compared to the knowledge from above, and this knowledge flow is shown at the individual level. But to develop a major software application such as discussed in this example, a large number of individual software architects and engineers must further learn to work effectively in groups and organizations. This team-building knowledge flow is depicted (i.e., “Team building”) in the figure, concerning relatively tacit knowledge, involving many people (e.g., 100) in a relatively large organization in terms of reach, and conceivably requiring years to complete its flow. Once again, the flow of work to develop a software application and the complementary flow of knowledge (e.g., software engineering, team-building) that drives it is distinguished.

Further, if we trace the flow of knowledge through the life cycle depicted in the figure, we develop a composite illustration of its dynamics. For instance, assume that the phases of the lifecycle are independent. That is, the composite process does not have any feedback loops from a phase to a previous phase. The composite knowledge flow begins with education and experience qualifying a person to develop software (i.e., “S/W development”), which is highly tacit and requires a decade or more to flow for a given individual. The next flow involves building an effective team to develop the software (i.e., “Team building”), which is delineated as tacit and involving many people over years. The knowledge required to write and test the installation instructions is more explicit, requiring fewer people and less time to acquire (i.e., “Doc creation”), and the flow of knowledge associated with reading the instruction and installing the software is labeled “S/W installation” (i.e., highly explicit, individual, hours). The broad arrows in Figure 4 delineate the composite knowledge-flow vector as it crosses these four life-cycle phases.

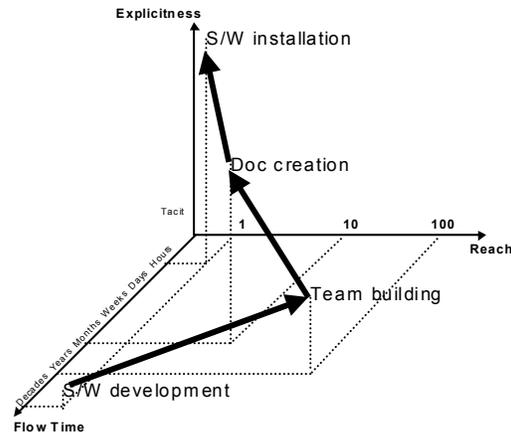


Figure 4. Composite Knowledge Flow

MODEL EXTENSION

The key to addressing context through our model is to examine the manner in which diverse knowledge-flow patterns intermedicate the relationship between enterprise coordination and performance. Specifically drawing from the organizational design and coordination literatures, it is clear that not every coordination approach is appropriate for every pattern of knowledge flows that may become manifest in a particular enterprise and context. Rather, one can use the manifest knowledge-flow pattern to *determine* which coordination approach is likely to be most effective in a given context. This represents a substantial step forward in terms of practical application of emerging knowledge-flow theory, and it serves to integrate the literature of knowledge management with those of organizational design and coordination. This integration is an important theoretical evolution.

This discussion begins by coarsely dividing a three-dimensional representation of knowledge-flow space into octants by making binary distinctions along each of the three axes. For instance, the explicitness axis is divided into two parts: one, near the origin, characterizing flows involving tacit knowledge, the other associated with explicit flows. Likewise, the reach axis is divided into two parts: one, near the origin, pertaining to knowledge flows limited to individuals and groups, the other associated with organization-wide and inter-organizational flows. Similarly, the flow-time axis is divided into two parts: one, near the origin, demarcating relatively short-duration knowledge flows (e.g., hours, days, weeks), the other to depict longer duration flows (e.g., months, years, decades). This divided knowledge-flow vector space is illustrated in Figure 5.

