Chapter 10-1 – CRITERIA FOR A CONCEPTUAL MODEL OF C2

Early in its deliberations, SAS-050 developed a set of criteria to be used to judge the success of the Conceptual Model of C2 that was developed.

These criteria for success also serve other purposes. They are intended to communicate the aims of the group to a broader audience and to provide a yardstick against which to assess progress towards that vision. Furthermore, they assist in identifying where further development is needed and what directions to take. Finally, the process of developing the criteria helped the group to capture some broader issues that might have been overlooked.

The criteria are grouped into three sets. The first set addresses the scope of the Conceptual Model: what aspects should or should not be included or addressed. The second set addresses some of the essential features that the group sought to incorporate into the model, while the third set addresses a more operational view of the CM by listing some of the ways in which one would like to use it to address C2 problems.

In this section, we will introduce and discuss the success criteria in general terms. They will be used as the group's basis for validation of the model (in Chapter 10-2). They will also be used to review what the Conceptual Model has achieved and to motivate proposals for further work.

CRITERIA RELATING TO SCOPE OF THE CONCEPTUAL MODEL

The intention behind the following six criteria is to ensure that the CM will be generic enough (S1, S4) and complete enough (S2) to not only be able to instantiate known forms of C2 (S3), but to permit the conception and exploration of novel approaches to C2 in a way that respects the minimum necessary constraints (S5 and S6).

Scope

S1

S2

S3

S4

S5

S6

S1. Be applicable at (all) different levels of scale.

S2. Be applicable and relevant to different user groups (tbd).

S3. Be generic enough that the known C2 concepts can be shown to be special cases.

S4. Be comprehensive enough to include all of the known and potentially relevant phenomena and views.

S5. Be clearly anchored in reality at both "input" (what decisions actually do affect outcomes) and "output" (what are the relevant consequences of decisions that are made).

S6. Also anchor the "process" in reality (within the bounds of existing knowledge and research).

DISCUSSION AND CONSEQUENCES OF THE SCOPE CRITERIA FOR THE CM

Criterion S1 arose from the recognition that C2 was a recursive concept that could operate at every scale from individual tactical level decisionmaking to force level strategic and force-shaping planning decisions. It was felt important that the Conceptual Model should not be focussed on a particular level of C2 but should be generic enough to be instantiated at the level(s) of interest.

Levels range from the individual human (soldier, seaman, airman, SF, or marine) or system (weapon, platform, sensor, etc.) through small teams (platoon, aircrew, artillery battery, etc.) through teams of teams (battalion, squadron, novel groupings such as manned-unmanned teams, etc.) up through larger groupings that may either be drawn from single service elements (e.g., Australian Army's Combined Arms Team) or from joint force elements, or even more widely from coalition force elements or from both military and non-military elements. There are also multiple levels of time-scale operating simultaneously with couplings between them so that faster executing loops generate consequences that become inputs to the slower loops, while these in turn create a more slowly changing context for the faster loops. Similarly, there is a range of effects-scales (from local to global) that are partly related to the time-scales (through the rate at which effects propagate), but which could also be thought of in other terms, such as the number of people affected by the effect or its severity.

So it becomes apparent that there are several important dimensions that characterise different aspects of the C2 scale of interest, for example:

- The number of elements that are appropriate to task at that scale;
- The diversity of those elements (single service, joint, coalition, multi-agency…);
- The time-scale over which the model is being applied (which determines which feed-forward and feed-back loops are executing complete cycles within the scale being considered);
- The effects-scale that is being impacted by the decisions being made in that C2 Application; and
- The number of nested levels of detail below the scale at which we are working, etc.

Another aspect of scale is that different levels of scale do not exist independently, but are intrinsically linked through causal and influence networks propagating effects in both directions through the levels and by aggregation upwards and unpacking of detail downwards. The nature of these links and the need to have them captured by the model should be dictated by an appreciation of the applications to which the model will be put.

But as a general observation, many model applications will require the linking of model instantiations at different scales so as to allow the tracing of changes at one level through to manifested consequences at other levels, or conversely the tracing of problems manifested at one level to their contributing causes operating at different levels. So the conceptual model will need not only to be generic enough to be able to be instantiated at different scales, but also to have the means of capturing and representing such causal and influence networks operating through the levels of scale.

