

Examining Disconnects as Drivers of Cost and Time Overruns in Complex Innovative Government Development Programs: A Multi -Method Approach

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Summary:

This research explains how “disconnects,” or large gaps in contract baselines, can occur in complex software-intensive government initiated programs and identifies ways to reduce significant unchecked miscommunications. Disconnects are important because they can and do contribute to uncertainty over project scope and significant cost overruns, and missed deadlines, all of which threaten timely and within budget completion of quality projects that fully meet initial design expectations.

We qualitatively analyzed a case study created from 30 semi-structured interviews of participants in multiple organizations involved in a multi-year government aerospace acquisition program that repeatedly encountered “disconnects,” episodes of discovery that the supervising program office, prime contractor, subcontractors, and vendors had sharply different understandings of the work to be done. These disconnects emerged despite multiple cross-organizational and cross-functional efforts to communicate and document clearly the technical and financial baselines describing the scope and schedule of the program work.

Additionally, we used simulation analyses of a system dynamics model grounded in the data. The model takes a differential equation based approach to the problem and considers feedback loops in the system which may exacerbate misunderstandings in a governmental project. An extensive number of simulation runs and sensitivity analyses are conducted for different parameters in order to compare the effects of communication clarity, orientation expertise level, and delays and interactive effects of the parameters on the dynamics of disconnects.

Our findings underscore the relative role that of number of iterations and pacing (and delays) of iterative communications can play in creating shared understanding. Delays, which in part represent how responsive a partner is, can have counter-intuitive effects on players’ convergence or divergence in a dyadic communication. Our study shows that reducing observation and orientation delay can be considered as a leverage point for communication convergence, while increasing decision and action delay may facilitate convergence. Additionally the findings corroborate and point to additional research to be undertaken to explain further the influence of actors’ expertise and artifacts’ clarity and accessibility in preventing miscommunications in very large multi-year programs requiring work from participants in multiple organizations.

KEYWORDS: Shared understanding, social construction, project management, system dynamics

1. Introduction

Innovation projects differ from other collaborative efforts because at the outset actors lack an understanding of the problems they will encounter as they work to create an end-product that has not been achieved before. Requiring the participants from multiple disciplines and resources across multiple organizations, these collaborations to innovate are often characterized by lack of a single governance office and an often unanticipated absence of shared understanding at the outset of the work-to-be-done. Examples of contexts in which aligning different players to create a shared understanding of a project or a policy is critical include governmental projects in the health sector (Bryant and Darwin 2004, Kim 2008), the environmental sector (Al-Rashdan et al. 1999), and construction projects with multiple contractors (Franco et al. 2004).

In doing innovative work, not only do project members not know what they do not know, but they also often lack common values, assumptions, and work methods to facilitate communications to mutually perceive problems and socially construct their technical solutions. Breakdown in collaborative innovation projects such as aerospace development, large information-system development and other information-intensive and operationally integrative programs lead to cost and schedule overruns and quality and capability shortfalls. A salient example is the IT-based baggage handling system at Denver International Airport, delivered with significantly reduced capability 16 months late and with cost overruns of \$2 billion (Montealegre and Keil 2000).

Research indicates that breakdowns in innovation projects may stem from the multidisciplinary nature of the work. Differing disciplinary and organizational values, assumptions and work processes necessary for truly innovative work can lead to increased uncertainty in planning at project outset (Anderson and Joglekar 2005). Working across

boundaries in networks involving federal, state, and local government managers collaborating with nongovernmental organizations necessitates mutual learning and adjustment (Agranoff 2006), which also leads to an evolving understanding of the work-to-be-done. This mutually influenced, evolving understanding of the work-to-be-done can lead to scope creep. Zhang et al. (2003) provide a wide range of evidence for scope escalation in governmental IT projects including different projects in California Department of Motor Vehicles (cost of \$49.4 million for a project before it was abandoned), and California Department of Social Services (a project cancellation after a delay of 26 months and \$270 million cost overrun estimation which was 357% above the initial plan).

Creating a shared understanding of the work-to-be-done requires that collaborators have similar if interdependent ideas—at the same time. While this notion indicates that cadence of communication is important to creating shared understanding in innovation projects, little attention has been explicitly focused on the role of delays in shaping shared understanding, and therefore the roles of delays in innovation project breakdowns. We undertook analyses of a simulation grounded in a case study and informed by theories of social construction, to explore the dynamics of creating shared understanding across organizational boundaries in large innovation projects. Our simulation results support the previously reported ideas that increasing communication clarity and expertise level in understanding messages can result in faster convergence in players' understanding (Greer et al. 2006). Further, our sensitivity analysis sheds lights on the different and counterintuitive effects of decision and action delay and observation and orientation delay on players' convergence of shared understanding.

1.1 Case Study and Empirical Methods. The empirical context giving rise to this study was very large, government-initiated software-intensive aerospace development programs whose focus was on, not “make-to-order” demands, but rather “research-to-order” and “engineer-to-order” work. This meant that the organizations involved had to integrate knowledge from multiple disciplines, often crossing organizational, geographic, and even societal sector boundaries, in order to accomplish large-scale implementation of innovative technologies. The presenting problem from the System Program Office (SPO) supervising the work was to reduce “disconnects” in understanding the scope of work among multiple organizations serving as the SPO, prime contractor, subcontractors and vendors, specifically, "How does system engineering identify a 'disconnect,' and what do we do when we find one?" Greer et al. (2006) defined a “disconnect” as a latent difference in understanding of the work to be done among program participants, at the team, group, or organizational level, that when recognized can cause significant rework, schedule slips, reputation damage, and cost overruns. In the extreme, “disconnects” become Nunn-McCurdy breaches (Nunn-McCurdy Amendment, H.Rept. 97-311, Department of Defense Authorization Act, 1982) requiring Congressional investigations of causes of cost and schedule overruns and quality shortfalls in governmental work.