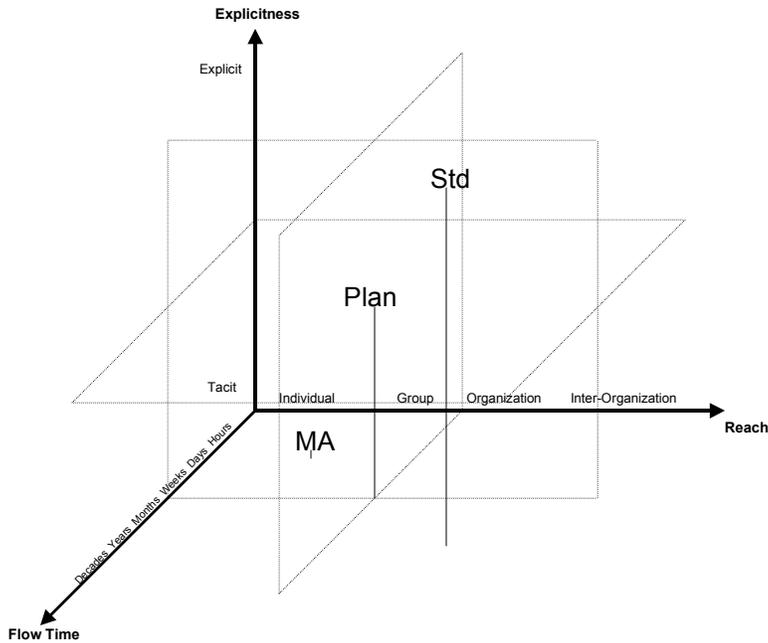


Figure 5. Divided Knowledge-Flow Vector Space

Within this space, several regions to various coordination approaches are mapped. Drawing from Thompson (1967), for instance, consider the three coordination approaches termed *standardization*, *planning*, and *mutual adjustment*, which correspond respectively to three different classes of task interdependence, namely, *pooled*, *sequential*, and *reciprocal*. These three classes of interdependence and their corresponding coordination approaches have been well studied and broadly discussed through the literature, and the relative advantages, disadvantages and appropriateness of each is well known. For instance, Grant (1996) draws from this rich literature to indicate that standardization represents the most economical approach to coordination, particularly for large enterprises, but this approach is ineffective beyond cases of pooled interdependence. And once such standards are established and the corresponding knowledge is internalized by an enterprise, processes relying upon this coordination mode become relatively inflexible and difficult to change in response to enterprise problems or environmental shifts. Conversely, mutual adjustment enables great process flexibility and rapid change by the enterprise, but this coordination mode requires extensive communication—along with a common base of knowledge and experience—and is not nearly as economical as its standardization counterpart. Coordination by planning falls somewhere in between these two in terms of economy and flexibility.

Considering the three- variable model of knowledge flows, the regions most suitable for coordination through these three approaches can be identified and plotted. Beginning with coordination by standardization, by definition, standards are explicit, and for them to be effective in coordinating enterprise activities, they must be applied organization-

wide. Thus, the region high on the explicitness axis and far to the right in terms of reach is so identified. And as noted above, it takes time for knowledge associated with standards to diffuse through the enterprise, and once diffused, standards are relatively inflexible in the short term. Hence the region associated with the standards approach to coordination is also quite far out with respect to the flow-time axis. Indeed, by examining the plot position of a standards-based approach to coordination in Figure 5 (i.e., listed as “Std”), one can see that the corresponding region of the space is extreme across all three dimensions (i.e., highly explicit, broad reach, long flow time). The suggestion from this model is that coordination by standardization is most appropriate for knowledge flows associated with this extreme region. The model would also suggest that coordination by standardization becomes less appropriate as knowledge flows diverge from this octant in the vector space.

Next, coordination by mutual adjustment is addressed. As noted above, mutual adjustment is communications-intensive yet flexible, enabling rapid change but restricting its applicability in terms of reach. This coordination approach is also based more on tacit knowledge shared between enterprise participants than explicit documents (e.g., published standards, policies and procedures, military doctrine). Thus, coordination by mutual adjustment is plotted in the figure (i.e., “MA”) low on the explicitness axis (i.e., involving tacit knowledge), low on the reach axis (e.g., pertaining to individuals and groups), and low on the flow-time axis (i.e., associated with fast-flowing knowledge). Notice, plot positions for coordination by standardization and coordination by mutual adjustment occupy opposite corners of the three-dimensional space delineated in Figure 5. As noted above, coordination by planning falls somewhere in between standardization and mutual adjustment, so it is plotted (i.e., “Plan”) at the center of the vector space depicted in the figure.