Criterion S2 was included to ensure that attention was paid to the eventual users of the Conceptual Model and to their needs for particular functionalities and effective user interfaces. This criterion can only be addressed when the users have been identified and prioritised, but even without known users it stands as a reminder that the CM should be able to support multiple views and tools.

Criterion S3 addresses two aspects of the generality the group has strived for in the context of the relationship between known C2 concepts and the Conceptual Model. On the one hand, recognising that familiarity with existing C2 concepts will sometimes make it difficult to separate the essential aspects of C2 from the biases and assumptions that underlie a particular concept, this criterion requires that it can be explicitly shown how known C2 concepts can be retrieved from the CM by making particular choices of CM variables. On the other hand, because the known C2 Approaches represent a wealth of valuable experience and distillation of lessons learned about C2, the generality and completeness of the CM is served by verifying that all the variables required to specify and distinguish the known C2 concepts are indeed included.

This criterion will also therefore create a set of benchmarks to calibrate the model, and the process of validation should include running some test cases of known C2 concepts such as the six in *Power to the Edge* to identify the degrees of freedom associated with each, the values they should take for each of the test concepts, and in each case, to demonstrate that the resulting instantiation does in fact exhibit the expected properties of the test concept.

Like S2, criterion S4 was included to ensure that attention was paid to areas that might have been overlooked (in this case, to various sources of C2-relevant phenomena and views), so this criterion also supports S3 in seeking to ensure completeness of the model. Obviously, this is an open-ended criterion which can never be completely satisfied because what C2-relevant phenomena and views are known is never complete either.

Criterion S5 is based on an implicit high level model of C2 about decisionmaking in a broad effects-based approach, and therefore the aspects of C2 that matter most are those that ultimately make a significant difference to the outcomes that matter. There are two parts to this: knowing about outcomes (what is required and what matters), and knowing about how various aspects of C2 affect outcomes. So to comply with this criterion, the CM should adequately address the questions of which processes and decisions to pay attention to and what variables influence them (the inputs), and what their consequences are in the outcome space (the outputs). This criterion essentially requires the CM to be adequately connected to the context within which C2 is being exercised.[1]

Specifically, the CM should be able to:

- Represent the structure and content of the space of possible futures including the effects potentially generated by each force (outputs), and also including relative values (desirable to intolerable) attributed to possible effects or outcomes; and
- Represent the structure and content of the space of decisions to be made, and identify those that are significant determinants of the outcomes and are independent of the C2 concept (i.e., inputs to the C2 process).

Compliance with this criterion requires the CM to take the form of a transformation of inputs into outputs, where both are grounded in real-world phenomena.

Similarly, criterion S6 is an extension of criterion S5 and addresses what happens between the inputs and outputs covered by S5. Specifically, this criterion requires the CM to model the transformation process in a way that respects the constraints of what is known to be possible. To assess compliance, a “reality check” of the explicit and implicit models of process in the CM should be performed by C2 and related subject matter experts. Relevant subject fields might include human factors, cognitive, and social sciences.

[1] One of the Peer Review criticisms of the CM was that the hooks were not there for the connection to the context.

CRITERIA RELATING TO FEATURES OF THE CONCEPTUAL MODEL

The next five criteria address some general requirements about clarity, transparency, consistency, efficiency, etc. that the group felt were essential for a Conceptual Model.

Features

F1

F2

F3

F4

F5

F1. Represent clearly what constitutes "success" and "failure" and thresholds of "acceptability."

F2. Make assumptions and value judgments visible and testable/explorable (including identifying weaknesses in them).

F3. Be clear about boundaries of content (what's in/out), application (where it can be used), and interactions across those boundaries (how what's in interacts with what's out).

F4. Be logically consistent (while allowing for modelling of ambiguities and inconsistencies).

F5. Variables should be as mutually exclusive and exhaustive as possible (given the complex highly interdependent nonlinear nature of the space).

