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Contingency Effects on Event-driven Collaborative Decision-making

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	1	**C2 Concepts, Theory and Policy**

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Abstract

Key to network centric operations is the social interaction between elements of a diverse force to create synergy, unity of purpose and harmony of action. This paper examines collaborative decision-making arrangements when addressing problems spanning the competency, authority and responsibility of different elements of the force. As an optimal approach to decision-making depends upon the nature of the problem, a model is developed that incorporates contingency factors of task uncertainty and task interdependence. The model, drawing upon the organisational and decision science literature, uses concepts of integration and differentiation of the force to derive the requirement for their coordination and specialisation.

The paper reports on a laboratory experiment to test the model. Decision-makers used a tool suite to collaborate with participants from across the organisation to solve time-critical problems. Within this sense-and-respond environment, five research propositions were tested using controlled variations of the nature of the problem, level of prescription used in the decision aid, collaborative approach and cooperativeness of collaborators. The paper presents and elaborates upon the findings of the experiment. Although the results associated with the propositions were mixed, the experiment provides validation of, and a foundation for future research in, the task-oriented approach to military decision-making.

Background

In their seminal work on network centric warfare, Alberts, Garstka and Stein (1999) proclaimed the Information Age's potential for fundamental improvement in warfighting capability through the linking of knowledgeable entities in the battlespace. Indeed, the past ten years has witnessed substantial efforts and investments by many military forces in the networking of sensors, decision-makers and weapon systems to achieve these improvements. At the same time, military force structures are being transformed to focus on the production of effects rather than the application of mass, with an assumption of enhanced coordination of these smaller force capabilities (Krause, 2006). Yet recent experience such as in Operation Anaconda suggests that coordination of a diverse force remains problematic (Naylor, 2005) and that the deficiency is not the technical integration of the force but the effective utility of integrating systems to achieve a decisive outcome.

This situation reflects a shift from the industrial-age division of work to an environment that features task interdependence and demands a greater emphasis on lateral coordination across specialisations. The modern military operational environment often is better suited to organic C2 arrangements rather than traditionally mechanistic structures (Kuah, 2007). The fundamental organisational activity, decision-making, similarly needs to progress from a segregated, formal and internally focused approach to a task orientation that is more collaborative and takes advantage of the synergies associated with knowledge and potential coordinated action across the force.

This paper presents a model that is broadly applicable to military collaborative decision-making. In order to adapt the model for the task context, use of the model is moderated by contingencies. As decision-making is essentially the cognitive element of organisational activity, the paper borrows concepts from the organisational literature. Specifically, it adopts the factors used in structural contingency theory as being central in adapting the decision-making approach.

The aim of this paper is to develop and validate a collaborative decision model. A laboratory experiment methodology was chosen to test the model, as it facilitated control over the input variables and decision-making processes, as well as measurement of the outputs.

Decision Models

A systems approach, in which the situation is compared with the desired end state and consequent actions produce effects that influence the situation, is an appropriate model for most military decision-making. Illustrated at Figure 1, Sterman (2000, 10-11) suggests that an event-oriented view of the world leads us to an event-oriented approach to problem solving.

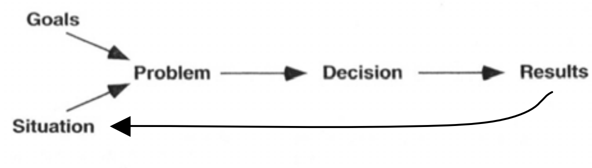

Figure 1 - Event Driven Decision-Making (adapted from Sterman)

Using Checkland's (1981) soft systems approach allows us to further develop this model as shown at Figure 2.

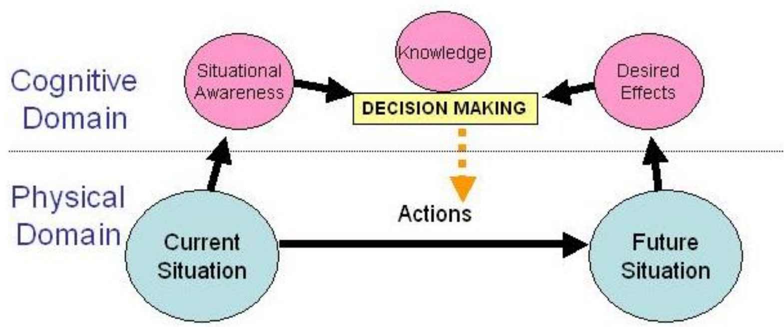

Figure 2 - Basic Decision Model

Key to this model is the search for and use of available information in support of effective decision-making. Decision-making tends to follow the *principle of least action*, in which the best effect is optimised with the least effort (Payne et al, 1993; Zipf, 1949). A decision is made at a time when the decision-maker determines that the selected action from a range of options is reasonable, given the situation and a comparison of the potential for improvement in the decision versus the required search to realise that potential. The economics of information therefore is essentially a consideration of return on investment in searching for information relevant to the problem.

Decision-making often, and especially in military operations, needs to be less rational because of uncertainty, time pressures, resource limitations, incomparability of possible actions and information-related constraints of attention, memory, comprehension and communication. In such situations, a bounded approach involves confining search and analysis efforts to avoid over-analysis, hyper-rationality, regressive planning and failure to act (Klein, 1998, 259-260). Simon (1957) developed the concept of satisficing, in which decisions are made based upon preconceived aspirations of outcomes – when an option is identified that will achieve those aspirations, the problem is said to be satisficed and the search for more information is halted. Janis and Mann (1977) criticise satisficing in comparison with analytical approaches, in that it addresses fewer requirements for the outcome, generates fewer alternatives and does not comprehensively test alternatives. Nevertheless, the view that human decision-making is mostly concerned with satisfactory alternatives and is only concerned with optimising approaches in exceptional circumstances is widely accepted (March and Simon, 1993, 162) and fundamental to more recent research in naturalistic decision-making.

Much of the challenge in decision-making is the ability to deal with uncertainty, which in this context is the difference between the amount of information required to achieve goals and the amount possessed by the organisation. Dispersion of knowledge is itself a cause of uncertainty (Becker, 2001) as the decision maker does not know whether a fact is simply unknown to him/her, unknown within the organisation or just unknown. Thus the search task involves not only reducing uncertainty caused by information gaps but also by addressing that which may be resolved by others in the organisation. The Johari window (adapted from Luft, 1970) at Figure 3 depicts the value that may be achieved through collaborative approaches to decision-making.