As reported in Greer, Black and Adams (2006), data collection proceeded through 20 semi-structured interviews (Eisenhardt 1989; Merton, Fiske and Kendall 1990) of individuals involved at various levels of technical and organizational responsibility in the SPO. Interviewees' years of experience in the SPO ranged from one to more than 20 years, and interviews lasted from 45 minutes to 2-1/4 hours. The research team conducted qualitative analysis and grounded theory-building (Glaser and Strauss 1967) to distill key categories and constructs causally related, in interviewees' minds, to the problem of disconnects. In keeping with Eisenhardt's (1989) view of

case studies and Glaser and Strauss's (1967) advocated method of grounded theory-building, data collection and qualitative analyses overlapped. As analyses of the data proceeded iteratively, discussions of research-in-progress with individuals and small groups in the SPO stimulated individuals' providing additional data, which were then used to check, corroborate, disconfirm, and/or add depth to the emerging picture. Interviewees' causal explanations for disconnects centered on several themes:

- People can't communicate.
- The SPO lacks expertise.
- People are too slow in making sense of proposed changes.
- People (esp. in the SPO) are too slow to act.
- Changing requirements cause disconnects.

The research team constructed a small simulation model representing the communication “system” among organizations, with delays and pacing of interactions consistent with the data gathered, and consistent with theories of social construction and decision-making processes, in order to test in a tractable manner these competing explanations for disconnects in this long-term innovation program.

1.2 Theoretical Basis. The formal model constructs are informed by symbolic interactionism theories (Mead 1934, Blumer 1969, Strauss 2008), which examines social interaction as a process of constructing, sustaining and transforming meaning. According to interactionism, meaning is situated, always. It is informed by an accumulation of experiences, according to Mead (1934), shaped by the meanings gained through previous interactions with others. Blumer (1969) stated that Mead's theory of interactionism was based on three premises:

First, a person acts toward/with/on a thing based on the meaning s/he ascribes to the thing. Second, people gain the meanings they ascribe to things from their interactions with others with regard to the thing. Meanings are, therefore, “social products” (Blumer 1969: 5). Third, a person gains and modifies meanings through a process of interpretation that includes, first, an indication or focus on the thing, and, second, a process of communication with oneself based on an internalized social process. Interpretation emerges as a person “selects, checks, suspends, regroup, and transforms the meanings in the light of the situation” in which s/he stands and the goal of his/her action (Blumer 1969: 5).

Strauss (1985, 2008), whose research often focused on trajectories of work that crossed boundaries of occupation, experience, duration, or discipline, has emphasized that interaction implies an intersection of actions arising from differences among actors’ perspectives. People from different technical disciplines and in different organizations have different dimensions of concern and work from different assumptions, use different language and have different objectives (Strauss 1985). These discrepancies can exacerbate the problem of creating shared understanding in multi-disciplinary projects, where there may be no shared culture to fill in or correct communication breakdowns that occur. Therefore many participants in interaction necessitate alignment or “articulation” of respective actions, since memberships in social worlds and sub-worlds condition actors’ perspectives (and interactions); and interacting (accumulating) social processes create, maintain, and reinvent social structures.

In constructing grounded theory of the aerospace program participants’ interactions, we attended to the decision-making cycles (Boyd 1992; Mintzberg and Westley 2001) of each organization involved in the innovation work. We noted that each not only used different language (or the same language but intending different meanings) but also each used different

durations for attending to and interpreting communications from collaborating organizations and for implementing actions based on new communications. Cued further by interviewees' attributions of "slowness," we began to explore explicitly the delays in observing and orienting, deciding and acting in the subsequent simulation analyses.

1.3 Prior Modeling Work. As with grounded theory, a formal model can be constructed by inferring from data some hypotheses about causal relationships that generate a particular pattern of behavior observed in the field. Here, prior modeling work focused on significant differences among the trajectories of the understanding of work to be done by four organizations: the SPO, the prime contract, a subcontractor, and a vendor. Model-building proceeded by representing hypotheses with connected elements of model structure, simulating the structure, comparing the simulated behavior qualitatively and in degree to the behavior observed in the field, and returning to the data to refine the hypotheses represented in the model by changing its structure. In this manner, we constructed a system dynamics model (Forrester 1961, Sterman 2000) of each organization's understanding of the baseline and its perception of the other parties' baselines—and how these perceptions are altered by requirements changes or by communication with other organizations on which its work depends. Dynamics of iterations in Production and Operations Management (POM) of innovative products is examined through considering feedback loops, accumulation processes, and delays in the system, which in many situations is helpful in addressing POM related challenges (Größler, Thun and Milling 2008). The model attends to the interactions among organizations as they seek to "get on the same page," since organizations cannot directly observe each other's understanding of the work to be done, even when that work is specified "in black and white."

Briefly, the basic elements of model structure in Greer et al. (2006) represent that each organization accumulates its understanding based on its own actions and on the communications it receives from others in the intellectual-capital supply chain, who also accumulate their own understandings, influenced in similar ways. These dynamic interlocking loops of floating-goal stock-flow information-smoothing structures common in many system dynamics models serves as an explicit representation of Mead's (1934) foundational theory of how meaning is constituted. As individuals accumulate experiences of their own actions and others' communications with them, these experiences affect how they interpret and then adapt to subsequent communications from others and even their own actions.

For example, the SPO's perception of the contractor's baseline will change based on the contractor's baseline, the clarity of the contractor's communication to the SPO about the baseline, the SPO's own expertise level in determining what the contractor's communication means, and the delays the SPO experiences in attending to and re-orienting (figuring out "therefore what?") to the baseline change based on the contractor's communication. As the SPO's perception of the contractor's baseline changes, the SPO may change its own baseline. The change in the SPO's baseline is influenced by its perception of the contractor's baseline, any requirements changes coming from users or other external parties, and the SPO's internal delays in deciding how to respond to and then act on the changes it perceives. This conceptualization of model structure is consistent with the dynamic pacing of an individual's Observe-Orient-Decide-Act (OODA) loop first articulated by Boyd (1992) and more recently interpreted in terms of organizational decision and action by Haeckel (1999), Mintzberg and Westley (2001), and Sull (2007).

