Path Dependency and the Role of Delays in Creating Shared Understanding in Dyadic Communication:

Lessons from a Simulation Model

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Abstract: Informed by a theory of symbolic interactionism, this research explores the dynamics of dyadic communications within which understanding is socially constructed. Based upon an earlier analysis of a case-study investigation in a large multi-disciplinary governmental project with multiple contractors and subcontractors, we modify, simulate, and analyze a dynamic model of dyadic communications. Our simulation results support the previous findings and, in addition, underscore the role of path dependency in creating shared understanding; that is, “first” interpretations affected by random and imprecise messages can influence subsequent shared understanding and meaning construction significantly. Finally, our sensitivity analysis sheds light on the effects of decision and action delay and observation and orientation delay. 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.

KEYWORDS: Shared understanding, meaning construction, large project management, path dependency, observation and orientation delay, decision and action delay

1. Introduction

The challenges of collaborating on innovative work in very large product and service development projects, moving from novel concepts to concrete products and services, are similar across contexts. Requiring the participation of multiple disciplines and resources across multiple organizations, these collaborations are characterized both by lack of a single governance office and by (often unanticipated) absence of shared understanding at the outset of the work-to-be-done. For example, in 2004 the U.S. Army awarded a $879 million five-year contract for the Aerial Common Sensor Aircraft. Four months later, contractors revealed that aircraft was rated for only 9 g’s of force, not 16 as Army required (Charette 2008). Other examples of these contexts include non-governmental organizations providing services in developing countries, product development using globally distributed “outsourcing” partners, and pharmaceutical research to meet previously unaddressed disease populations. Multi-disciplinary projects incur more risk that they will not be completed to cost, schedule, and performance specifications than other projects because of difficulties in communicating across organization structures or entities, political, relative expertise, knowledge domain, time, or location boundaries.

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. Because multi-disciplinary projects often require higher levels of investment by participating organizations to bridge these boundaries, failures in these projects can impose significant costs for the organizations.

Greer et al. (2006) reported a case study of a large scale government-initiated aerospace program with multiple contractors and subcontractors in which “disconnects” in understanding of the baselines (technical, schedule, and cost) jeopardized program quality, cost, and schedule targets. Greer et al. analyzed a model representing meaning as constructed through noisy communications during program progress, and convergence of the players’ shared understanding was central for the program’s success. The study focused on how to keep the (simulated) system program office, contractor, subcontractor, and vendor of a large aerospace technology development program “in sync,” that is, holding similar conceptions of the scope of work at the same time. Because each organization’s understanding of the work-to-be-done evolves as it learns from stakeholders up and down the “intellectual-capital supply chain” (Greer et al. 2006) and as it advances its own work-in-process, communication with other parties is necessary on an ongoing basis to create and sustain shared meaning of the innovative work in which all must play a part. Making use of rich interview data, the simulated explorations focused on understanding the consequences of the range of delays in observing and orienting and acting (Boyd 1992, similar concept found in Haeckel 1999) on other stakeholders’ assertions about the work at hand; the communication clarity from other parties (which the authors related to sociological studies of boundary objects—for example, see Star and Griesemer 1989, Henderson 1991, Carlile 2002); and of each organization’s expertise level in sifting and making sense of others’ communications.

Building on the previous study, and building on the theory of symbolic interactionism (Mead 1934; Blumer 1969; Strauss 1993), this research develops a modified model to further 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. This study presents the structure and behaviors of a high-level generic model that captures the essential dynamics of dyadic communication patterns. When replicated, these dynamics can reproduce the large communication networks and behaviors observed in the aerospace acquisition program case study.

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 paper, based upon the case-study investigation and simulation model and analysis reported in Greer et al. (2006), we construct an unarrayed model of dyadic communication behaviors in three steps (section 2) and analyze the behaviors of the sub-structures along the way. Then we conduct sensitivity analysis experiments with different model parameters (section 3) to extend our understanding of how different delays affect baseline-understanding convergence, and finally, we discuss the implications of simulation results (section 4).

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. Further, these simulation results highlight the significant effects of "first" interpretations in meaning construction, arguing for high inertia and path-dependent behavior in shared understanding. Finally, our sensitivity analysis sheds lights on the differential effects of decision and action delay and observation and orientation delay on players' convergence.