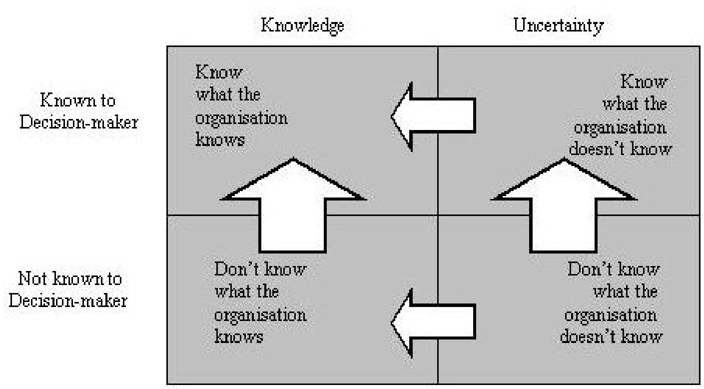

Figure 3 - Collaboration to Reduce Uncertainty

The search effort in identifying and comparing options in everyday decision-making requires information, regardless of whether it relates to the knowledge of the individual or is known by others, whether it is explicit or intuitive, whether it exists or needs to be created from other knowledge based upon the circumstances, or whether it is processed, stored or communicated via technology. In this paper, we define the search effort in terms of depth (that is, the amount of analysis required of the problem) and breadth (the extent of organisational participation in solving the problem).

Decision theory is mostly divided into two disciplines: normative and descriptive. Normative theory is based upon the axiomatic or logical procedures of how people should make decisions. Descriptive theory is based upon the reality of how people do decide. There is a third category of theory, prescriptive, which is based upon what support might be provided to train or assist the decision-making process (Bell et al, 1988, 1-5); in effect, acknowledging the descriptive while striving for the normative. In order to promote and assist collaborative decision-making, the desired model should be prescriptive. This prescription should incorporate consideration of the problem within an explicit meta-planning activity. Based upon these requirements, the basis for the model should be a prescriptive process that addresses meta-planning, search effort and facilitates collaboration.

Contingency Theory and its Relevance to C2

As mentioned earlier, the model requires contingency factors that modify decision processes based upon respective tasks. Specifically, it should borrow from the organic element of structural contingency theory, which describes the moderating effects of task uncertainty and task interdependence on organisational structure (Donaldson, 2001, 35). The difference between organic and mechanistic systems were first highlighted by Burns and Stalker (1961), who determined that more dynamic conditions (leading to task uncertainty) demand the use of organic arrangements, with less rigidity, informal communication, more participation and innovation. The key concept of organic theory is that tasks featuring low uncertainty are more effectively managed under hierarchical control, whereas uncertain tasks are more effectively managed participatorily (Donaldson, 2001, 36). In the military context, the environment is increasingly turbulent, in which case loose management coupling and self-organising arrangements are more suited than centralised decision-making (Atkinson and Moffat, 2005, 92-93; Alberts and Hayes, 2006, 76-78).

Task uncertainty's relevance to collaborative decision-making and network centric operations can be explained in terms of the Law of Requisite Variety (Ashby, 1956, 206-207) and viable systems theory (Yolles, 2000). In the same way that each of those theories matches the variety of a system with its environment, the uncertainty of a problem may be resolved by the application of equivalent variety in the decision-making process (Weick, 1969, 29). Self-synchronisation works in this fashion, by developing rule sets that facilitate a variety of actions to match the variety of situations. Risks with this approach, however, arise from inadequate collaboration in planning to establish the rule sets or the existence of such high uncertainty in the environment that the rule sets cannot be adequately defined. The apparent failing of the aforementioned Operation Anaconda might be attributed to both of these risks (Naylor, 2005, 329-331).

Environmental turbulence, the training-related advantages of developing specialisation within differentiated structures and the benefits of network centric operations combine to mean that military structures and the task environment are increasing unaligned; thus, military missions in the 21st Century environment are characterised by greater task interdependence. Task interdependence demands more attention be given to integration mechanisms, providing coupling between organisational units through organic structural forms or the implementation of lateral relation mechanisms (Thompson, 1967, 54-55; Galbraith, 1973, 46-65).

As described by Pigeau and McCann (2002), command comprises dimensions of competency, authority and responsibility (the CAR dimensions). Interdependence may relate to a spread of competency relevant to the task across the organisation, as reflected at Figure 3, but also to shared accountability or responsibility. Accordingly, collaboration may be pursued not only in situations when the decision-maker does not have the requisite competency, but also when he or she does not have the required responsibility or authority. Thus, the distribution of information relevant to the situation must be considered in the context of the distribution and possible reallocation of decision rights (Alberts and Hayes, 2006, 82-83). Figure 5 maps out typical participative roles in a collaborative decision process, based upon Pigeau and McCann's dimensions. Note that, to preserve the principle of unity of command, some of these combinations may not be suited to all military operations.

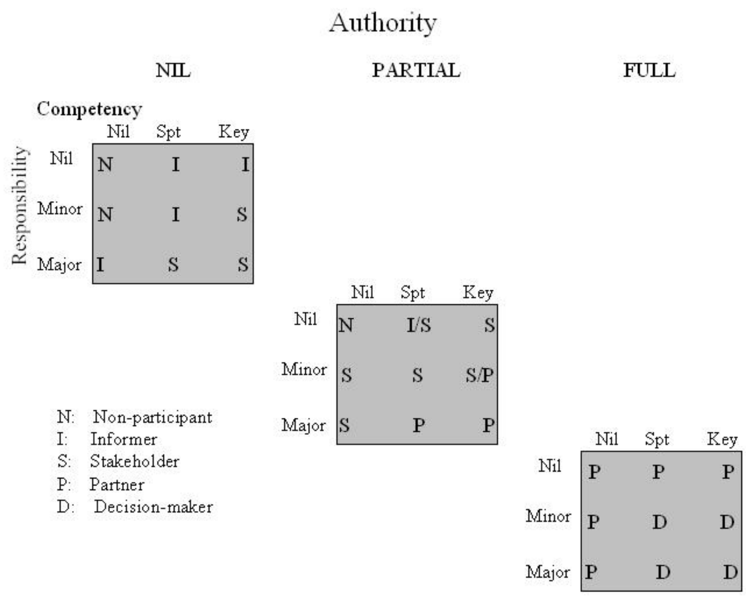

Figure 4 - Collaborative Participation

Lawrence and Lorsch (1967) expanded upon the contingency approach to organisations through the concepts of differentiation and integration. Differentiation describes the differences across specialisations within the organisation, whereas integration provides the mechanisms to coordinate the diverse elements to achieve a common purpose. In diverse organisations, Lawrence and Lorsch found that matching high levels of differentiation with high levels of integration was associated with higher performing firms. In the decision-making context, the variety of capabilities that contribute to solving problems represents differentiation, whereas the collaborative processes are integration mechanisms. This balance of differentiation and integration characterises an organisation's ability to deal with complex and interdependent tasks.