DISCUSSION AND CONSEQUENCES OF THE FEATURES CRITERIA FOR THE CM

The first criterion obviously relates to the Value[2] View and requires the ability to assign value (along a continuum from success to failure, and crossing a threshold of acceptability in between) to the outcomes that are produced in the Value variables. The importance of being able to do this derives from the need to explore the consequences of different C2 Approaches in different contexts.

On the other hand, criterion F2 reminds us not to fall into the trap of assuming that assigned values are absolute.

The questions of boundaries and domains of applicability are always critical to the successful use of any model. Criterion F3 requires the CM to support the user in explicitly defining what the limits are and in considering how external influences are to be addressed.

Criterion F4 does not need much justification: inconsistencies in the CM could be problematic in many ways and at worst could render the model misleading. The consistency being referred to is of course that of the logical structure of the CM, not of the values and information taken on in any particular instantiation of the CM, which must retain the potential to display the full spectrum of complex real-world confusion.

[2] This section is really difficult to write clearly because the word "value" has several senses in this context: a label for variables that indicate how something that is appreciated is being created (Value View, value chain); the amount of a measurable variable (the resulting value of a Value variable; and the amount of appreciation attributable to something (the value of SA). So there is value in being able to articulate the value of different values that value variables can take.

Finally, criterion F5 reflects the ideal desire to find the minimal set of variables that span the space we wish to explore. Or as Einstein was alleged to have put it: "Make it as simple as possible, but no simpler."

CRITERIA RELATING TO THE USES OF THE CONCEPTUAL MODEL

These next thirteen criteria are arguably the most important criteria because they describe in detail how the model is envisioned to be applied and therefore they dictate the functional aspects of the model that will be needed to deliver successfully on these uses.

U1. Represent clearly and support the testing and refinement of our understanding of causal and influential relationships between variables.

U2. Lead to a generic framework of metrics (which should relate independent system measures to dependent outcome measures).

U3. Identify the natural modes at all levels (e.g., attractors or stable regions) of the hyper-dimensional space of variables in which the system operates.

U4. Identify the resulting emergent properties at all levels (including the force and policy levels).

U5. Suggest points of influence / pressure points that may affect the -ve (control) and +ve (growth) loops operating to help manage:

- Overall effectiveness;
- Congruence of objectives and intent;
- Synergy of effects and tempo;
- Suppression of unwanted effects;
- All costs and benefits;
- Risk;
- Robustness;
- Sustainability; and
- Adaptation (e.g., learning, agility, flexibility, adaptive evolution of capability).

U6. Help in rapid generation and evaluation of ideas.

U7. Help us reason about conditions or indicators under which particular C2 concepts are more or less applicable.

U8. Help us understand how much is "enough" for enabling properties, and how they are interdependent.

U9. Discover/identify correlations between and among variables.

U10. Support analysis of vulnerabilities and failure modes.

U11. Perform Balance of Investment studies.

U12. Identify important gaps in knowledge and data to be prioritised in further research and experimentation.

U13. Generate customised views for specialist audiences.

These criteria fall naturally into four groups, and the four groups themselves also have a logical relationship building towards our goal of improving overall effectiveness through better C2 effectiveness, as shown in Figures 10-1.1 and 10-1.2.