2. Modeling

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.

Greer et al.'s (2006) four-player model was constructed and then extended to study a complex network of contractors and subcontractors. Though four-player model yielded insights about why communication clarity and expertise level in communication are important factors, it is difficult to distill a detailed behavioral analysis and communicate them due to the arrayed structure of the model. In general, 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.

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 dyadic communication.

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: If there is 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. (Fig. 1b)

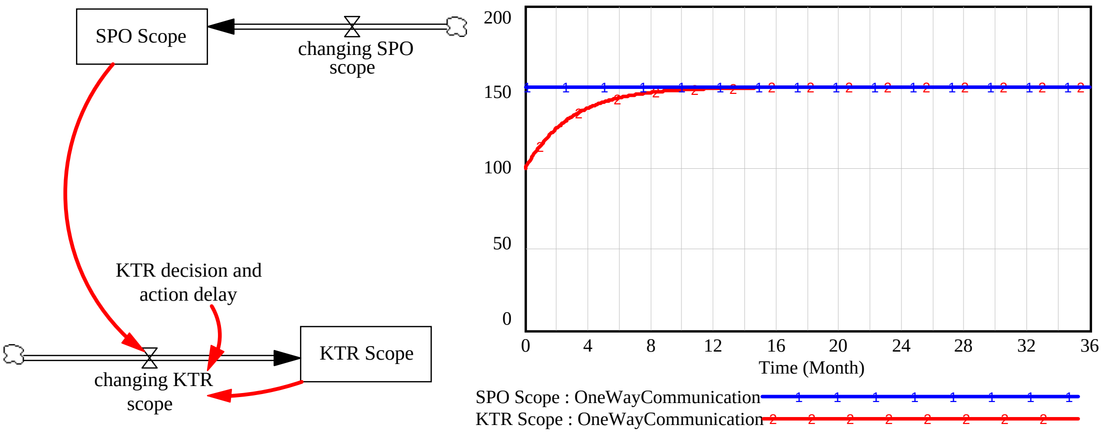

Figure 1 – A one-way unambiguous communication – a) the structure, b) the behavior (KTR decision and action delay = 3 months)

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).

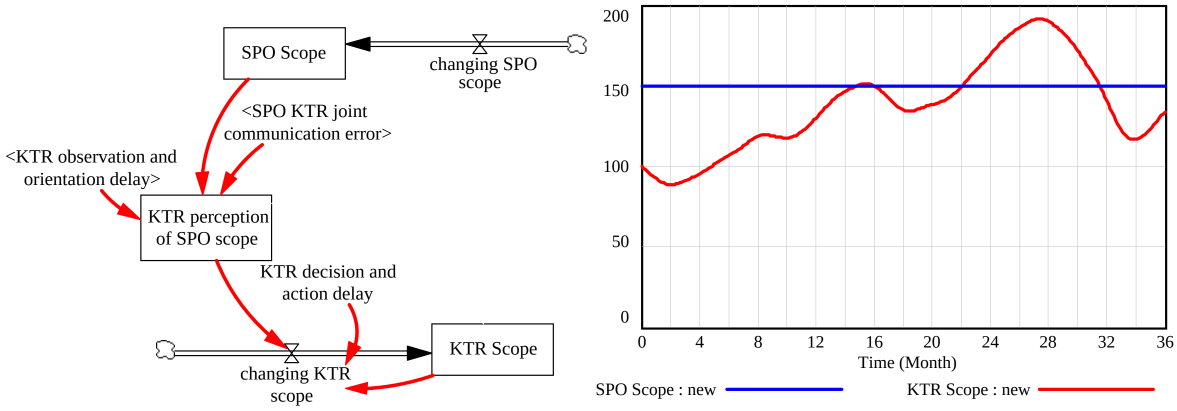

Figure 2 – A general one-way communication – a) the structure, b) the behavior (both delays=3 months, communication clarity=0.5 and orientation expertise level = 0.5, on a scale from 0 to 1)

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

KTR perception of SPO scope = Smooth3 (SPO Scope + SPO KTR joint communication error, KTR observation and orientation delay) *(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 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.