Referring back to the search effort associated with informing the decision process, it could be logically assumed that the breadth of the search effort is influenced by task interdependence, whereas the depth of the search effort is affected by task uncertainty (as complex and equivocal issues may require greater analysis). This assumption is fundamental to the collaborative decision model.

The Collaborative Decision Model

The prescriptive model, shown at Figure 5, is based upon the POWER framework (Andrews and Lewis, 2006). The logical sequence of the planning process in this model comprises defining the purpose (desired effect on the situation), rationalising the problem (meta-planning), identifying options and relevant capabilities, picking and executing a course of action and reviewing the effectiveness of that option for future use. The model is titled the PROPER process as a mnemonic to assist in following the steps. Key to the model in the context of task orientation is the explicit meta-planning step, in the same way that Rasmussen's cognitive control model (1995, 166-168) adapted the decision process based upon the level of familiarity with the problem. This step determines whether the decision should be intuitive or analytical, how much effort is required and who should be involved in deliberation, as well as guiding satisficing of the decision. The two elements to this step, rationalising and strategising, respectively reflect the contingencies that need to be considered for meta-planning: the nature of the task and the nature of the organisation's capabilities relevant to the task. This facilitates the decision-maker's comprehension of the problem in terms of relevant knowledge (as per the Johari window at Figure 3) and thus awareness of the method of information search and the accuracy required for satisficing the problem.

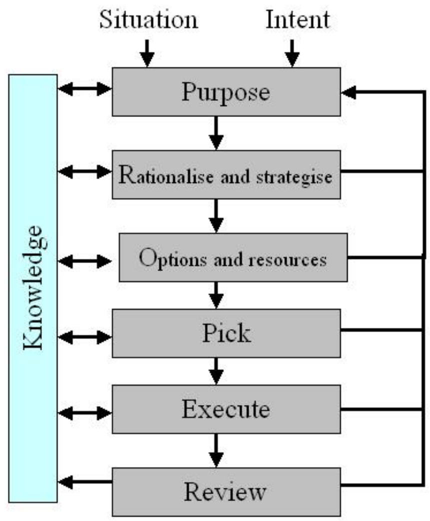

Figure 5 - PROPER planning framework

The determination of the level of rationality to be applied in the decision will be influenced by the urgency and importance of the task, but above all will be influenced by its uncertainty. Time critical problems that do not involve high stakes and are familiar (and have accustomed responses) will not require high rationality, to the point that decisions are naturalistic. More important matters that do not have time pressures and involve uncertainty will demand greater deliberation. Thus, the rationalising step determines the depth of deliberation.

The strategising element focuses internally on task interdependence through the organisational authorities, responsibilities and competencies relevant to the problem. Thus, the strategising step determines the breadth of deliberation. This will support the decision-making process in three areas: firstly, to identify which other stakeholders need to be involved in the process; secondly, to determine what level of involvement those stakeholders require, especially what level of consensus is required; and thirdly, to use this consideration of internal capabilities as the basis for generation of options.

This meta-planning step frames the remainder of the process. Familiar and certain situations will lead to a reduced effort invested in the problem, representing the pattern-recognition approach taken with naturalistic decision-making (NDM; Klein, 1998, 94-96). However, the suggestion by many NDM advocates (Klein and Klinger, 1991, 16-17; Orasanu and Connolly, 1995, 7-10; Lipshitz, 1995, 136-137; Means et al, 1991, 319-320) that pattern recognition is also dominant in other situations (ill-structured problems, dynamic environments, shifting goals, feedback loops, high stakes, multiple players, organisational norms, uncertainty and the existence of relevant experience) is not supported by empirical evidence. The implication of familiar and certain situations is that consideration of available resources should lead option generation. This is an important requirement in respect of time-constrained and event-driven situations. However, a key criticism of NDM, and its prominence of pattern recognition and mental models, is that it may impede organisational learning. Processes that reinforce satisficing moderation potentially encourage organisational mediocrity (Slote, 1985), not because of some virtue of moderation but because of expediency and habit. This is resolved in the model through the explicit review of the effectiveness of decisions.

Research Propositions

Essentially the key variables to the effectiveness of the decision model are the complexity of the problem and the manner in which collaboration is conducted. The concept of a *complex* problem is concerned with a situation that is not familiar to the decision-maker or involves competencies that the decision-maker does not possess, which aligns with the contingent factors of task uncertainty and task interdependence. The manner in which collaboration is conducted refers to the way in which collaborative input to the process is conducted, the options for which are the prescribed PROPER approach described above and a purely naturalistic approach. Additionally, the manner of collaboration can be affected by the way in which participation is managed and the potentially differing strengths of relationship between participants. Five propositions are developed below that relate to collaborative decision-making.

Firstly, the use of a prescribed approach is tendered as a preferred method of collaborative decision-making over naturalistic collaboration. A more consistent method should provide greater likelihoods of consensus, of mutual appreciation of roles, of clarity of the decision process in a collaborative setting, of an appropriate approach to satisficing and of more informed decisions. It is possible that a prescribed approach developed for universal application may be inadequate for more specialised problems or unnecessary in the case of typical or intuitive situations. Nevertheless, over a range of problems, it may be a fair generalisation to suggest prescriptive decision-making will improve the quality of decisions.

P1 *Use of a prescribed approach to collaborative decision-making is positively associated with the quality of decisions.*

The second proposition relates the value of collaboration to the complexity of the given problem. The value derived from collaboration effectively is the return on investment of the collaborative process: that is, did the resultant payoff justify the effort of developing and choosing options? If the payoff is logically related to the completeness of information and the complexity of the problem is defined as the decision-maker's familiarity with the problem (that is, whether there is completeness of information), then such a proposition could be viewed as somewhat self-evident. However, in most cases the information initially available to the decision-maker about the completeness of information (and who might possess such information) is itself incomplete and may require some intuition. As this issue deals with the types of problems facing an organisation that demand collaboration between distinct specialist units, the proposition is at the heart of contingency theory in identifying the conditions that provide a balance of organisational integration and differentiation.

P2 *The derived value of collaborative decision-making is positively associated with the complexity of the problem.*

If we consider complexity of the problem in terms of its two constituents, task interdependence and task uncertainty, it is possible to further refine this proposition into two sub-propositions:

P2A *The derived value of collaborative decision-making is positively associated with the task interdependence of the problem.*

P2B *The derived value of collaborative decision-making is positively associated with the task uncertainty of the problem.*

On this basis, a key requirement in testing the propositions will be for the research design to provide for a controlled variance in the levels of task uncertainty and task interdependence.