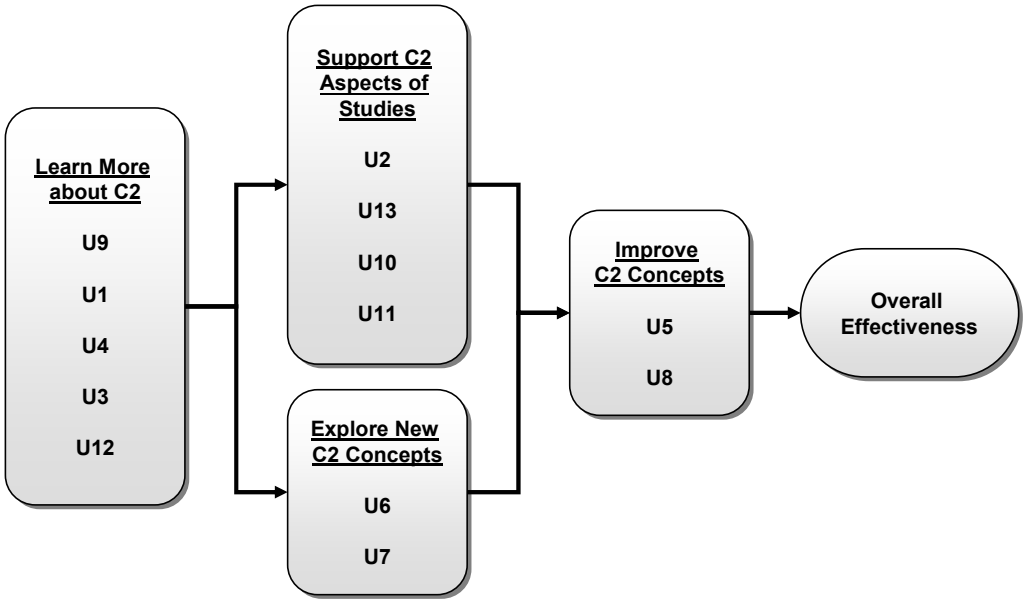

Figure 10-1.1: Logical Relationship of the Four Groups of Uses Criteria.

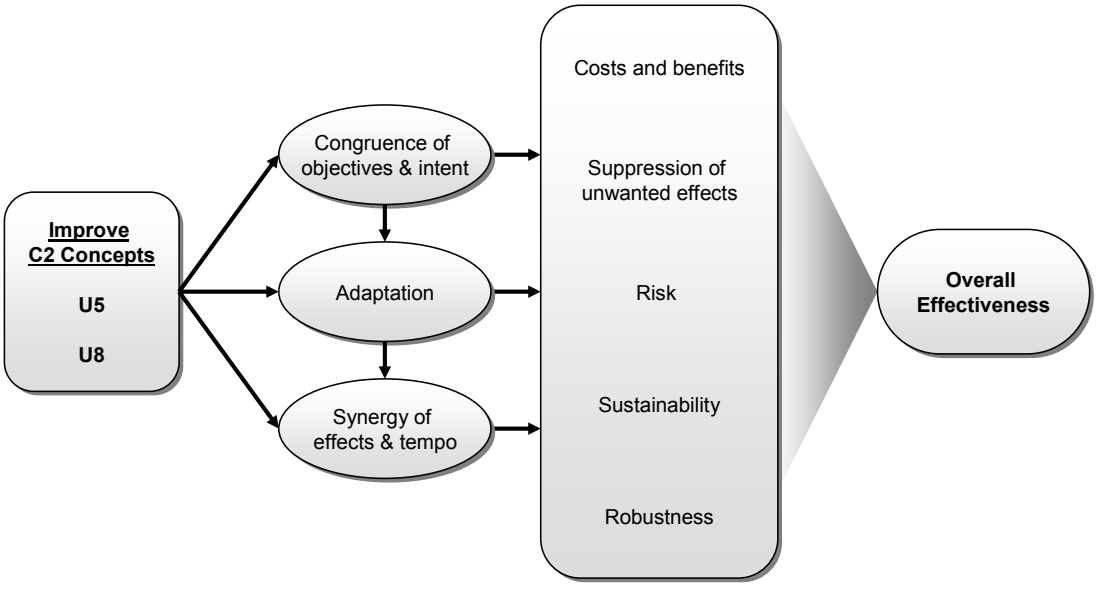

Figure 10-1.2: Improve C2 Concepts.

DISCUSSION AND CONSEQUENCES OF THE USES CRITERIA FOR THE CM

Each of these types of applications of the CM will create its own demands on the structure and functionality of the model. The logical flow of the four groups also implies that the quality of the outcomes that can be supported in improving overall effectiveness will be limited by the quality of our ability to support C2 aspects of studies, and to explore new C2 concepts, and these in turn will be limited by the depth of the learning about C2 that is supported by the first group. In developing the CM to better support that group, one should therefore have an eye upon the flow of benefits to the right.