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[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.

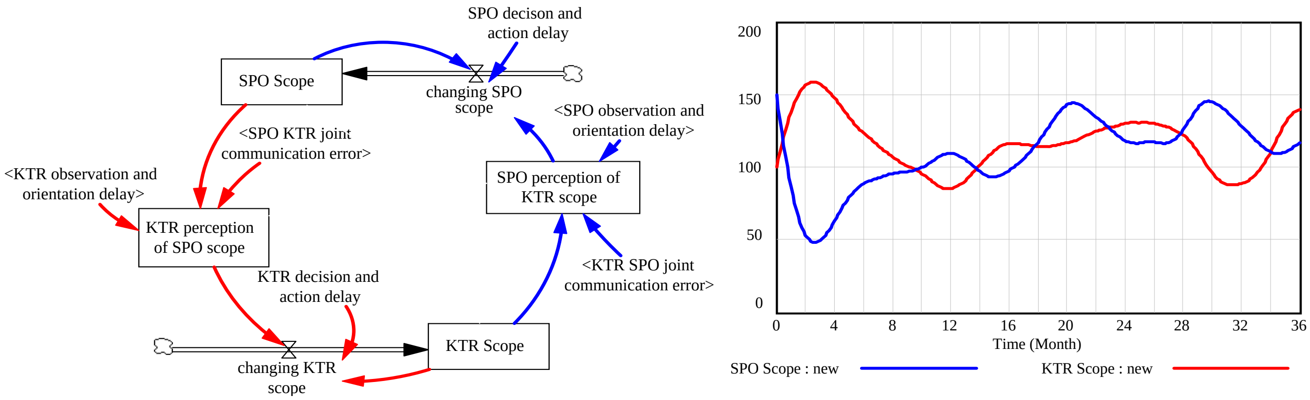


Figure 3 – A dyadic communication – a) the structure, b) the behavior

(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):

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

(Equation 3)