The potential downside of collaboration also is recognised. Just as the advantage of collaboration is that it provides increased likelihood of complete information, the disadvantages are that it might be a strain on attention (and therefore a poor use of resources) and, if constrained by consensus, might not provide the best decision in a timely manner (due to competition, variations in norms and goals, and competing rationalities; Weick, 1969, 7-12; March and Simon, 1993; 85-90). Moreover, excessive participation represents unnecessary effort and can lead to problems of overload and contradictions (Perry and Moffat, 2004). Targeted collaboration, as opposed to using a standard group of participants, might help to reduce attention and consensual difficulties. This needs to be weighed against the uncertainty of who might have relevant competencies and the possibility that a non-obvious participant might contribute to innovation.

P3 *Decision-making return on investment is optimised with targeted collaboration.*

Innovation is a key product of collaboration as new knowledge is created through a combination of existing knowledge (Skyrme, 1999, 60-63). If the collaborative process results in existing knowledge being combined in new ways, it is reasonable to suggest that increased collaboration may result in increased innovation. Some simple problems will not pose any prospect for innovation, regardless of the extent of collaboration, but the employment of collaborative processes based upon the complexity of the problem will provide an optimum level of effort for the expected payoff in innovation.

P4 *The level of innovation in problem solving is positively associated with the level of collaborative participation.*

Finally, there is the matter of politics and self-interest that influence collaboration. There is a range of possible causal factors that contribute to or detract from the relationship between participants, including trust (eg, past experiences in collaboration), socialisation, culture, reward, recognition and competition for resources. This paper will not deal with the reasons for and treatments of these individual causal factors, but will substitute a construct that reflects their effect – strength of the relationship. With a strong relationship (indicating positive aspects of the above causal factors), the collaborative process is likely to be more effective.

P5 *The derived value of collaborative decision-making is positively associated with the strength of relationship between the participants.*

Research Design and Implementation of the Experiment

The research design was based upon experimental observation of decision-makers and supporting collaborators as they addressed problems of varying complexity. The two independent variables were collaboration manner and the complexity of the problem. The levels of the first variable were assigned to different participants, with the second variable repeated over all participants as they undertook a sequence of problem-solving activities.

The design involved the participation of three decision-makers and several (nominally four) collaborators working on problems in real time. Of the three decision-makers, two were instructed to follow the prescribed approach, with the third allowed to use a naturalistic decision-making approach. Of the two following a prescribed approach, one enjoyed (unbeknown to him or her) a better relationship with the collaborators. Thus the three decision-makers were:

- DM1 – Control participant;
- DM2 – Naturalistic decision-maker (testing P1);
- DM3 – Popular decision-maker (testing P5).

Variation of problem complexity was achieved by adjusting the competency, authority and responsibility implications of problems relative to the roles of the decision-makers and their understanding of other participants' command dimensions, as well as the level of recognition of the problem in comparison with their scenario briefs. This resulted in the task types shown at Figure 6.

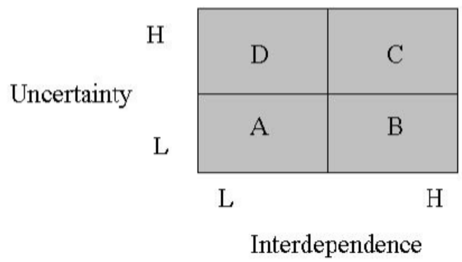

Figure 6 - Decision Task Types

Within a one-hour session of an experiment, each decision-maker considered problems of each of the above variations, thus an experiment session comprises four rounds of three parallel problem-solving activities. P1 and P5 were tested across these types of decision-makers, whereas P2 (value of collaboration) and P4 (innovation from collaboration) were tested across the different problem types. Proposition P3 (manner of collaboration) was tested in separate sessions, using the same problem sequence but with two types of collaborative approaches (targeted and inclusive).

In order to reduce nuisance variables, the experiment sessions utilised participants of similar abilities and problem scenarios that were unfamiliar to all participants (a future-based scenario where the decision-makers were responsible for the security of a sector of space and the collaborative participants represented specialist, supporting and other commands). The participants were given roles and knowledge scripts prior to, and problem scenarios during, the experiment and decision-makers were required to articulate the purpose and then provide direction subsequent to the conduct of their respective decision-making process.

The collaborative tool suite used was Groove Virtual Office 3.1, with customised forms for prescriptive and naturalistic approaches. In the naturalistic tool, decision-makers were only required to articulate the purpose (end state) and decision. In the prescriptive version, decision-makers also were required to consider their level of familiarity with the problem, the uncertainty and the nature of any interdependence, as well as to articulate a number of candidate courses of action. The participants used discussion threads, chat windows and (for targeted collaboration) instant messaging to communicate on problems (all collaboration was undertaken using these tools). The participants were given familiarisation on problem solving and the Groove tool before the experiment. Eight experiment sessions were conducted, comprising 56 participants, with all communications and entries recorded using Groove logs.

The data for each session was comparatively analysed by the researcher to determine whether collaboration was used, whether collaboration influenced the decision, whether the decision-maker used the collaboration to achieve consensus, whether the decisions involved creativity and an assessment of the decision performance. The performance assessment was based upon the normalised sum of three criteria (effectiveness, efficiency and acceptability), each subjectively and comparatively scored blind to the independent variables and using a 5-point Lickert scale. The Lickert assessments were based upon the standard approach to the five-point scale; for example, 1 (strongly ineffective), 2 (somewhat ineffective), 3 (neither effective nor ineffective), 4 (somewhat effective) and 5 (strongly effective).

A general observation of the experiments was that the variance arising from individual behaviour was higher than expected. The most evident aspect was the difference in cognitive abilities, with some individuals struggling with the problems whereas others appeared to handle them quite comfortably. A second observation related to the difference in individuals' abilities to adequately distinguish between ends and means. Individuals who provided a constricted statement of purpose based upon assumptions of likely action often had difficulty in satisficing their decision. Thirdly, there was a noticeable difference in the attitude of some participants towards collaboration. Some decision-makers tended to exhaust their own knowledge sources and options before referring to a collaborator, whilst at the other extreme others tended to refer problems to collaborators in the first instance. Similarly, the first type tended to make all decisions in isolation, whereas the second type often sought reassurance from collaborators on matters that had little to do with them. Fortunately, instances where the collaborative behaviour did not match with the situation (due to a predetermined approach by the individual) were in the minority, comprising only 11% of the decisions. Thus, nearly 90% of the participants collaborated according to the nature of the problem, seeking input when there was a lack of information and seeking consensus from those who were stakeholders in the problem.

Prescriptive Decision-Making

A simple parametric comparison of the average performance of prescriptive and natural decision-making is not suitable in these experiments, because of the small sample size and the method of scoring not reflecting ratio scores. In order to compare samples, the scores were converted to ordinal values and subjected to the non-parametric Mann-Whitney U test, which is appropriate in the case of potentially weak measurement scales (Siegel, 1956, 116-127). Conducting this test on the two samples (DM1 prescriptive and DM2 naturalistic) provides U=347.5 and z=1.23, revealing a probability that DM2≥DM1 of 0.109; this is too large to reject the null hypothesis.