Table 1. Knowledge Flows and Coordination Approaches

Explicitness	Reach	Flow Time	Coordination
High	High	High	Standardization
Medium	Medium	Medium	Planning
Low	Low	Low	Mutual Adjustment

As the model is further developed, it is possible to identify a correspondence between various classes of knowledge flows and the most appropriate coordination approaches. This correspondence is summarized in Table 1 where only high, medium, and low levels are distinguished across each of the knowledge-flow model dimensions. The table also lists the most appropriate coordination approach corresponding to the knowledge flow characteristic.. Clearly, entries in the table correspond with plot positions of each coordination approach delineated in Figure 5

This table can be used both prescriptively and diagnostically. For instance, in terms of prescription, if knowledge flows that are extreme across all three dimensions (i.e., high in explicitness, high in reach, high in flow time), then this model would point to coordination by standardization as most appropriate. In terms of diagnostics, if

knowledge flows that are low across all three dimensions (i.e., low in explicitness, low in reach, low in flow time) are encountered, for instance, corresponding to coordination by planning or standardization, then the model would suggest a potential mismatch between the knowledge flows and coordination approach.

MODEL APPLICATION

Model application pertains to an environment in which the contextual considerations exert an extreme influence over knowledge and the relative efficacy of alternative approaches to its flow and management: military combat. Specifically, we discuss a case following the 1991 Gulf War in Iraq. Military combat in this case involved a very large number of people (e.g., over 500,000 U.S. troops, many coalition forces from other countries), associated with heterogeneous organizations (e.g., U.S. Air Force, Army, Marines, Navy, foreign services), dispersed over wide geographical areas (e.g., U.S., Southern Europe, Middle East, Southwest Asia, North Africa), operating in hazardous environments (e.g., combat zones), and performing time-critical missions (e.g., disrupting enemy command and control capabilities, suppression of enemy air defenses, ballistic-missile interceptions). Using the model developed above, we explain how coordination mechanisms and knowledge flows in this extreme, combat context led to one of the most disturbing military events that can occur: fratricide, which involves allied forces killing and wounding allied forces. This is oxymoronically referred to as *friendly fire*. The contextual situation is outlined first and then the explanatory model is applied to the friendly fire case.

Combat Context

When the Gulf War in Iraq ended in 1991, the United Nations established no-fly zones at the 32nd and 36th parallels in order to prevent the Iraqi military from continuing to attack ethnic minorities (e.g., Kurds) within its own population. The southern zone was enforced by Navy aircraft based on carriers operating in the Persian Gulf, and the northern zone was enforced by Air Force fighters from land bases in Turkey. Aircraft enforcing both no-fly zones flew many; daily missions to ensure that Iraqi military aircraft did not cross the parallels, plus they destroyed anti-aircraft batteries, continued the hunt for mobile ballistic missile launchers, and performed a number of other military missions for more than a decade following the war. Our focus in this case is on Air Force enforcement of the northern no-fly zone where the friendly fire incident occurred.

Although only a relatively small number of aircraft would generally be airborne over northern Iraq at any one time, due to the omnipresent risk of conflict, it was essential for everyone associated with both air and ground operations in the area to know the locations, directions and intentions of all other aircraft and ground vehicles. Otherwise, Iraqi aircraft or ground units may travel into restricted areas, or even worse, allied aircraft or ground units may be mistaken for Iraqis and attacked.

In addition to Air Force fighters patrolling the skies to enforce the no-fly zone, other missions required aircraft to fly in the region. These included cargo planes moving supplies and equipment, tanker planes performing aerial refueling operations, helicopters moving troops and other personnel between various locations on the ground, and others. To help coordinate the many flights, the Air Force employed a unique kind of aircraft—

airborne warning and control system (AWACS), which served as an air traffic controller in the sky—to track, guide and direct all aerial traffic in the area. Additionally, all Air Force flights were planned in advance through a process to develop air-tasking orders (ATOs), and all airborne operations were subject to a set of standard operating procedures (SOPs) that addressed everything from flight formations and radio frequencies to rules of engagement for combat and operation of identification friend or foe (IFF) equipment.

Further, military personnel are extensively trained and highly skilled. Combat pilots, for instance, undergo years of education and training before even beginning to acquire on-the-job experience, and fighter squadrons are staffed with many combat veterans able to share important knowledge gained through their many years in the cockpit. Intelligence personnel monitor the evolving situation in Iraq and the rest of the operating area continuously, and all personnel—pilots and others alike—receive daily briefings on current events before performing their missions and duties. Planning personnel look forward, in great detail, several days to schedule each mission and flight, and the U.S. Military empowers a Unified Commander to oversee and direct forces from all the services. At least by formal design, the context appears to be tightly controlled and highly organized.