Interestingly, Greer et al. (2006) represented the causal influences on each party's perception of the baseline with the common formulation for auto-correlated noise. Unlike many model

implementations of noise, however, the variables associated with noise have real-world analogs here. It used "clarity of communication" as the (inversely related) standard deviation in the signal from one party to another, since clearer, more robust, and more specific means of communication reduce the variance between what is intended and what is actually communicated. It used "expertise level" (inversely related) as the min-max range of the random function associated with the variance in the signal, since high expertise can actively sift information and orient on the more relevant aspects of the information at hand. The "observation and orientation delay" is the correlation time in the noise function.

Validation processes for the prior modeling work are well described in Greer et al. (2006), as are the simulation analyses findings and implications. In summary, the research reported that disconnects arise even when all requirements changes are eliminated; speeding up the SPO's decision and action actually exacerbated disconnects, while speeding up the SPO's observation and orientation reduced disconnects; and the greatest points of leverage in reducing disconnects were to increase expertise and to increase clarity of communication, which the authors related to sociological studies of boundary objects (Star and Griesemer 1989, Henderson 1991, Carlile 2002).

2. Current Modeling

Building on a previous study (Greer, Black, Adams 2006), this research develops a modified system dynamics model to explore communication dynamics in a chain including a government system program office (SPO), a general contractor, and a subcontractor, as they interact to negotiate scope changes to a large project that requires collaboration across many disciplines and organization responsibilities. The model reported in Greer et al. (2006) was arrayed (using the

same structure for each of the four players' baseline understanding and their communication to other players), which made some of the dynamic behaviors more difficult to analyze. In this effort, based upon the case-study investigation and simulation model and analysis reported in Greer et al. (2006) and summarized above, we construct an un-arrayed model of shared understanding in product development work teams in three steps and analyze the behaviors of the sub-structures along the way. An un-arrayed and a simpler representation of a model can help tractable exposition of the structure. In addition, lower dimension models more easily lend themselves to behavioral analysis, and building a lower dimension model of a model can help us to push forward our understanding of the dynamics, dominant loops, and interactive effects of different parameters on the behavior. Then we conduct sensitivity analysis experiments with different model parameters to extend our understanding of how different delays affect baseline-understanding convergence, and finally, we discuss the implications of simulation results.

In the following, we develop a simple, lower dimension, un-arrayed version of the model proposed in Greer et al. (2006) in three major steps. More specifically, we rely on the interviews and the grounded theory approach taken in Greer et al. (2006), and develop a simple version of the original model for a chain of two dyads (three players), with a few modifications in some formulas. This simpler version allows extensive detailed experiments and analyses and leads us to new propositions about if and how convergence emerges in collaborative product development work teams.

2.1. A One-Way Communication: In the first step we assume the communication is between the system program office (SPO) and a prime contractor (KTR) in a large government acquisition program to create new applications of technology. For simplicity, let's assume the

communication is about a single dimension concept, e.g. the program scope. The players can have different perceptions about this dimension, and they can communicate in order to understand the other side's expectations.

First, we begin with a one-way, top-down communication: Let's assume there is a gap between initial scopes of SPO and KTR (SPO and KTR scopes are assumed to be 150 and 100 respectively. Scope unit can be Million Dollars, time unit, number of major tasks, etc.). If we have a one-way communication from the SPO to the KTR, it is expected that the SPO will be able to change the KTR scope with some delays (Figure 1a). Assuming no ambiguity in the communication (i.e., no noise in the model representation), the KTR will be able to understand and change its scope toward the SPO's. (Figure 1b)

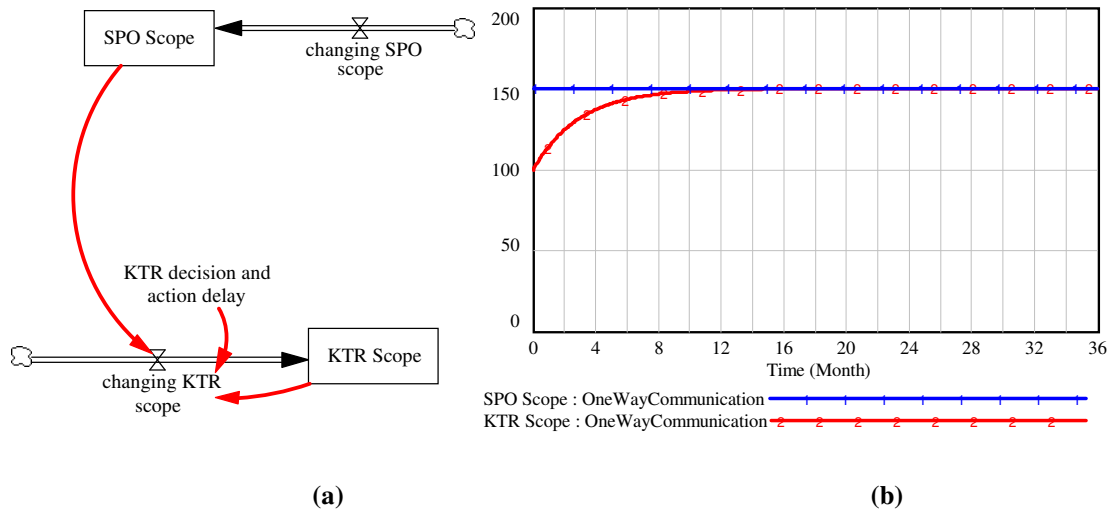


Figure 1 – A one-way unambiguous communication – a) the structure, b) the behavior

Note: KTR decision and action delay = 3 months

Although it is commonly believed by many people that their own understanding can be unambiguously communicated, rarely can we have perfect and clear communication. People may not be able to send a clear message to their partners, or the partners may not be able to

understand the received message. Both the clarity of message sent from the SPO and the KTR's orientation expertise level can influence the KTR's perception of the SPO's scope, and therefore the KTR's understanding of program scope. Adding noise to the model, representing lack of clarity in the sender's message and lack of expertise in the message receiver, we can modify the formulation.