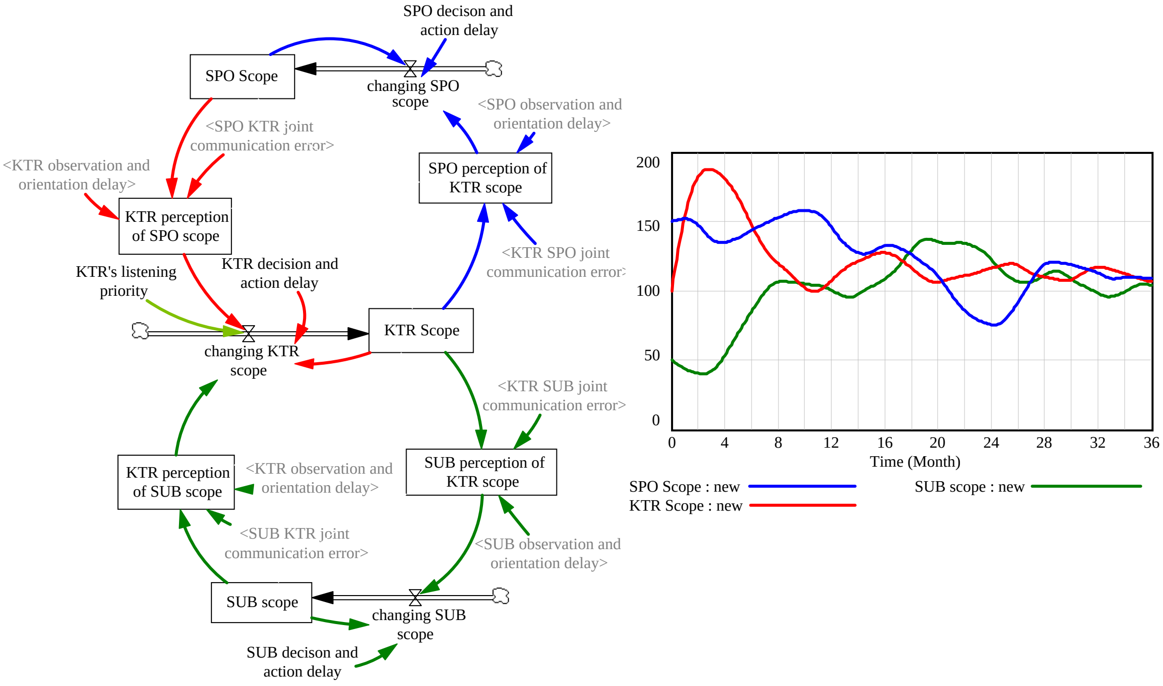


Figure 4 – A chain of two dyads – a) the structure, b) the behavior

(all delays=3 months, communication clarity=0.5, orientation expertise level = 0.5)

As we see in Figure 4b, the players start from different initial conditions (their respective understandings of the work-to-do vary), and after some interactive communications they converge around an equilibrium. A reasonable question is whether they always converge or whether convergence can depend on different variables. In addition, we can ask whether there is a unique final equilibrium stage for communication convergence, or whether different variables can affect the final stage (e.g., do players always converge around the average of initial scopes?). In the following we test the behavior for different values for communication clarity, expertise level, random seeds, orientation and observation delay and decision and action delay.

3. Results

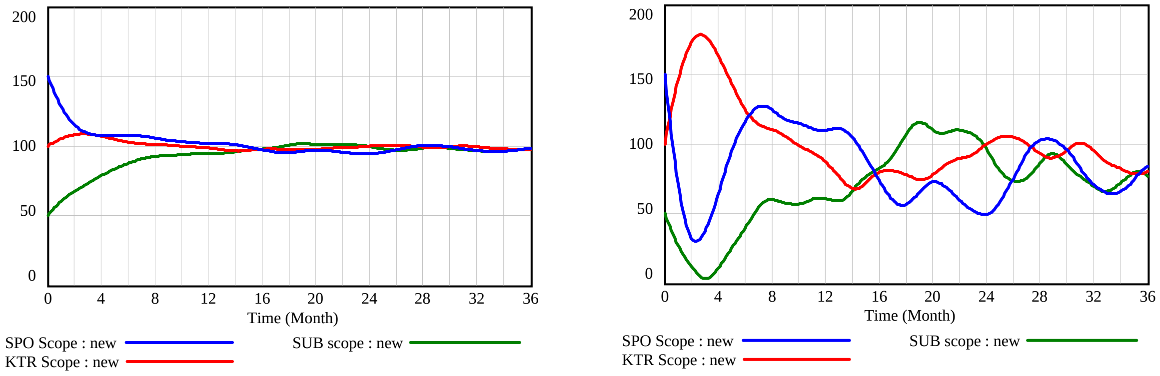
To be able to compare the divergence (convergence) of scopes in different experiments, we define average divergence index (ADI) as following:

Average divergence index = smooth(abs(SPO scope-KTR scope)+abs(KTR scope-SUB scope)+abs(SPO scope-SUB scope),12) *Equation 4*

whereby *abs(x)* is the absolute value of *x*. So, for a larger ADI, we have more divergence among the players' scope, and so 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).