Alternatively, the system associated with this military operation is very large and quite complex, with myriad interrelated elements interacting 24 hours each day, seven days a week. Understanding that people have bounded rationality, it is clear that no single individual has knowledge of all workings of the entire system, and dynamics of this large system are practically impossible to predict in detail. Further, the military organization is highly specialized, so most participants are expected to have little insight into what others are doing and why. Plus, personnel rotate in and out of units and assignments with considerable frequency, so people do not have the benefit of working and learning with the same team over extended periods of time. But as long as all participants adhere to SOPs and follow specific plans (e.g., ATOs) that are developed to guide their missions, the system is expected to operate without serious problems, and on a statistical basis, the number of such problems is remarkably small given the hazardous, geographically dispersed, time-critical nature of its processes. When problems do arise, however, even when the context and operations are indistinguishable from normal patterns, they can have mortal consequences. This is what happened when the friendly fire incident occurred.

The Chairman of the Joint Chiefs of Staff, the highest-ranking officer in the U.S. Military, summarized the incident as follows (Shalikashvili 1994).

For over 1000 days, the pilots and crews assigned to Operation Provide Comfort flew mission after mission, totaling over 50,000 hours of flight operations, without a single major accident. Then, in one terrible moment on the 14th of April, a series of avoidable errors led to the tragic deaths of 26 men and women. . . . In place were not just one, but a series of safeguards—some human, some procedural, some technical—that were

supposed to ensure an accident of this nature could never happen. Yet, quite clearly, these safeguards failed.

Summarizing from Snook's (2000) detailed account of this incident, the following description helps to illustrate the context associated with knowledge flow in this incident (pp. 3-7).

There were three key players in this incident: a U.S. Air Force ... AWACS aircraft, a two-ship flight of Army UH-60 Black Hawk helicopters, and a two-ship flight of Air Force F-15 Eagle fighters. ... The AWACS took off from Incirlik Air Base in Turkey as the lead aircraft of 52 sorties of coalition air missions scheduled for that day. ... [To direct all other aircraft,] this air-traffic-control-tower-in-the-sky was always the first mission off the ground each day. ... [W]ith sophisticated radar and communications equipment, the AWACS could 'positively control' all coalition aircraft flying in support [of the operation]. The crew reported 'on station' at 0845 and began tracking aircraft.

At 0935, [two Army] Black Hawks reported their entry into the no-fly zone to the AWACS enroute controller and then landed six minutes later just inside the United Nations (UN) designated security zone in northern Iraq [where] they picked up sixteen members of the UN coalition charged with leading the humanitarian relief effort. ... At 0954, the helicopters reported to the AWACS enroute controller that they were departing ... enroute to the towns of Irbil and Salah ad Din Iraq for meetings with UN and Kurdish representatives.

Meanwhile, at 0935, a flight of two Air Force F-15C fighter aircraft had taken off from Incirlik enroute to the air space over northern Iraq. ... Their mission was to 'perform an initial sweep of the no-fly zone to clear (sanitize) the area of any hostile aircraft prior to the entry of coalition forces.' At 1020, the F-15C flight lead reported entering northern Iraq to the AWACS controller. ... Two minutes later, the lead reported a 'radar contact on a low-flying, slow-moving aircraft.' [A series of communications between the F-15C pilots and the AWACS crew ensued, and the fighter pilots turned to intercept the unidentified aircraft. After repeated queries, the F-15s did not receive the proper response from the unidentified aircraft IFF systems].

Following established procedure, the F-15s continued their intercept by conducting a visual identification (VID) pass of the contact. ... The flight lead visually identified a helicopter and called, 'Tally 2 Hinds.' 'Hind' is the NATO designation for a Soviet-made attack helicopter currently in the Iraqi inventory. The second F-15 ... immediately followed with a visual identification pass of his own and called, 'Tally 2.'