As shown at Figure 7, drilling down into the individual types of problems revealed a higher performance of prescriptive over the naturalistic approach in cases of low interdependence and high uncertainty. Again applying the Mann-Whitney U test gave U_{obs} = 47 versus U_{crit} = 42 (for low interdependence) and U_{obs} = 41 versus U_{crit} = 42 (for high uncertainty). Under a level of significance of $\alpha = 0.05$, the null hypothesis would be rejected for the situation of high uncertainty but (narrowly) cannot be rejected for low interdependence. This confirms a difference between the prescriptive and the naturalistic decision making, which would be validated in both cases if a less conservative level of significance (eg, $\alpha = 0.10$) was applied for these exploratory tests.

Measure	DM1 Mean	DM1 SD	DM2 Mean	DM2 SD
All Tasks	0.87	0.18	0.81	0.18
High Interdependence	0.88	0.12	0.87	0.15
Low Interdependence	0.87	0.23	0.76	0.20
High Uncertainty	0.84	0.22	0.74	0.18
Low Uncertainty	0.91	0.15	0.90	0.16
Low Interdependence and High Uncertainty	0.81	0.30	0.67	0.18

Figure 7 - Comparison of DM1 and DM2 Performance

While the measured performance has not provided a clear distinction between the planning method and the quality of individual decisions, this might be attributed to variance of problems and individual abilities. The variance in problems could be resolved by averaging each decision-maker's performance across the four problems they undertook. Conducting the Mann-Whitney U test on the two samples of average performance scores of all prescriptive participants versus the naturalistic participants, the results are as shown at Figure 8. The observed U is 12 (versus critical U of 12 at $\alpha = 0.05$), which supports rejection of H_0 and upholds the proposition that generally the prescriptive approach will benefit the quality of decisions.

DM1 Score (round)	Rank	DM2 Score (round)	Rank
0.967 (5)	15	0.95 (5)	13
0.95 (6)	13	0.85 (4)	5.5
0.95 (3)	13	0.85 (2)	5.5
0.933 (7)	10.5	0.8 (6)	4
0.933 (7)	10.5	0.767 (1)	3
0.917 (2)	9	0.683 (3)	2
0.883 (1)	7.5		
0.883 (7)	7.5		
0.567 (4)	1		
	R_2=87		R_1=33

$$U_{obs} = n_1.n_2 + n_2.(n_2 + 1)/2 - R_2$$
$$= 12 \quad (U_{crit} = 12)$$

Figure 8 - Non-parametric Comparison of Participants

With respect to the results for the types of problems, the difference between prescriptive and naturalistic approaches in circumstances of high uncertainty is not surprising. High uncertainty translates into a requirement for greater variety of options for action, as per the Law of Requisite Variety. The ability to understand the required depth of the analysis task, as well as to maintain an appreciation of the alternatives and how they might satisfy the desired outcome, is an important influence on decision quality. To what extent the naturalistic decision-maker has the cognitive ability to manage this analysis without aids will therefore determine the relative benefit of the prescriptive approach.

The difference between the two approaches in circumstances of low interdependence was not so expected. The performance of naturalistic decisions with respect to interdependence contrasted with a consistent result across the remainder of the experiment. One possibility is that these results were erroneous and arose from nuisance variables, although this is unlikely due to the consistency of poor decision events. In fact, six of the twelve naturalistic decisions featuring low interdependence (involving five of six different decision-makers) were assessed as poor. The reason for each of these deficiencies was either a failure to make a decision within the required time or an error of logic by the decision-maker. Thus it is probable that the poor results for naturalistic decision-making under low interdependence reflects the inability of individuals to deal with several facts, logical relationships and options to the same extent as decision-makers using a more structured process. The reason that these results were not similarly reflected in the tasks with high interdependence is that, in those cases, collaborators were able to contribute to the discussion of options and thus collectively compensate for analytical deficiencies.

The expectation, however, was that the prescriptive process should have assisted tasks of high interdependence by the meta-planning step's identification of the breadth of the problem. This was not the case, with similar incidence of participation not matching interdependence (eg, excessive or inadequate collaboration and failures to seek authority or to negotiate responsibilities) for DM1 (25%) and DM2 (21%). Clearly, the key benefit of the prescriptive approach was the management of complexity through maintaining options, with no comparative advantage evident in the use of the meta-planning step to determine breadth. The expansion of the 'strategising' element to help manage participation (as per Figure 4) may have improved the effect of meta-planning, but would have to be traded off against time pressures and the appropriate level of effort for the problem.

The results tend to support the concept that the prescriptive approach makes up for cognitive limits of the decision-maker, which became more pronounced in situations of high uncertainty and when collaborative assistance was limited. The difference in performance might have been even greater had the naturalistic decision makers not been required within their decision-making tool to articulate a purpose for each problem.

Value of Collaboration in Complex Tasks

In this proposition, we distinguish between decision events in which collaboration was initiated and those in which collaboration influenced the decision. In some cases, collaboration was initiated but did not add value to the decision-making process. Referring back to the model at Figure 3, often the decision maker does not know whether there is an absence of information relevant to the problem or whether others in the organisation might know that information. In many cases, this collaboration simply confirms the existence of uncertainty.

The results showed that cases where collaboration influenced the decision were associated with a higher quality of decision than decisions not influenced by collaboration. These statistics reflect variation arising from problems that involved interdependence of tasks, which were far better handled when collaboration influenced the decision (0.94) than when it didn't (0.77). Application of the Mann-Whitney U test provided a U factor of 218.5 and a standard score of $z = 3.66$. This test established a probability for the null hypothesis of less than 0.001, thus strongly confirming the proposition in respect of interdependence. The first part of the proposition, that the derived value of collaborative decision-making is positively associated with the task interdependence of the problem, is strongly supported. This outcome was expected: a problem that might best utilise the knowledge or capabilities of another part of the organisation, or for which that other part of the organisation has a stake, should best be managed through consultation with them.

The results were not as supportive for the second part of the proposition. There was no evidence that uncertain tasks benefited from collaboration, except in cases where task interdependence was also involved (task interdependence can assist in the resolution of apparent uncertainty, as per Figure 3). The results showed that the quality of decisions with no task interdependence actually were higher when not influenced by collaboration (mean 0.88, SD of 0.20) compared with when influenced by collaboration (mean 0.81, SD of 0.14). Within these results, the quality of decisions with low task interdependence and high uncertainty were higher when influenced by collaboration (mean 0.89, SD 0.04) than when not influenced by collaboration (mean 0.80, SD 0.24). This difference, however, is certainly not significant, as reinforced by application of the Mann-Whitney U test, with U_{obs}=22.5 against U_{crit}=7.