Furthermore, there are always observation and orientation delays for all parties. It takes time for people to assess their partner's understanding of the program's scope and it takes time to observe and make sense of the implications of that understanding. That delay, in combination with the effects of communication clarity and the receiver's orientation expertise level, influences the dynamics of communication (Figure 2a).

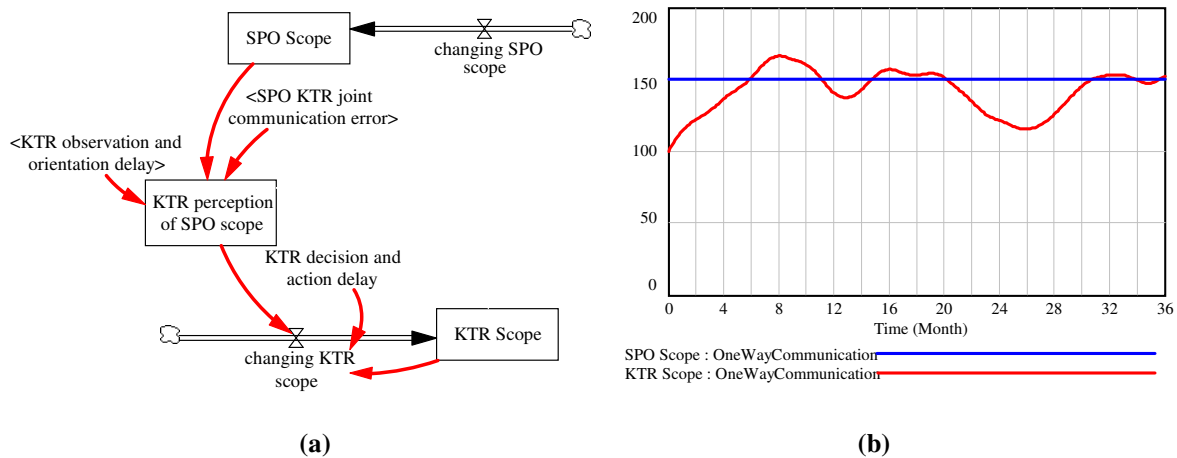


Figure 2 – A general one-way communication – a) the structure, b) the behavior

Note: both delays=3 months, communication clarity=0.5 and orientation expertise level = 0.5, on a scale from 0 to 1

Mathematically, we can use the following formulation to model KTR perception of SPO scope:

KTR perception of SPO scope = Smooth3I (SPO Scope + SPO KTR joint communication error, KTR observation and orientation delay, SPO scope) (Equation 1)

SPO KTR joint communication error = (1-Clarity of SPO Communication)(1-KTR orientation expertise level)*Normal communication error*(24 * KTR observation and orientation delay/ TIME STEP)^0.5 * RANDOM UNIFORM(-0.5, 0.5, seed) (Equation 2)*

Equation 1 represents how observation and orientation delay can influence the KTR's perception of the SPO's scope. In Equation 2, the communication error is formulated by considering the effects of communication clarity and expertise level. The ambiguity is represented by a simple uniform random generator in [-0.5, 0.5]. The main logic behind these equations is adapted from Greer et al. (2006), which used a pink-noise formulation in which communication clarity was represented by the (inversely related) standard deviation and orientation expertise level served as the (inversely related) min-max range. In comparison to the original model, there is a modification in the noise generator function which is still consistent with the data and was made to make the model more consistent with the generic pink noise formulation in system dynamics (Sterman 2000, p.918).¹ As Figure 2b shows, the KTR is still able to understand the SPO generally, but there is oscillation around the SPO's scope due to the noise.

2.2. A Dyadic Communication: In the real world, the KTR can also communicate with the SPO, so there is a dyadic communication structure, i.e. a two-way communication channel. This

¹ This formulation is consistent with the suggested formulation in system dynamics for the pink noise generator in which standard deviation is $(1-Clarity\ of\ SPO\ Scope)*(1-KTR\ orientation\ expertise\ level)*Normal\ communication\ error$. Therefore the absolute value of joint communication error increases as clarity of SPO communication or KTR orientation expertise level declines.

happens especially in innovative projects when no one necessarily knows everything about the work to be done in a project but participants make sense of it as the program unfolds. Based on Mead's (1934) theory, each participant creates meaning as they interact through gestures, language, and reified symbols. In other words, in the communication between the KTR and the SPO, the players seek to understand each other through communication. Like the previous stage, again, communication can suffer from ambiguity due to difficulties of communication. Figure 3a, replicating the constructs and formulations described in Greer et al. (2006), shows a simple structure of dyadic communication, and Figure 3b displays the simulation results of such a structure.