By this time the two Black Hawks had entered a deep valley. ... Following their low-level VID, the F-15s circled back behind the helicopters approximately ten miles to begin their firing passes. At this point, the lead notified the AWACS that fighters were 'engaged' and instructed his wingman to 'arm hot' [(i.e., conduct his own independent

targeting)]. ... The lead pilot fired an AMRAAM missile at the trail helicopter from a range of approximately four nautical miles. Immediately following his lead, the F-15 wingman then fired an AIM-9 Sidewinder missile at the lead helicopter from a range of approximately one and a half nautical miles. Both Black Hawk helicopters were instantly destroyed. All twenty-six people on board perished.

Combat Knowledge Flows

To analyze this incident, the focus is on knowledge flows and the extended model from above. Clearly, timing was critical in this incident. Also by formal design of the organization process, someone should have known that the F-15s were firing on helicopters. Such situations are highly dependent upon rapid and effective knowledge flows. The discussion is organized in terms of a few key questions pertaining to the flow of knowledge in this military context.

First, who had knowledge that two U.S. helicopters were flying over northern Iraq that fateful morning? Obviously, all personnel onboard the two Black Hawks were aware of their position, as were their Army commanders on the ground and the UN representatives in northern Iraq. If the people onboard the two helicopters are categorized as one group in terms of the reach axis of our knowledge-flow model, and the Army/UN people on the ground as a second group, then at least these two groups had such knowledge. Additionally, recall from the summary above that the helicopter pilots notified the AWACS crew of their departure toward the two other Iraqi towns. If the AWACS crew are categorized as a third group in terms of the reach axis, then all three groups had knowledge of the helicopters' presence over northern Iraq.

Alternatively, it is clear that the F-15 pilots—our fourth group in the mission organization—did not possess such knowledge, and despite a series of communications between the F-15 and AWACS groups, this knowledge failed to flow to the fighters. Thus, in terms our model, this knowledge of U.S. helicopters flying over northern Iraq that morning—knowledge which is highly explicit and able to flow almost instantaneously by military radio—reached three of the groups associated with the mission organization but not the fourth.

Using the three-dimensional space depicted in Figure 6 to delineate some key relationships between knowledge flows and coordination approaches, the flow associated with this knowledge of U.S. helicopters flying over northern Iraq at the group level is plotted on the reach axis, for such knowledge failed to reach all groups in the mission organization (i.e., fell short of organization-wide reach). This knowledge flow is also plotted at the high end of the explicitness axis, for AWACS and Black Hawk personnel knew exactly where the helicopters were flying most of the time, and this plot is placed at the low end of the flow-time axis, for such knowledge can flow almost instantaneously (e.g., sensed as radar contact, communicated by radio). This point is labeled “H-loc” in Figure 6 for reference. Graphically speaking, had this knowledge flow extended to the organization level in terms of reach (i.e., also reached the F-15 group),

then the friendly fire incident would probably not have occurred. This highlights the criticality of knowledge flow in the combat context.