The lack of influence of collaboration on situations of uncertainty in the results might be attributable to observed instances in which decision-makers were unable to make a decision in the presence of uncertainty and either were confused by responses from collaborators or continued to attempt to reduce uncertainty through collaboration. In the time restricted scenarios, with little slack resources to devote to clarification of uncertainty and with participants having little basis for expanding upon their answers, the experiment did not allow for collaboration to provide any value specifically associated with task uncertainty. This result might differ in other settings, particularly where there are no time pressures. However, in circumstances of operational, event-driven decision-making, the experiment offers no evidence to support that collaboration adds value to situations of task uncertainty, unless the situation also involves interdependence. Therefore, the results support proposition P2A but do not support proposition P2B.

Targeted versus Inclusive Collaboration

This proposition was addressed through rounds seven and eight of the experiment. In round seven, the three decision makers were required to employ a prescriptive approach to the given problems and collaborated with all in their workspace using the Groove chat tool. The input variables to this experiment were the same as used with decision makers DM1 and DM3 during the first six rounds (except that collaborators did not employ any prioritisation). The average performance across all of the scenarios for decision makers in round seven (DM4) was 0.92 (SD 0.12), which was less than 1% higher than the average performance for DM1 and DM3 (0.91, SD 0.14) across the first six rounds, and thus well within the margins of error arising from nuisance variables.

In round eight, the three decision makers (DM5) employed the same approach to the given problems, except that they were required to individually target collaborators using the Instant Messaging (IM) tool within Groove, rather than the chat facility. Targeted collaboration should reduce the incidence of 'nuisance' collaboration to ensure lateral communications are purposeful, focused and direct. However, the average performance across all of the scenarios for this round was 0.80 (SD 0.23), well less than in the inclusive approach to collaboration. The small sample size (half the comparisons undertaken for the other propositions) and the variance of performance in round 8 suggest the difference may not be significant. Application of the Mann-Whitney U test to compare the samples provides a U_{obs} of 47 against a U_{crit} of 42 for a level of significant of $\alpha = 0.05$, thus it is not possible to reject a null hypothesis of DM4≥DM5. Conversely, the results certainly do not appear to support the proposition P3 that targeted collaboration provides a greater return on investment of decision-making than inclusive decision-making.

It should be remembered that decision performance is only one side (the return) of the return on investment equation associated with this proposition. The investment is the amount of effort used by all concerned in collaboration. No formal measurement was conducted on the level of activity of participants, but the general observation was that collaborators in round eight were clearly less occupied than in previous rounds (having to answer IMs directly addressed to them instead of maintaining a vigil over three chat windows). On the other hand, the decision-makers appeared to be busier and the main cause of poor performance appeared to be that they were rushed to make their decisions.

In this regard, the results accurately reflect the issue of targeted versus inclusive collaboration: it is a balance between the inconvenience of bothering collaborators with irrelevant discussion versus the inconvenience of making it harder for the decision-maker to search the organisation for possible knowledge, options and actions. Given the voluntary nature of lateral relations in most organisations and the reality outside the laboratory that collaborators have their own tasks, perhaps the latter is more realistic.

Discussions with the participants after the experiments revealed an undisputed preference for the targeted collaboration approach, in that it provided participants with the ability to pose direct questions and get direct answers, as well as to avoid the inconvenience of irrelevant communications. Although the IM tool was capable of being used for multilateral communications, the majority of use was bilateral. Therefore, any issues that involved multiple logical relationships could be resolved quickly in the inclusive 'chat' method (assuming all relevant parties were attentive) but required a chain of messages in the targeted collaboration approach. This meant that the decision-makers using the targeted method often took longer to satisfice. Additionally, the targeted approach assumes that the decision-maker is aware of who may have key knowledge relevant to the problem at hand; this was not always the case.

An interesting aspect to this proposition is that the inclusive 'chat' approach was similar to a forum, in which participants could submit ideas, challenge assumptions and contribute without direction. The targeted 'IM' approach exemplified a star network in which the decision-maker controlled the agenda and the participation. Whilst some instances of direct communication between collaborators was observed, on each occasion this communication was at the direction or suggestion of the decision-maker. Thus, the inclusive approach appeared to be more informal and the targeted approach more disciplined. It is noteworthy that there were no examples of creativity in round eight, although it is unclear as to whether this was because of the formality of communications or the time pressures brought about by the collaborative arrangements.

Various factors that are not task-related might influence the manner of collaboration. Payne, Bettman and Johnson highlighted influences on the effort-quality balance of the decision process, including the response mode, information display, framing of the problem and the nature of the alternatives, in their work on adaptive decision-making (1993, 34-66). Additionally, the content richness of the collaborative system (Nunamaker et al, 2001, 6), the synchronicity of communication (which may vary for each participant, depending upon respective workloads) and the level of awareness support of the participants (Swanson et al, 2004, 7-9) all may affect the collaborative approach.

The inclusive and targeted approaches to collaboration each have relative advantages and disadvantages. The targeted approach provides a disciplined means of seeking specific information from collaborators and reducing the burden of unnecessary collaboration on participants. It also places control of the process with the decision-maker. However, the inclusive approach may be more appropriate where the nature of interdependence is unknown and where time pressures require a broadcast method of lateral relations, where consensus is required of the participants or uncertainty means the decision-maker is seeking input from participants on potential options.

The experiment provided insufficient evidence to support proposition P3. As the optimal return on investment of collaboration is dependent upon the context of the problem, it is not possible to universally advocate a targeted approach.

Collaboration and Innovation

As discussed earlier, collaborative interactions were expected to stimulate the cross-fertilisation of ideas from different perspectives, thus enabling innovation and the creation of new knowledge. In the experiment, 11 of the 96 decision situations produced new knowledge that were considered to be examples of innovation. These examples involved the combination of disparate ideas to create unpredicted alternatives, many of which were superior to the expected solutions.

Of the eleven examples of innovation, only five of these were in situations that had involved collaboration. Of these five, innovation could be attributed to the collaborative interactions on only one occasion. Accordingly the proposition that innovation in problem solving is positively associated with the level of collaborative participation was not supported by the experiment. As the theory behind the proposition has some foundation, there must be a reason for this contradictory result. Some possible reasons are offered.

Whilst not arising directly from collaboration, the instances of observed innovation still may be attributed to the combination of knowledge. Rather than the combination of the knowledge of the participants, the innovation in all but one instance emerged from the combination of the decision-maker's individual knowledge with the given script that articulated facts regarding the role's knowledge. The individual's internalisation of this knowledge while considering a problem created an environment to question the script and to suggest other alternatives. This does not however explain why ideas weren't similarly generated from collaboration.