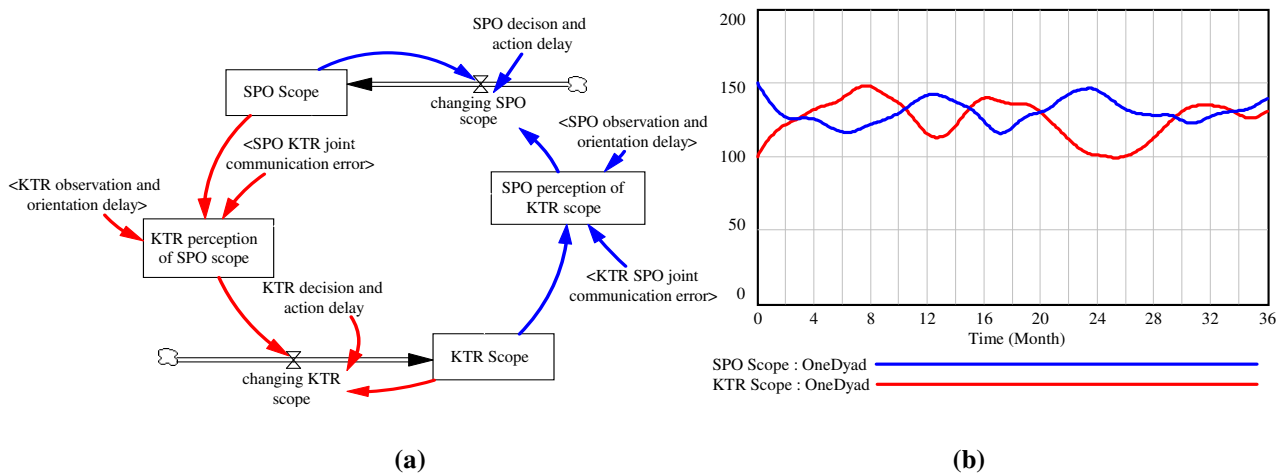


Figure 3 – A dyadic communication – a) the structure, b) the behavior

Note: all delays=3 months, communication clarity=0.5, orientation expertise level = 0.5

As we see, the KTR and the SPO can start from different initial conditions and through interactions their understandings of the program scope can become more similar. However, as long as ambiguity exists in communication as represented by these interlocking floating-goal loops, their understandings will not totally converge.

2.3. Chain of Dyads: In many industries material and intellectual supply chains can include a number of dyadic relationships, as contractors work with multiple subcontractors, subcontractors with multiple vendors, and so on. In this chain, studying effects of a change in the understanding of one of the players on the whole system's collective understanding can be interesting. We can expand the model by adding a subcontractor (SUB) to the chain, in which the SUB is in contact with the KTR, and the KTR is in contact with the SPO (Figure 4a) and examine the dynamics of convergence/divergence among different players' scope (Figure 4b). As before, we have a supply chain in which understanding is communicated, rather than material and money.

Obviously, the middle player (here, the KTR) is not necessarily paying attention equally to the other side (here, SPO and SUB), but may assign different priorities to different messages. Consistent with Ocasio's (1997) research on attention, Greer et al. (2006) considered listening priority in communication as a variable in their model. They defined KTR's listening priority as a ratio between 0 and 1, and this model thus formulates KTR scope as following (Equation 3):

$$\text{Change in KTR scope} = (\text{KTR perception of SPO scope} * \text{KTR's listening priority} + \text{KTR perception of SUB scope} * (1 - \text{KTR's listening priority})) / \text{KTR decision and action delay}$$

(Equation 3)

$$ADI = \sum_{t=1}^{\tau} (|SPO\ scope_t - KTR\ scope_t| + |SPO\ scope_t - KTR\ scope_t| + |SPO\ scope_t - KTR\ scope_t|) / \tau$$

Equation 4

So, for a larger ADI, we have more divergence among the players' scope, and less shared understanding.

3.1. Effect of communication clarity and orientation expertise level: First, we test for the effects of these parameters. Based on Greer et al. (2006), we can hypothesize that higher communication clarity and higher orientation expertise level can result in faster convergence among players. Let's put listening priority equal to 0.5, indicating that the KTR's overall perception is equally influenced by the SPO and SUB.

As we expect, the simulation results support the notion that sender's communication clarity and recipient's expertise play a significant role in the dynamics of communication. High values for these can decrease the discrepancy between one's scope and the other's perception of that scope. In the model, we see more convergence as a result of increases in communication clarity and expertise level. Figure 5 shows this prediction by comparing two extremes for communication clarity (high clarity vs. low clarity).

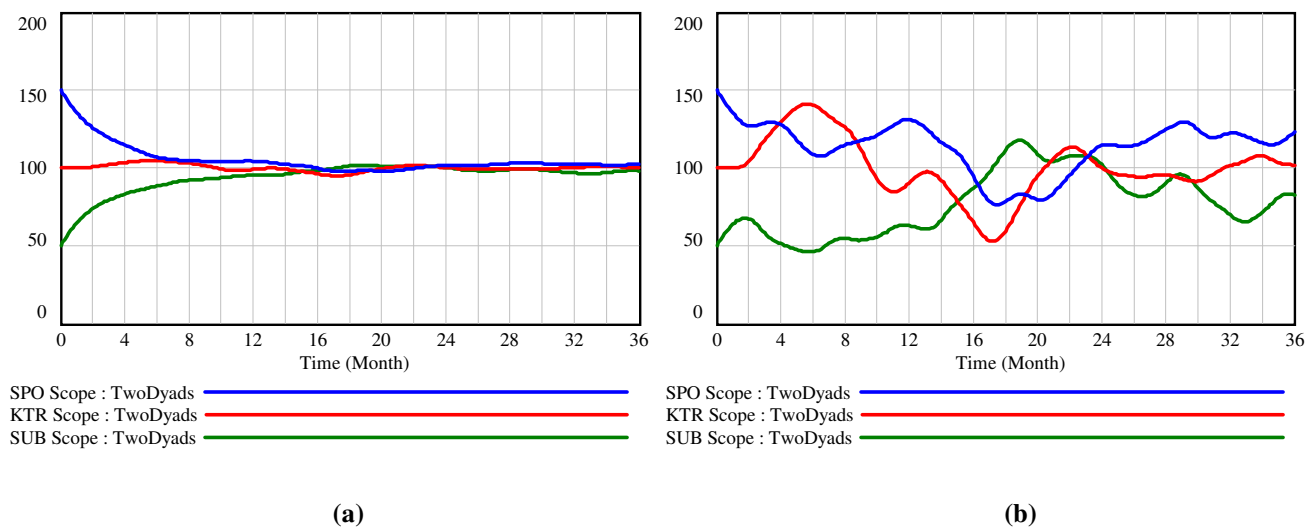


Figure 5 – Effect of communication clarity on dynamics of convergence for different levels of communication clarity and orientation expertise level. a) high clarity (0.9), b) low clarity(0.1).