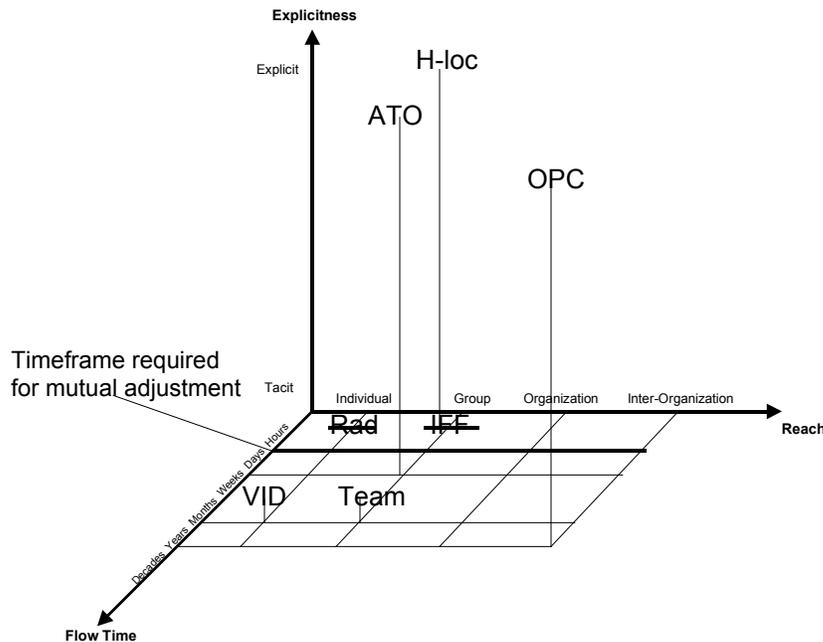


Figure 6. Mission Knowledge Flows

This prompts our second question: what kept the F-15 group from knowing about the helicopters’ presence over northern Iraq? The answer to this question lies in the coordination mechanisms employed for this military operation. Specifically, standardization was the most heavily used coordination approach employed in the combat context, as every combat participant had been explicitly trained to know how such operations were conducted. Such explicit training falls under the rubric of military doctrine. For instance, every participant in the mission organization was informed that AWACS crews monitor and control the airspace, and standard operating procedure was that no flights are undertaken in the no-fly zone until the fighters have “sanitized” the area. Thus, coordination by standardization was designed to ensure that such explicit knowledge would flow throughout every mission organization (i.e., at the inter-organization level of reach). And given the multiple years that Operation Provide Comfort had been underway; such knowledge should have had adequate time to diffuse to all organizations. This plot point is labeled “OPC” in the figure for reference.

So why were the helicopters in the no-fly zone prior to the F-15 sweep? Clearly, coordination by standardization broke down in this case. Even though the helicopters were, technically, operating outside the SOP, their excursion beyond this standard was clearly not the first. Snook (2000) reports that nearly all military units make periodic process adjustments to accommodate changes in local conditions, but such local

variations are not coordinated organization wide, and SOPs are slow to incorporate group-level adjustments enacted by local units.

Moreover, the helicopter pilots, clearly, did not feel that they were in danger, for they had filed a flight plan within their Army organization on the ground and notified the AWACS group of their presence and destination in northern Iraq. Nonetheless, knowledge of the helicopter flight—and knowledge associated with the UH-60 unit’s local variations to SOP—did not flow to the F-15 group. Indeed, from our discussion above, note that coordination by standardization is relatively inflexible and not responsive to change in the short term. So it is not expected that this coordination approach to accommodate knowledge flows associated with a group operating outside the standard (e.g., the two Army Black Hawks) would be effective.

Planning was also a heavily used coordination approach in the military combat context, as every Air Force mission and flight was explicitly delineated on the ATO, and the crew of every aircraft was required to read the ATO prior to the start of a mission. This plot point is labeled “ATO” in the figure for reference. But Army helicopter flights were not included on the ATOs, so Air Force aircrews relying upon this explicit knowledge would not tap into the knowledge flow associated with planned helicopter flights. Indeed, from our discussion above, we note that coordination by planning falls somewhere in between standardization and mutual adjustment in terms of flexibility and reach, so one would not expect for this coordination approach to accommodate knowledge flows associated with groups that are not included in the plans (e.g., the Army Black Hawks excluded from ATOs).

Alternatively, mutual adjustment was attempted as a coordination mechanism in this combat situation, as every aircraft and ground unit was equipped with radios for communication, radar and other sensors to detect and track other aircraft, IFF systems to distinguish between allied and enemy aircraft, and clear canopies for VID. In the present case, the F-15 pilots exchanged numerous communications with members of the AWACS group, as well as communications between the lead and wingman. The Black Hawk pilots likewise communicated by radio with the AWACS crew. Such radio communications are supported by shared knowledge across participants, as military radio messages are generally transmitted through cryptic verbal codes that require considerable cultural compatibility between communicants as well as extensive military experience to interpret appropriately. This enables tacit knowledge to flow between individuals on a rapid basis. The knowledge flow associated with such radio communications is labeled “Rad” in the figure.

So why didn’t the AWACS group relay knowledge of the helicopters’ presence over northern Iraq to the F-15 group? For one thing, the AWACS group employs considerable specialization and division of labor, so the individuals onboard the AWACS responsible for communicating with enroute aircraft (e.g., Black Hawks, F-15s) are not the same people supporting aerial operations after the aircraft arrive in the no-fly zone. And radio communications are generally transmitted from individual to individual, not group to group. Hence, even within the AWACS group, knowledge of the helicopters’ presence in

the no-fly zone failed to reach all members of the aircrew. Thus, the division of labor onboard the AWACS—which represents a standards-based approach to coordination—failed to support the vital knowledge flow required for coordination by mutual adjustment between aircrews of the F-15 and AWACS groups.