The four uses relating to learning more about C2 are directly addressed to the CM itself, and seek first to improve the quality of understanding of the variables and their relationships, second to focus on the variables that capture the emergent properties of C2, the force, and the situation it influences, and third to recognise where further research and analysis is needed to extend and deepen the understanding of C2. The central focus on emergent properties and that subset of them that might be called the "natural modes of operation of the system being studied" is entirely appropriate from the point of view of the insights being derived from the science of complexity, and complex adaptive systems in particular, and seeks to build a base from which those insights can be applied and further developed in the context of C2.

The direct consequence for the CM is that an increased emphasis on dynamic properties is needed. To better achieve the intent of these criteria, the CM will need to include variables that capture dynamic emergent properties at multiple levels, including for example, some lower level emergent properties that, under the right conditions, can lead to particular higher level emergent properties that influence value outcomes in significant ways, and also include the more complex and coherent relationships between independent and emergent properties that are in play.

Criterion U2, the first of the four Uses Criteria that address how the CM should seek to support C2 aspects of defence capability studies, requires a generic framework of metrics to be developed from the CM. Such a framework would give guidance as to what sets of variables should be selected in particular studies, how to measure them, which variables need to be controlled for, which represent degrees of freedom to be explored, and which dependent variables need to be monitored as indicators of emergent outcomes, or as ultimate measures of value or effectiveness.

The second of this set of Uses Criteria, U13, is related to S2 (the second of the Scope Criteria that asks the CM to be relevant to different user groups) and requires that the CM be customised for particular purposes. The purposes or users need to be specified to see what the implications for the CM actually are, but one general observation is that open formats that preserve the useful information in the CM would in general be preferred because they would facilitate the importing and exporting of CM data from or into particular tools that may have specialised views or analysis functions desired by different user groups.

The third Criterion, U10, identifies a particular type of analysis that needs to be supported, one that is an important slant to take on any C2 or capability study: the analysis of vulnerabilities and failure modes. This implies that the CM is able to produce representations of instantiations of C2 concepts that lend themselves to analysis by suitable methods, for example making use of existing network analysis tools.

Finally in this set, Criterion U11 emphasises the importance of the CM being able to support Balance of Investment Studies, which require the ability to combine metric frameworks that address two or more capability areas into a common bottom line of impact on overall effectiveness, so that meaningful comparisons can be supported.

Any particular study would certainly rely on functional aspects of the CM addressing each of these four criteria, and indeed on most of the other criteria as well.

The third set concentrates on what is needed in the CM to make it useful for improving the application of C2 concepts so as to increase their contribution to overall effectiveness. While it consists of just two Uses Criteria, U5 and U8, if fully developed these would provide extremely powerful tools.

U5 addresses the exploitation of adaptive mechanisms to foster better outcomes in terms of overall effectiveness through the outcomes in five key contributions to overall effectiveness (costs and benefits, suppression of unwanted effects, risk, sustainability, and robustness) that are in turn driven by the extents to which various aspects of adaptation are successfully exploited. While adaptation is a generic concept that can be implemented in many different ways and at different levels, these criteria do not yet capture the full spectrum of what is going to be possible here, but recognise that the complex nature of the network of interactions that will result from any realistic instantiation of C2 will necessarily create many interdependent feedback loops, and that these will in turn create the possibility of various direct interventions to influence the natural and designed adaptive mechanisms present in the system, or more simply the congruence of (lower level) objectives and (higher level) intent (what one might call vertical alignment) and the synergy of effects and tempo (what one might call horizontal alignment). An alternative route to achieving the latter is through exploitation of adaptation rather than direct intervention, and adaptation itself is critically dependent on the degree to which vertical alignment is achieved because it is the internalised success measures in any adaptive mechanism that are used for guidance in the direction of adaptation – hence the additional two vertical arrows linking these three concepts.

The other member of this set, U8, is important because it addresses an essential distinction between enabling properties and value outcomes: the fact that the former are often variables for which there is a “just right” amount, while the latter are usually variables that we seek to maximise, and that they are often related, in the sense that the value outcomes are improved by tuning the enabling variables closer to their “just right” levels. The CM should help to clarify these relationships and to determine the target levels of the enabling properties.

The implications of these two criteria for the CM are significant and profound. It needs to be able to represent the presence of adaptive mechanisms, the factors that will influence their effectiveness, and the linkages between them.