Note: all delays=3 months, orientation expertise level = 0.5

The same result exists for the effect of expertise level, in which a higher level of expertise results in lower ADI. So far, we have shown that our basic prediction about the effects of clarity and expertise level of dynamics of shared understanding can be qualitatively replicated by the model.

3.2. Effect of decision and action delay: Effect of decision and action delay does not seem intuitive in the first glance. Delay can be a source of oscillation, and we expect that by increasing delay, the level of total divergence may increase. Further, we may expect that players’ fast response to their partners’ messages (shorter decision and action delay) should result in faster convergence. Conducting some experiments with the model does not support this notion in some situations. In many cases an increase in decision and action delay does not necessarily result in more divergence.

To shed more light on the effect of decision and action delay, we conduct a set of simulations for different values of this parameter in different levels of communication clarity, and compare the final divergence among the players. Figures 6a and 6b show the results. The figures are drawn based on averaging the results from 200 different sets of random seeds.

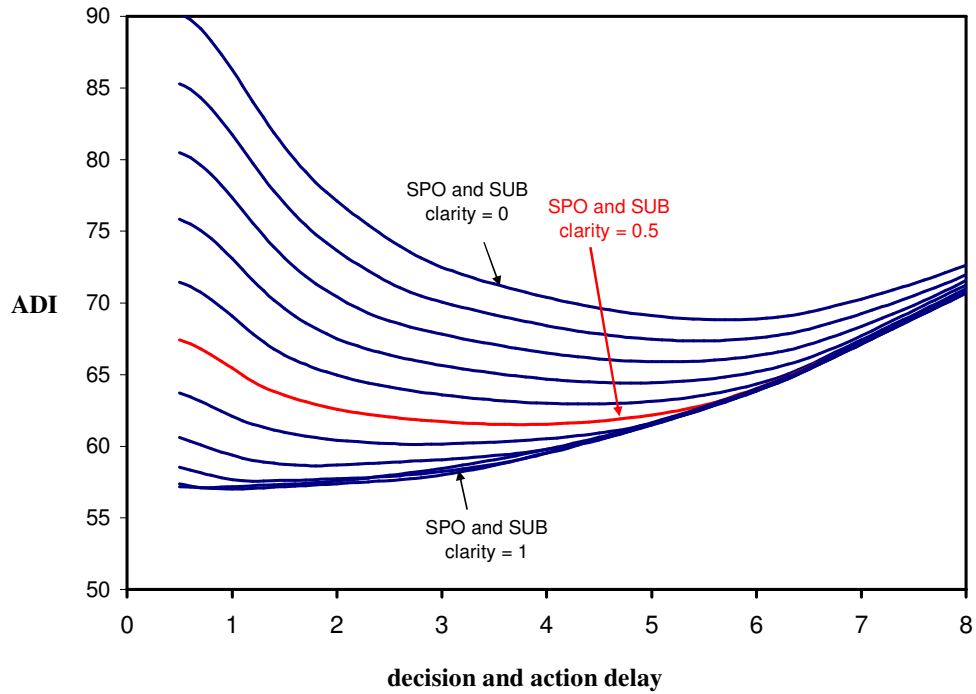


Figure 6a: ADI versus decision and action delay for different values of SPO and SUB clarity

Note: expertise level for all players=0.5, KTR clarity=0.5, all other delays=3 months

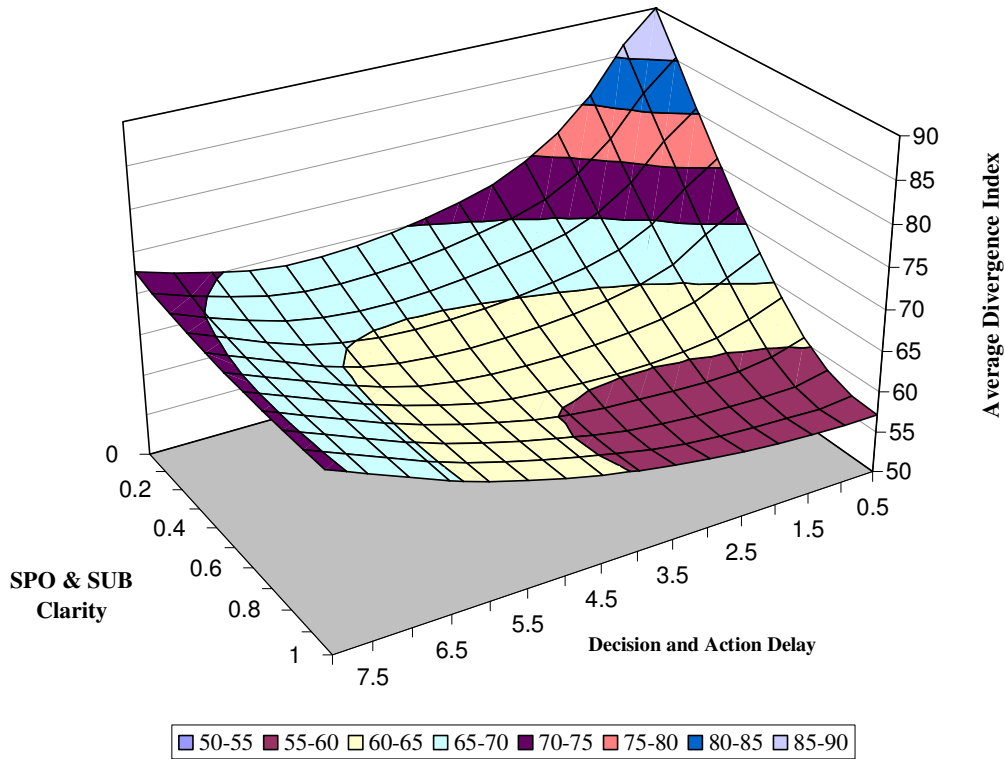


Figure 6b: ADI versus decision and action delay versus SPO and SUB clarity

Note: expertise level for all players=0.5, KTR clarity=0.5, all other delays=3 months

These figures illustrate that there is an interactive effect between communication clarity and decision and action delay. With a high level of communication clarity, as decision and action delay increases, the players' divergence increases. In a low and medium level of communication clarity, the effect is different. An increase in decision and action delay can lead to a decline in the average divergence index. As we see, in the medium range of communication clarity, there exist optimal delays which lead to minimum divergence. This may seem a complicated pattern of behavior as it shows we cannot independently discuss if a change in the decision and action delay is proper for communication convergence without knowing about the level of communication clarity.