Further, it turns out that this particular AWACS crew had not trained together as an integrated team, so crew members had not yet learned to work effectively with one another. Such group-level working knowledge is highly tacit, and it can take weeks or months for an aircrew such as this to become proficient as an AWACS team. We plot this group-working knowledge as “Team” in the figure. Notice that the flow time (i.e., months) associated with this knowledge flow is incompatible with the kinds of rapid knowledge flows (i.e., minutes) required for mutual adjustment in this case.

So why didn't the F-15 and Black Hawk groups communicate directly by radio? It also turns out that the radio systems used by the Air Force F-15 group differed from those employed by the Army Black Hawk group. Although the AWACS crew was able to communicate with both groups, the F-15s and Black Hawks were unable to communicate directly with, and hence mutually adjust to, one another. Here, standardization of radio equipment had been effectively accomplished within two of the flying-group pairs (i.e., F-15s and AWACS, AWACS and Black Hawks) but not the third (i.e., F-15s and Black Hawks). Hence, equipment incompatibility also prevented the flow of critical knowledge required for mutual adjustment.

Other problems further contributed to the impeded knowledge flows. For instance, the Black Hawk IFF equipment failed to respond with the signal expected by the F-15 pilots. Each day, a plan outlining new IFF codes to be used in various geographical areas is distributed to all flying groups, and IFF equipment on all aircraft scheduled for missions is checked before every flight. If all goes according to plan, IFF signals can enable the flow of explicit knowledge (i.e., friend or foe) between aircraft on a near-instantaneous basis, but interpreting the signals correctly requires tacit knowledge. The flow of such interpretation knowledge is labeled “IFF” in the figure. Unfortunately, a combination of technical and procedural factors prevented the Black Hawk IFFs from “squawking” with the right code, and the F-15 pilots never thought to check other codes (e.g., appropriate for flights outside the no-fly zone) that allied helicopters might be sending before downing the Black Hawks. Here, an over-reliance upon coordination by standardization via by planning prevented a vital flow of knowledge required for the F-15 group to adjust to the IFF problem exhibited by the Black Hawk group.

As another instance, SOP required VID by the F-15 group prior to firing weapons, and all F-15 pilots receive some training on how to distinguish between allied and enemy aircraft. Such knowledge flows at the individual level and is quite tacit in nature, sometimes requiring months—or possibly even years—for pilots to learn completely. This knowledge flow is plotted as “VID” in the figure. But if such knowledge has not been learned before the pilots begin their mission, there is insufficient time for them to acquire VID knowledge while in the air. Here, both fighter pilots—one of which had considerable combat experience—misidentified the Black Hawks as Soviet-made Hinds,

so the mutual adjustment associated with the VID failed to occur. As above, the flow time (i.e., months) associated with this knowledge flow is incompatible with the kinds of rapid knowledge flows (i.e., minutes) required for mutual adjustment in this case. In all, three separate opportunities for mutual adjustment—any one of which could have prevented the friendly fire incident—failed, and the requisite knowledge (i.e., that two U.S. helicopters were flying over northern Iraq that morning) failed to flow to the most important group: the F-15s.

Summary

To summarize, Figure 6 shows the plot points of several different knowledge flows associated with this incident. From our analysis of the incident, note the tradeoff between coordination by mutual adjustment and standardization (e.g., Black Hawks entering the no-fly zone prior to F-15 “sanitization”) and planning (e.g., helicopter flights excluded from the ATO). Mutual adjustment was required in the incident to compensate for problems of standardization. Note also that the model from above suggests mutual adjustment is most appropriate to support knowledge flows near the origin of the space (i.e., low explicitness, low reach, and low flow time). However, notice from the plot points in the figure, however, that only two knowledge flows correspond to this region supporting mutual adjustment (i.e., “Rad,” “IFF”).