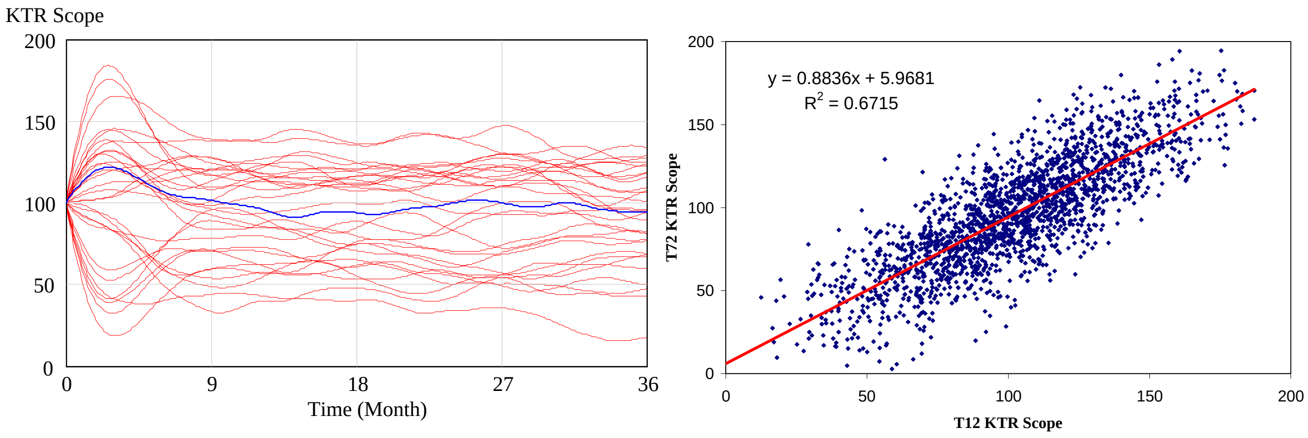
(a) **(b)**

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 replicated by the model.

3.2. Effects of first noisy interpretations: The model's behavior has basically two different drivers: feedback loops, and stochastic changes. While we may intuitively expect that stochastic part of the model which is driven by a noise generator function should cancel out and not influence the main trend, our sensitivity analysis shows that the model is sensitive to the random seeds (Figure 6). In another words, the final stage of the model is more significantly affected by the first random numbers rather than the late ones. This kind of behavior is usually referred as path dependency – a pattern of behavior in which the ultimate stage is highly influenced by initial conditions and random shocks and the system is locked in a narrow range of possible behaviors. In a path-dependent system, small events in early stages can significantly influence the final stage of the system (David 2000, Pierson 2000, Sterman 2000).



(a) **(b)**

Figure 6: Sensitivity of KTR Scope to different random seeds in the model: a) dynamic graph, b) KTR Scope in T=12 versus T=72 for 2000 experiments with different random seeds

Note: The same pattern of behavior exists for other players' scope.

This sensitivity analysis reveals a very important phenomenon in shared understanding and meaning construction. The graph shows that some first random interpretations in the first stage of communication can limit the range of possible understanding to be constructed in the chain and lock the players in a narrow range of final outcomes for shared understanding of scope. In another words, how players initiate their communication and their clarity in the first stage is much more important for project success. This underscores the importance of using boundary objects (Star and Griesemer 1989, Henderson 1991, Carlile 2002) in the first stages of projects in order to improve communication clarity early and avoid being locked in an undesired final stage. Figure 6b shows path dependency in KTR scope by comparing its status in t=12 and t=72 for 2000 simulation runs with different random seeds. This figure indicates that there is a high correlation between one's scope in t=12 and t=72, close to one, with a relatively high R^2.

3.3. 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 in balancing loops, and we expect that by increasing it, the level of total divergence may increase. 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 7a and 7b show the results.

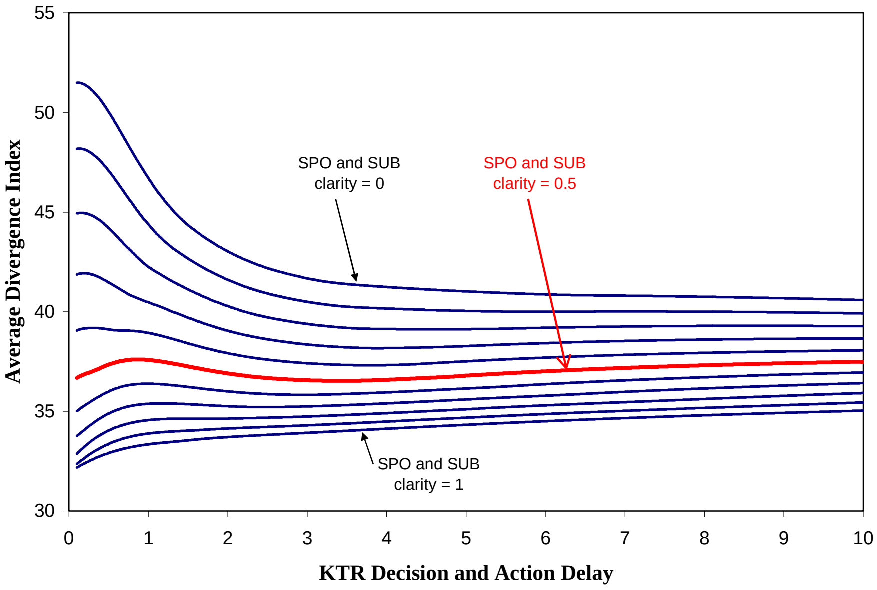


Figure 7a: ADI versus KTR decision and action delay for different values of SPO and SUB clarity (expertise level for all players=0.5, KTR clarity=0.5, all other delays=3 months)