The complex effect of decision and action delay on communication divergence can be decomposed and explained as the result of two different phenomena which work in opposite

directions. On one hand, increasing delay increases oscillation which results in a bigger gap between the players. When players act with a long delay in response to what they have perceived, it may result in a larger gap between their scopes. Simply, when the KTR responds slowly to the SPO's observed scope, it introduces the opportunity for the SPO to change its scope (having perceived no reinforcement in its understanding from the other player). So, the convergence may decrease as delay increases. Also, slower response to one's partner's message is expected to delay convergence.

On the other hand, delay helps to damp noise. Information delay plays a smoothing role, and when there is noise in the system, delay helps us to cancel out the noise and perceive more accurately the "average" signal. Practically, if individuals are uncertain about the importance of a particular topic, they often wait to see if it comes up again. When KTR's decision and action delay is long enough, KTR is able to smooth the noisy signals that have come from the SPO, and understand better what the SPO communicating, rather than changing its scope multiple times based on unclear and ambiguous pieces of information. So, these two phenomena play totally opposite roles, and that's why there is a trade-off for acting quickly on erroneous information. While being responsive to the other players is important and can help project progress, when less clarity exists in communication, a fast response can be based on a wrong interpretation, resulting in more divergence and subsequently higher costs.

3.3. Effect of observation and orientation delay: A similar analysis can be conducted for observation and orientation delay. In addition to the effects that we reviewed for decision and action delay, there is a third effect which is exclusive for observation and orientation delay: organizations that rarely communicate with their partners, i.e. a high observation delay, can

suffer from receiving more noisy messages. In other words, with less frequent communication, the amount of ambiguity in messages increases since people have fewer opportunities to catch and correct any misunderstandings from differences in disciplinary vocabulary, application context, or organizational culture. Mathematically, considering Equations 1 and 2 as the way we have represented ambiguity, an increase in observation and orientation delay not only can increase the delay of smooth function (Equation 1) but also increases the deviation of the uniform random function (Equation 2)². Figure 7 illustrates ADI versus observation and orientation delay for different levels of SPO and SUB clarity. The figures 7a and 7b are drawn based on averaging the results from 200 different sets of random seeds.

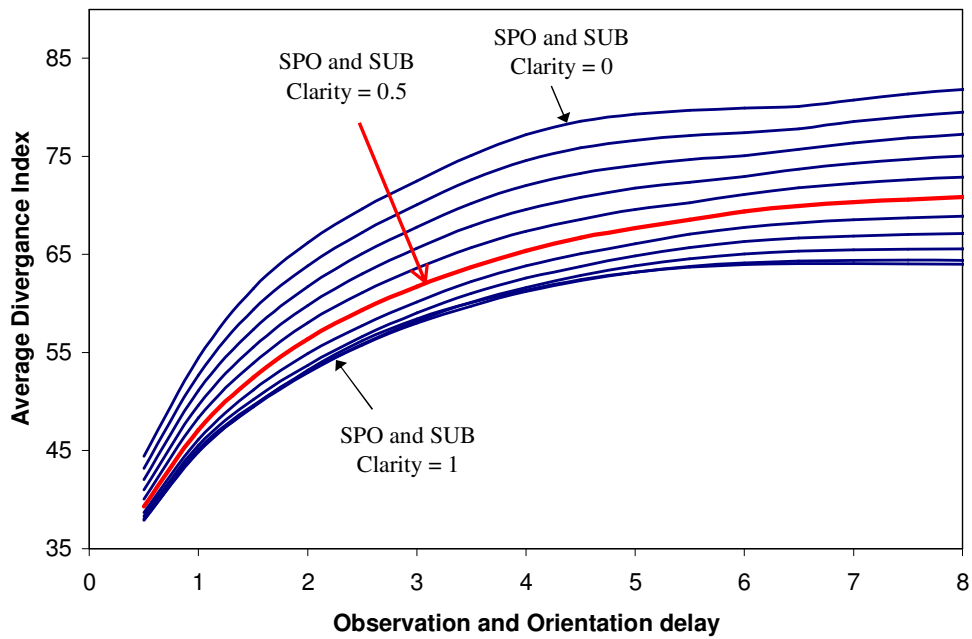


Figure 7a: ADI versus observation and orientation delay for different values of SPO and SUB clarity Note:

expertise level for all players=0.5, KTR clarity=0.5, all other delays=3 months

² In further studies observation and orientation delay can be decomposed to the observation delay and orientation delay.