Unfortunately, the communication-based knowledge flow enabled by radio equipment was ineffective due to incompatible systems on the Black Hawks and F-15s. With equal misfortune, the knowledge flow associated with IFF equipment was also ineffective due to incorrect interpretation by the F-15 pilots. In the figure, we draw lines through the corresponding labels “Rad” and “IFF” to indicate that these knowledge flows were ineffective at the time of the friendly fire incident. Additionally, an inexperienced AWACS team failed to relay knowledge of the helicopters’ presence inside the no-fly zone to the fighters, and the F-15 pilots lacked the requisite knowledge to correctly VID the U.S. helicopters. In the figure, we draw a thick line across the vector space at the hour’s level along the flow-time axis. This symbolizes that any knowledge involving longer flow times (e.g., “VID,” “Team,” “ATO,” “OPC”) was incompatible with the kinds of rapid knowledge flows required for effective mutual adjustment.

Therefore, when examining this figure, one can see that no knowledge flows associated with the mission were available to support the kind of coordination by mutual adjustment that was required. This is not to place blame for the incident on any one or even multiple participants. But this shows how a mismatch between the knowledge flows required to prevent this tragedy (e.g., F-15 radio communications with Black Hawks, correct interpretation of Black Hawk IFF signals by F-15s) and the coordination mechanisms available to support such flows (e.g., standardization, planning) can explain the friendly fire incident. This provides some evidence to support the use and utility of our contextually extended knowledge-flow model, and it illustrates, most graphically, the contextual criticality of knowledge-flow dynamics in military combat.

Future Research

This technical report provides an overview of the thrust of the authors' collaborative research. In future technical reports and follow-on journal articles, we will provide the details to enrich the understanding of the model and expand the model to encompass additional phenomena. In particular we anticipate focusing on:

- The distinction among the concepts knowledge, information, and data.
- The relationship of knowledge management to organizational process performance and fitness in the organization's ecology of conflict and cooperation.
- The extension of the model's application to other organizations, military and civilian, and organizational processes.
- The development of knowledge management as a organizational coordination, control, and adaptation technique.
- The development of a comprehensive time-dated model that provides an understanding of the expanded domain of the model using the what, where, when, and if modeling technique.

CONCLUSION

Recent research has produced models that improve our ability to identify, describe and explain a diversity of knowledge-flow patterns that manifest themselves in various enterprises, which improves our efficacy in designing organizations and processes. But enterprises do not all operate in the same environmental context and current theory is relatively silent on contextual implications of knowledge flow. The research described in this technical report builds upon current theory to explicitly address the contextual implications of knowledge flow in terms of organization and process design. Using a recently developed, multidimensional model to characterize and delineate a variety of enterprise knowledge flows, we integrate key aspects of Coordination Theory and extend this model to address context.

The use, utility and implications of this extended model are described through application to an extreme case in which knowledge flows are embedded within a hazardous, time-critical context with mortal consequences: a military "friendly fire" incident in Northern Iraq. Through analysis of this incident using the model, the tragic incident is explained in terms of incompatibility between knowledge flows and the coordination mechanisms employed to support such flows. In the end, one can graphically observe that the military organization lacked adequate coordination mechanisms to accommodate the kind of real-time mutual adjustment required to prevent the fratricide.

The extreme nature of this application incident provides revelatory insight into the contextual importance of knowledge-flow dynamics, and by using such an extreme incident for application, the **generalizability** of the model to less extreme environments

that are more commonly associated with non-military enterprises (e.g., corporations, governmental agencies) is enhanced. For instance, many large, geographically dispersed corporations, governmental agencies and other classes of enterprise employ standards-based coordination mechanisms in a manner very similar to that described in this technical report, and coordination by planning is equally prevalent in non-military enterprises of all sizes. To the extent that knowledge flows in these non-military enterprises require mutual adjustment for process efficacy, then mismatches between such knowledge flows and appropriate coordination mechanisms to support are likely.

Further, our contextually extended knowledge-flow model may prove to be equally useful in terms of explanation, prescription and diagnosis as described in the friendly fire case. Of course, this requires additional empirical research to verify, and such mortal consequences of accidents are far less likely in most corporations and governmental offices than in combat zones. But the routines and communication patterns of knowledge workers are likely to be quite similar across a wide variety of domains—in the public and private sectors alike—and the kinds of insights provided through research along the lines of this investigation may prove to be useful across a diversity of enterprises. Thus, the present technical report strives to take a step in this direction and add to the foundation of cumulative research associated with knowledge management in context. There are many research opportunities to explore.

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