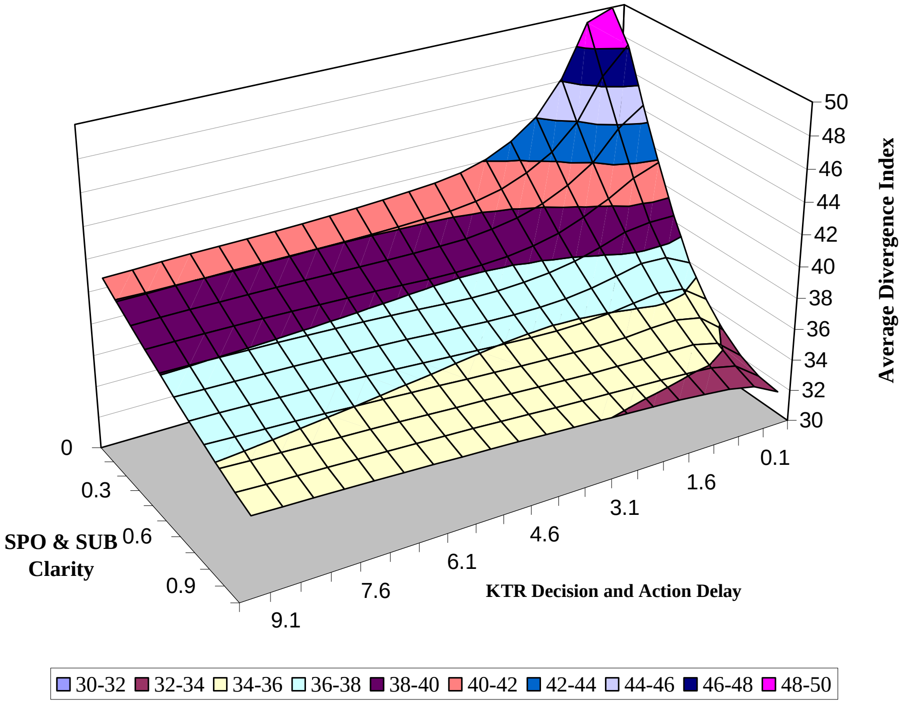


Figure 7b: ADI versus KTR decision and action delay versus SPO and SUB clarity (expertise level for all players=0.5, KTR clarity=0.5, all other delays=3 months)

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 level of communication clarity, there is an opposite effect. An increase in decision and action delay leads to a decline in the average divergence index. In the middle range of values for communication clarity, a combination of these effects occurs. As we see, in the medium range of communication clarity, there are tipping points around which the direction of the effect of decision and action delay on ADI changes. 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, usually in balancing feedback loops, 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.

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. 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.

3.4. 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 8 illustrates ADI versus observation and orientation delay for different levels of SPO and SUB clarity.