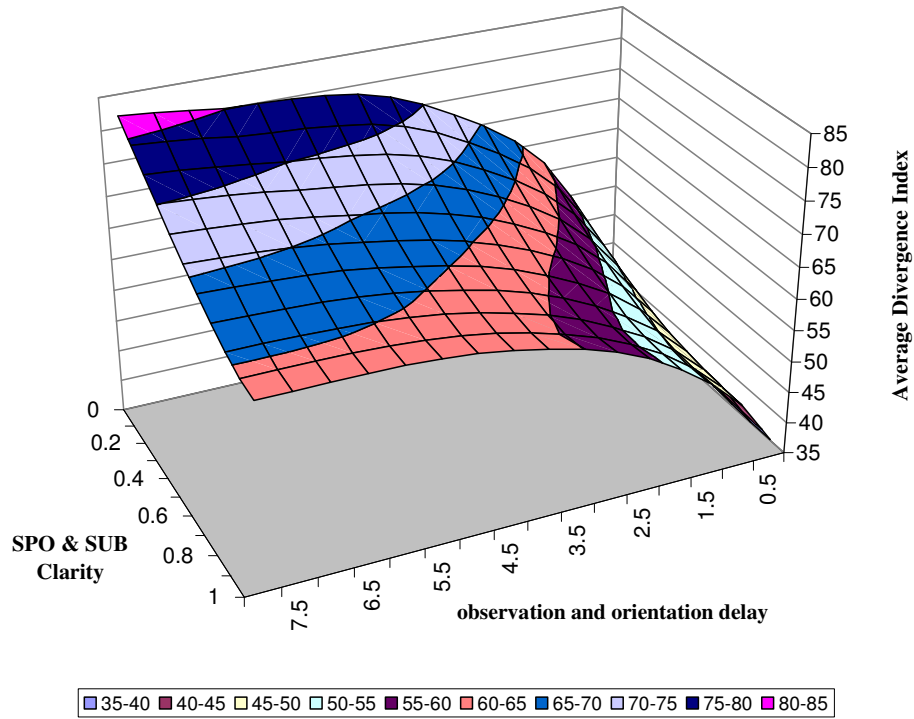


Figure 7b: ADI versus observation and orientation delay versus SPO and SUB clarity

Note: expertise level for all players=0.5, KTR clarity=0.5, all other delays=3 months

As we see in this figure, the effect of observation and orientation delay is totally different from decision and action delay. There are two major differences between the effects shown there and those shown in Figure 6. First, always, an increase in observation and orientation delay increases divergence in communications. In contrast to decision and action delay, there is no tipping point for the effect of observation and orientation delay on divergence. While a decrease in decision and action delay, as discussed, can have a positive or negative effect on shared understanding and convergence in understanding, Figure 7a shows that getting faster information has a positive effect in increasing shared understanding.

Second, in Figure 7b, the graphs for different levels of communication clarity follow a similar pattern. In comparison to Figure 6b, there is less interaction between communication

clarity and the effect of observation and orientation delay on the average divergence index. This simply says that for any level of communication clarity, shorter observation and orientation delays favor communication convergence. More specifically, decreasing observation delays can always be recommended.

4. Conclusion

The simulation results suggest a number of implications in order to increase cross- boundary understanding in collaborative product development teams. First, these results corroborate that communication clarity and orientation expertise level can significantly influence communication performance. When communication clarity increases, that is, when players send clearer messages, players' understandings of scope converge much faster. Further, when players have increased ability to receive and understand the message sent, they are able to perceive the other players' understanding and align with them. These points intensify the importance of using proper tools and techniques to increase communication clarity and expertise level. As it is discussed in Greer et al. (2006), boundary objects — concrete objects used to communicate and transform meanings across different boundaries of expertise, norms, and time frames (Carlile 2002) — play a crucial role in this respect.

Second, the sensitivity analysis shows that decision and action delay and observation and orientation delay can have different and unexpected effects on the performance of communication. Our analysis revealed that decision and action delay has interactive effects with communication clarity on players' convergence. The simulation results show that, given a very high level of clarity, as we intuitively expect, faster decision and action processes result in more convergence among players' understanding. Interestingly as the level of communication clarity

decreases, the effect of decision and action delay on convergence changes. In other words, decreasing decision and action delay does not necessarily lead to more convergence. In addition, simulation results show that for a long range of values for communication clarity, there are points where the effect of decision and action delays can yield unexpected and sudden shifts in communication convergence.

Unfolding this interesting effect, we can say decision and action delay can have two different effects on communication dynamics. On one hand, increasing it can slow convergence and increase oscillation due to the feedback based structure of communication. On the other hand, this delay can help us to cancel out noisy interpretations which are caused by the stochastic part of the model representing communication noise. These phenomena warn us about believing that “faster is always better” in new product development work teams, and suggest more careful actions especially when communication clarity or orientation expertise level is low. However, one can argue that the former is more difficult to be aware of, and one cannot know accurately about how clear the communication is until later identifying misunderstandings that resulted from previous communications. This adds to the complexity of dealing with shared understanding in communication. Further, one can argue that communication clarity – in contrast to the model’s assumption – is not necessarily constant through a project, but people may get to know others’ languages as they continue to work together. This can lead to the idea that delays can have positive effects in the first stages of a project leading to more understanding before taking any action, but as the project continues, responding faster to the other partners may be a more effective strategy for shared understanding. In short, the “optimal” value of decision and action delay may vary dynamically as a project progresses. In contrast to decision and action

delay, the simulation results show that longer observation and orientation delays lead to more divergence.

This study can be improved in different ways. First, the proposed model is one of shared understanding in cross-boundary communications, and we can add various factors about material resources and financial information that also influence players' behaviors in negotiating shared understanding as a project progresses. Second, the arguments in this paper can be moved again toward empirical examinations. Effects of delays on shared understanding can be tested through different empirical studies.

Overall, we claim that this paper had two major contributions. First, this study contributed to the literature of meaning construction by proposing a modified and simple simulation model for shared understanding in new product development work teams based on the work presented in Greer et al. (2006). The model revealed interesting and complicated dynamic effects of delays on meaning construction. Second, this paper contributed to the literature of large-scale project management from a behavioral perspective. The study gave a different explanation for why large-scale multi-disciplinary projects can perform inefficiently and cause considerable unplanned costs. While acknowledging the classical arguments in project dynamics studies about the challenges of allocating resources (e.g., Roberts 1974, Cooper 1980), managing concurrency (Ford and Sterman 1998), “firefighting” tipping points (Repenning 2001, Repenning Gonçalves and Black 2001) and others (e.g., Lyneis and Ford 2007), this study offers a different and complementary explanation for project failures. We argue that some portion of the failures — and even some of the problems focused on in other investigations — may be attributed to challenges of creating shared understanding, as influenced by the effects of communication clarity, expertise level, decision and action delay, and orientation and observation delay.

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