One possibility is that collaborators did not feel confident enough to venture opinions or ideas outside of the scripts they had been given. This reluctance of collaborators to be adventurous was despite, rather than consistent with, the instructions they had been given and may have been caused by a lack of comfort with the subject material. The fact that they were contributing to the decision effort, rather than responsible for it, may have led to a desire for unanimity that overrode any motivation to suggest alternative courses of action. This situation appears similar to the phenomenon that Janis coined Groupthink, where members are unwilling to challenge the consensus of the group (Janis, 1972, 8-9). The participants' behaviour in collaboration may be driven largely by the social approval or disapproval he or she anticipates from the group as a result of his or her contribution (Janis and Mann, 1977, 133).

A final possibility is that the problem-solving conditions were not conducive to creativity. Although decision-makers sought ideas and options from the workgroup on some occasions, typically the questions put to collaborators were more direct. By contrast, creative problem solving is more likely to eventuate from a facilitative style of leadership (Rickards and Moger, 2006). Additionally, in circumstances that feature time and attention pressures, many collaborators opted to provide the answers they knew (or had written in front of them) as a matter of expediency.

Whether the cause was groupthink, apathy of the collaborators in the laboratory setting or time pressures, the experiment failed to provide any support for the generation of innovative options through collaboration. Therefore the results do not support proposition P4.

Strength of Relationships

The final proposition was that the value of collaborative decision-making is positively associated with the strength of relationship. This was constructed within the experiment through instructions to the collaborators (unbeknown to any of the decision-makers) that they should always answer DM3 as a priority whenever there is any contention in requests from the decision-makers for their attention.

During the experiment, it appeared from simple observation that it would not bear any significant results, as the collaborators did not appear to be under stress (although often there were concurrent calls for assistance). The collaborators were attentive to requests from each decision-maker and, during the wrap up of each of the first six sessions, not a single decision-maker remarked or realised that they had received better or lesser service from the collaborators. Nevertheless, the instructions to the collaborators to give priority to DM3 appeared to have the desired effect. The average performance of 'favoured' decision-makers was consistently higher than the others across all types of scenario, as shown at Figure 9. Using the Mann-Whitney U test to compare DM1 and DM3 across all tasks (24 observations of each decision maker and U_{obs}=362.5) gives a probability of the null hypothesis (that DM1≥DM3) of 0.06. This is marginally higher than the level of significance of $\alpha = 0.05$, meaning that the null hypothesis is not rejected. Similarly, using the Mann-Whitney test against the various task categories provides U_{obs} of between 50.5 and 56 for the task categories against a U_{crit} of 42. Despite a seemingly consistent difference between DM1 and DM3 average performance, the deviations in measurements preclude a significant finding.

Task type	DM1 Mean	DM1 SD	DM3 Mean	DM3 SD
All tasks	0.87	0.18	0.95	0.07
High Interdependence	0.88	0.12	0.93	0.09
Low Interdependence	0.86	0.23	0.97	0.05
High Uncertainty	0.84	0.22	0.93	0.08
Low Uncertainty	0.90	0.14	0.97	0.06

Figure 9 - Comparison of Favouritism in Decision-Making

A surprising outcome was that favoured decision-makers' performance scores were greater across all categories of task, including those that would have involved little or no collaboration. This outcome could be a reflection of a chance result that DM3 decision-makers performed better; or it could be a reflection that the DM3 decision-makers resolved interdependent tasks more expediently, allowing themselves more time to devote to the non-collaborative tasks.

Notwithstanding the fact that the difference is not significant, it would still appear likely that a small difference in attentiveness of collaborators affects performance. The favoured decision-maker receives a complete and prompt picture of the situation and options, whereas those who receive a lower priority can, under circumstances of time pressures, make a hasty decision on incomplete information. Whilst the influence of individual behaviours means that the proposition is not proven, the consistency of higher performance of DM3 lends some support to the importance of constructive relationships between participants in collaboration.

One implication of this finding is that ad hoc collaborations may not be as effective as those in which the relationships are established. Even in an established relationship, effectiveness of collaboration is dependent upon the willingness of participants to contribute when faced with other task priorities. This highlights the requirement for collaboration to be enabled by measures such as cohesiveness, identification, supervision and control arrangements, incentives, cultural pressure, prestige of the group, importance of the task and the extent to which goals are perceived as shared (March and Simon, 1993, 71-102). It also places greater importance on the participants' mutual awareness of workloads and priorities.

There is a potential for a game theory version of the experiment, where the factors that influence competition and cooperation can be explored; however inclusion of this dimension in this research activity would have complicated testing of the propositions.

Limitations

A laboratory experiment presents benefits in the ability to control variables, but often suffers from external validity problems of realism and reactivity. Realism is a key limitation of these results, in that the scope of the experiments was limited to event-driven decision-making involving time constraints, thus the findings may not be applicable to more analytical problem situations. Additionally, there were some contingent factors that influence decision strategy that were not included in the experiment. Of particular note is the 'stakes' factor and political behaviour.

The experiment did not measure the stakes involved in various decisions, although this is a factor in determining the depth of analysis in the rationalise step of PROPER and was undoubtedly an implicit consideration by the participants for each problem. Variance in stakes of the different types of problems could affect decision strategy and performance. However, such differences would not have affected the findings of this research against the five propositions, as this factor was controlled through all problems being equally undertaken by each type of decision maker. The importance or value of the decision-making outcome has been addressed fairly well in the literature and is the basis of the return on investment approach to satisficing developed by Simon. Yet its influence on collaborative dynamics is an area that could be further investigated. In situations where attention is a scarce resource and participation in lateral communications is discretionary, the method of prioritisation in collaborative activities might best be managed by a prescriptive approach based upon the value of the outcome.

Regarding political behaviour, the omission of such influences was an intentional aspect of the design as a control measure (but was incorporated in Proposition P5 to some extent and could be further enhanced through use of a game theory variation). Although the participants were clearly instructed to be cooperative, the participants were known to each other and it is possible that individuals might have acted with allegiances that were not known or measured.

Two potential limitations relating to internal validity should be mentioned. Firstly, the sample size was a limiting factor. More confidence in the results could have been achieved from the conduct of more than eight experiments, however availability of participant resources constrained this option. Secondly, although every effort was made to measure performance objectively and comparatively across all decision events using blind scoring of the results, there is some potential for error introduced through the scoring method.

The greatest limitation in this experiment, however, was the uncontrolled variances of individuals. These variances were both cognitive (ie, different abilities to solve problems) and reactive (ie, variances in behaviour of individuals in response to the experiment; Neuman, 2003, 256). The variation in cognitive ability was the most notable and had considerable impact on the findings.

The Effect of Individual Variance

In retrospect, it was ambitious to think that variations of individual cognitive abilities could be controlled. The difference in cognitive abilities of participants will, in any non-simple problem-solving situation, result in a distribution of performance. Rather than clarifying the results, an increase in sample size will simply confirm these distributions. The resultant findings for propositions P1 and P5, for example, have shown a discernible variance in performance that accords with the respective propositions. As shown at Figure 10, the broad distributions of performance resulting from cognitive abilities and unexpected behaviour limit the statistical inference that can be drawn from the results.