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

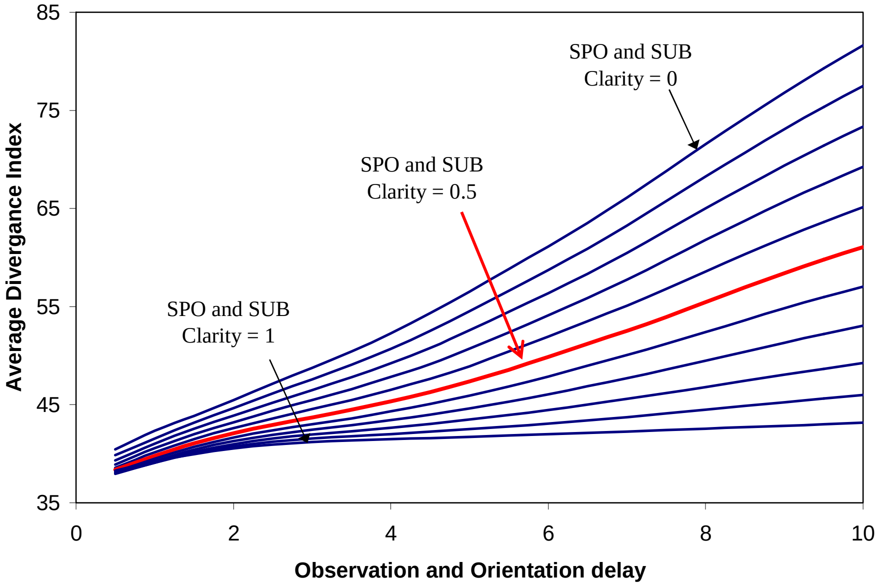

Figure 8a: ADI versus KTR observation and orientation delay for different values of SPO and SUB clarity (expertise level for all players=0.5, KTR clarity=0.5, all other delays=3 months)

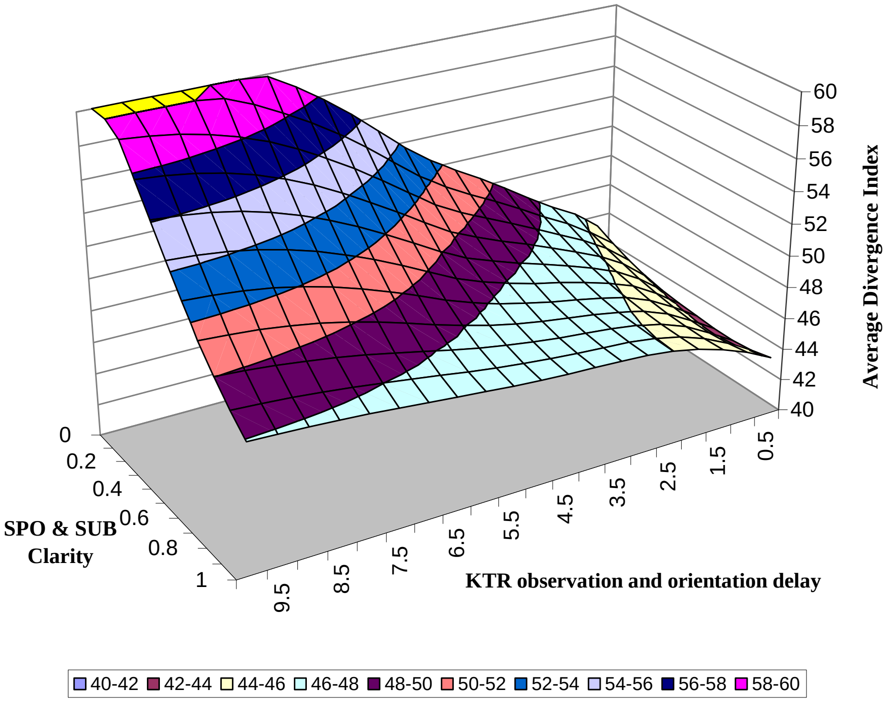

Figure 8b: ADI versus KTR observation and orientation delay versus SPO and SUB clarity (expertise level for all players=0.5, KTR clarity=0.5, all other delays=3 months)

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 7. 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 8a shows that getting faster information has a positive effect in increasing shared understanding.

Second, in Figure 8b, the graphs for different levels of communication clarity follow a similar pattern. In comparison to Figure 7b, 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.

Finally, interestingly, on average, the slope of graphs in Figure 7a is much smaller than the slope of graphs in Figure 8a. To shed more light on this phenomenon, Figure 9 illustrates marginal ADI versus decision and action delay and observation and orientation delay, given a medium level of communication clarity (0.5).