Finally, the last set of Uses Criteria tackles the Holy Grail of how to produce valuable new C2 ideas. It seeks to build on the powerful functionality developed in addressing all of the previous criteria, and to apply it to generate and evaluate new C2 concepts (U6) and to characterise under what conditions they are likely to be more or less effective (U7). Speed will be of the essence here simply because the space of possibilities to be explored is so vast.

These two criteria do not attempt to indicate what particular strategies are likely be useful in this quest, but early indications suggest that understanding and exploiting adaptivity is once again going to be key.

CLOSING DISCUSSION OF THE CM IN RELATION TO THE CRITERIA

The Conceptual Model presented in this report has made substantial progress towards the vision portrayed by the criteria, although there is still much work to be done to fully deliver on that vision. This is to be expected given the scale and complexity of the challenge undertaken.

As illustrated in Figure 10-1.3, the criteria fall naturally into six groups: Scope, Features, and four subgroups of Uses: Learn more about C2, Support C2 Aspects of Studies, Explore New C2 Concepts, and Improve C2 Concepts.

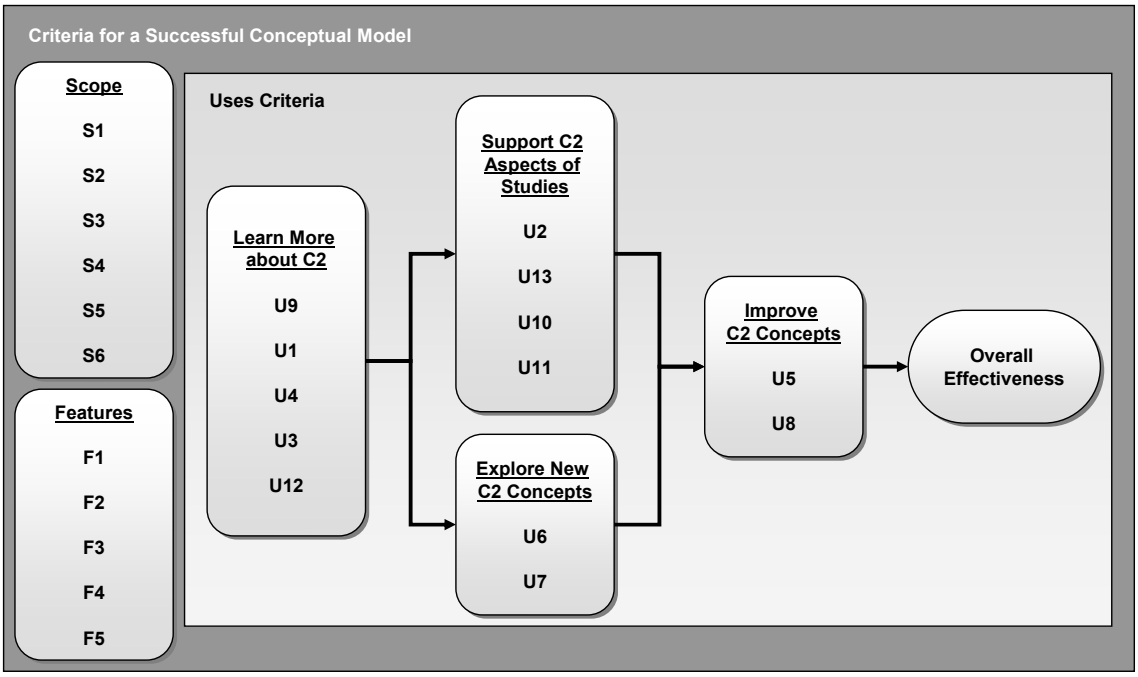

Figure 10-1.3: Schematic Showing the Groupings of the Criteria Adopted by the Group for a Successful Conceptual Model.

The most significant progress made in the Conceptual Model has been against the three left-most criteria boxes in the above diagram: the Scope and Features criteria and the Learn More About C2 subgroup of the Uses Criteria. While there is of course still room for improved compliance with these criteria, the degree of compliance achieved does create a sound basis on which to build a more solid CM and start exercising it for some limited applications in the Support C2 Aspects of Studies subgroup of the Uses Criteria.