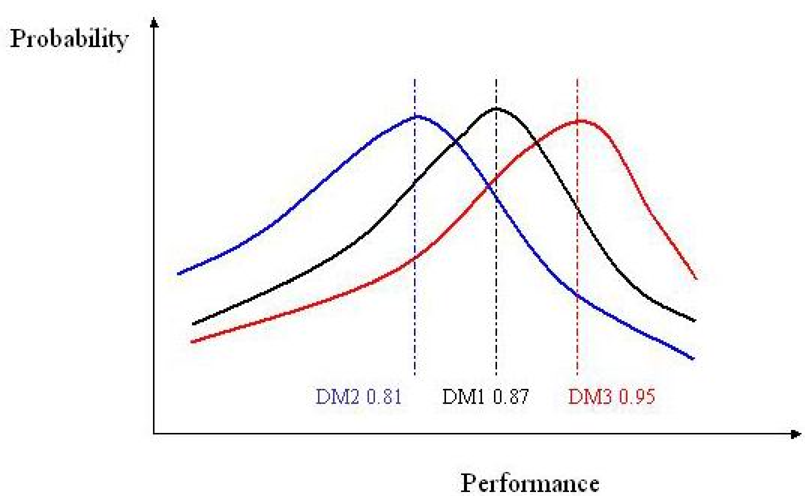

Figure 10 - Distribution of Decision-Making Performance

The results of assessing the performance of the three types of decision makers associated with propositions P1 and P5, using the Friedman two-way analysis of variance by ranks, are shown at Figure 11. Applying Friedman's equation gives a value of χ^2 of 5.54. For two degrees of freedom, this establishes a probability of H_0 (that the three decision-making results are from the same population) of 0.07. With a typical level of significance of α=0.05, the null hypothesis strictly cannot be rejected; however, this low probability does suggest the variations across the three sets of results are attributable to more than chance.

Task	DM1	Rank	DM2	Rank	DM3	Rank
A1	1	1.5	0.8	3	1	1.5
A2	1	1.5	0.8	3	1	1.5
A3	0.765	3	0.965	2	1	1
B1	1	1	0.8	3	0.935	2
B2	0.735	3	1	1.5	1	1.5
B3	0.93	2	1	1	0.87	3
C1	0.935	2	0.67	3	1	1
C2	0.73	3	0.83	2	0.865	1
C3	0.93	1	0.9	2.5	0.9	2.5
D1	0.935	2	0.87	3	0.965	1
D2	0.9	2	0.565	3	0.935	1
D3	0.6	2.5	0.6	2.5	0.935	1
	0.872	24.5	0.817	29.5	0.950	18

Figure 11 - Friedman Two-Way Analysis of Decision Makers

Summary of Findings

The experiment has provided partial support for propositions P1, subject to the constraints on statistical inference discussed above. Use of a prescriptive approach to collaborative problem solving was shown to be beneficial, particularly in addressing tasks of low interdependence and high uncertainty. However, the variance of performance indicates that individual cognitive ability is an independent variable that, in combination with the analysis process, affects the quality of decision.

The collaborative decision experiment has provided strong support for the first part of proposition P2 and no support for the second part. The confirmation of the relationship of collaboration and interdependence is illustrated at Figure 12.

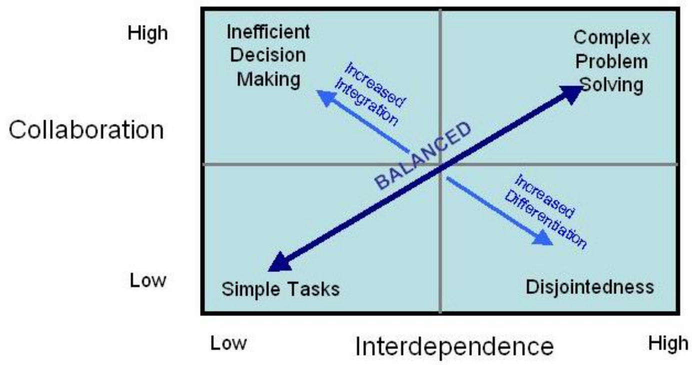

Figure 12 - Balance of Collaboration and Interdependence

The results for proposition P3 were mixed and ultimately inconclusive, but highlight the potential for further research into targeted versus inclusive collaboration strategies, encompassing meta-planning of the respective participative roles and manner of collaboration. Targeted collaboration did not result in improved decision quality; in fact there was some evidence of a reduction in decision quality and the ability to arrive at decisions under time pressure using sequential, targeted messages in lieu of a forum approach. There was also evidence of the targeted approach involving a reduced level of effort of participants, which might still lend some support to Proposition P3. However, this level of effort was not measured.

The results for proposition P4 contradicted the belief that collaboration would facilitate innovation, which may reflect a limitation of the laboratory experiment or may indicate the difficulty of challenging accepted ideas in group situations under time pressures. It is likely that the time-sensitive nature of the experiment was not suited to the interaction required to generate collaborative innovation.

The results provided an indication of the importance of a strong relationship between collaborative participants. However, the independent variable (providing priority to one of the decision-makers over others) was provided to participants as guidance and therefore neither adequately controlled nor measured. Moreover, differences in performance between the favoured decision-maker and others were consistent across all tasks, as well as being subject to the nuisance of individual cognitive variations.

Conclusion

Military forces cannot aspire to network centric operations without a shift of C2 arrangements to a more organic approach. Whereas traditional military hierarchies remain relevant in respect of goal-setting and static environments, harmonisation of the force in a dynamic environment requires greater use of lateral integration mechanisms. This paper has addressed one aspect of this integration: processes for the conduct of event-driven collaborative decision-making.

The paper has described and tested a model for event-driven collaborative decision-making, based upon a task orientation derived from organisational theory. The experiments have shown the importance of collaboration as an integrating mechanism, particularly in the presence of task interdependence. While the results of laboratory testing are partially obscured by variations of individual cognitive abilities and the effects of time pressures, the model provides a useful framework for understanding the factors that impact upon collaborative performance.

The results associated with prescription and the collaborative approach add some weight to the importance of meta-planning within the decision-making process. Understanding the consequences, time pressures and uncertainty of the task helps to determine the level of analytical effort required, or depth, required to devote to the problem. Understanding the level of interdependence across the CAR dimensions, as well as time pressures, helps determine the extent and method of collaboration, or breadth, associated with solving the problem. These aspects of meta-planning could usefully be developed in further research, providing a better understanding of decision processes and inter-unit dynamics that would help enhance the human aspect of network centric operations.

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