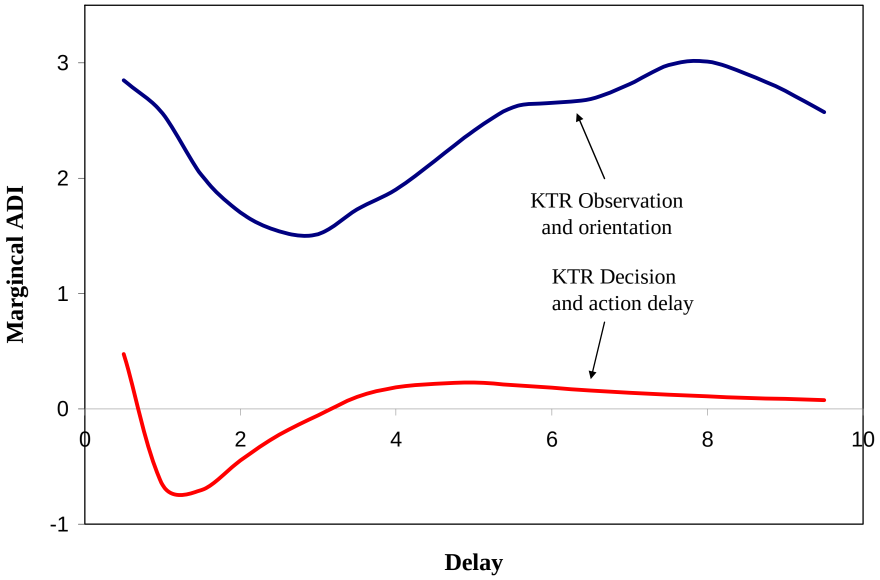

Figure 9: Marginal ADI versus decision and action delay and observation and orientation delay (communication clarity = 0.5, other delays = 3 months).

As we see for decision and action delay longer than 3 months, marginal ADI is close to 0, which represents a very small effect of a change in delay on communication divergence. But the effect of observation and orientation delay is significantly at a higher level and is always more than zero. This means that ADI is much more sensitive to observation and orientation delay. In another word, a change in observation and orientation delay has a much stronger effect than a similar change in decision and action delay. This indicates that reducing observation and orientation delay is very crucial for communication convergence and suggests that attending to this variable can yield drastically improved outcomes (reducing program problems in budget, schedule, and quality resulting from misunderstandings of program scope).

4. Conclusion

The simulation results suggest a number of implications in order to increase cross-boundary understanding in dyadic communication. 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 rule in this respect.

Second our sensitivity analyses reveal path-dependent behavior in the system. In shared understanding, the "first" random and imprecise interpretations can influence meaning construction significantly and lock the system in a limited range of possibilities. As people start building their interpretations based on the messages, and continue their communication based on those first interpretations, they narrow the range of possible outcomes. This implies that clear communication and high expertise in the first stages of a project plays a crucial role in a project success, and organizations can improve outcomes by placing their best people on a project first, rather than bringing in experts as deadlines near, as is common practice. Furthermore, the analyses indicate that investing more in early-stage boundary objects can yield significant improvements in producing shared understanding earlier in the project. Different sorts of artifacts, including causal diagrams, time tables, graphs of important variables in a system over time, and road maps, which help revealing people's mental assumptions about the work at hand accelerate early identification of gaps in language, time-frames, and processes dependencies. As misunderstandings are surfaced and discussed, artifacts can be modified to represent changed understanding of players, thus iteratively refining (and often discarding) boundary objects as they alter their understanding of program scope.

Further, 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, for a long range of values for communication clarity, there are tipping points for the effect of decision and action delay on communication convergence. That is to say, players may become trapped in a local optimal value for decision and action delay and do not recognize that if they continue on decreasing the delay, after a tipping point, they may obtain more 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 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 dyadic communication, 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 dyadic 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. Furthermore, we show that the ADI (average divergence index) is much more sensitive to observation and orientation delay than decision and action delay. This implies that investing in decreasing observation and orientation delay in projects – for example, by having more effective meetings – before implementing our own understanding through decision and action results in faster convergence among players. Especially for program planners and project leaders, observation delay can play the role of leverage point and merits a careful attention.

This study can be improved in different ways. First, the proposed model is one of shared understanding in dyadic 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 and effects of first interpretations in final products of the projects 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 dyadic communications based on the work presented in Greer et al. (2006). The model revealed interesting and complicated dynamic effects of delays and "first interpretations" 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, and decision and action delay, and orientation and observation delay.

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