One priority area for development that has not been significantly progressed yet is that touched on by the criteria relating to emergent properties and natural "modes" in the Learn More About C2 subgroup, and that is further articulated by the criteria in the Explore New C2 Concepts and Improve C2 Concepts subgroups, an area that springs from the inherent complexity of the context that C2 aims to influence. These criteria require a more comprehensive analysis of the dynamic properties of complex systems and their interactions, their emergent properties, and in particular, how adaptive properties arise and how they can be harnessed to foster increased effectiveness, and to explore the space of possible C2 concepts. This constitutes a considerable program of work and will require extensions to the current CM in the form of higher level variables to capture essential characteristics of adaptive mechanisms and of the relationships they require between capability elements.

Another area earmarked for further development is the elaboration of U9 and U1 in the domain of individual and team behaviours and characteristics (ITCB). SAS-050 has identified over 300 C2-relevant variables and their relationships, of which about one third are related to individual and team characteristics and behaviours.

Addressing the above mentioned criteria U1 and U9, a literature-based search for relevant empirical findings concerning relationships between variables within the ITCB part of the model, as well as between ITCB variables and variables of other parts of the model, was conducted. Chapter 10-5 presents an overview of the relationships between variables captured by the CM. It reveals that so far only a small number of these relationships have been empirically validated. The majority of them represent plausible hypotheses about their principal nature such as, for example, the relationship between individual alertness and stress level depicted in Figure 10-1.4. It is hypothesized to have the shape of an inverted "U" which depends, among others, on individual characteristics such as cognitive flexibility.

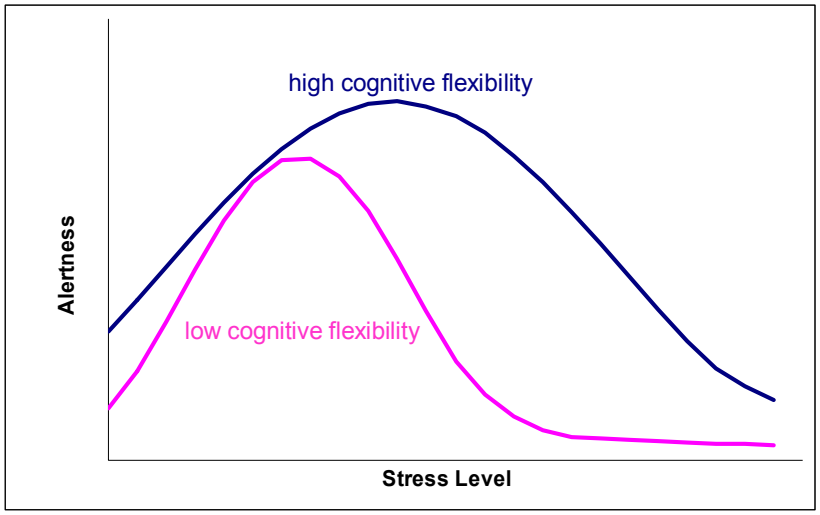

Figure 10-1.4: Alertness as a Function of Stress Level.

As is well known to automobile drivers, alertness (in the sense of paying attention to the traffic environment and being ready for a timely control response) increases up to a maximum level as the stress level (caused by traffic density, speed and speed differentials, erratic behaviour of other drivers, road obstacles, and other factors) grows, and decreases as the stress level keeps increasing further because of cognitive and physical limitations of the driver. However, the location and shape of the functional relationship between alertness and stress level depends, among others, on the cognitive flexibility of the driver, which reflects his understanding of a situation when confronted with new information. For a given stress level, high cognitive flexibility is associated with a higher degree of alertness than low cognitive flexibility, or a certain degree of alertness involves lower stress levels, or can be maintained at higher stress levels for drivers with high cognitive flexibility.

In order to develop a knowledge base for specifying relationships between ITCB variables for instantiations of the CM and the development of workable C2 models, systematic empirical research is indispensable.

REFERENCES

Grisogono, Anne-Marie. "Criteria for a Conceptual Model of C2." Presented at the Peer-to-Peer Workshop, 4-6 October 2005. Virginia Beach, VA USA.