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"The Evolution of C2"

Title: Organizational Agility

Topic 7: C2 Approaches and Organization

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Abstract

Organizational Agility has been discussed during SAS-065 NATO NEC Command and Control Maturity Model development, the Exploratory Team on C2 Agility, and other similar research efforts. In these contexts, agility is being defined as the ability to recognize changes in situation complexity and move quickly to the most appropriate C2 approach (edge, collaborative, coordinated, or de-conflicted). Proposed agility attributes are robustness, resilience, responsiveness, flexibility, innovation, and adaptation (Alberts & Hayes, 2003). However, more research is needed to determine how these attributes and their intensity relate to agility.

This paper presents a conceptual model that helps us understand how certain agility attributes contribute to an organization's potential and dynamic behaviour particularly dynamic transitions from one C2 approach to the next. Conceptually, a motion system may be used as a metaphor to understand the organization's dynamic behaviour. Under this metaphor, it follows that mass is analogous to organization size attribute, damping factor is related to organization resistance to change attribute, and spring constant is equivalent to organization flexibility attribute. We find that Organizational Agility is the ability for an organization to optimize its attributes through compensatory, anticipatory, adaptive, and learning methods. Modelling and simulation is used to illustrate various C2 Approach transition profiles by varying organization size, resistance, and flexibility, while case studies are used to provide anecdotal evidence for the model.

Introduction

Organizational Agility is sometimes considered to be an oxymoron, particularly in large bureaucratic settings. However, private and public companies use Organizational Agility to set the conditions for effective and efficient services and healthy profit margins by improving and adopting situation-tailored governance and management approaches. The same is true for multiple organizations (i.e., a collective) that work together towards common objectives during complex endeavours such as the Vancouver 2010 Olympics and the Afghanistan mission, which are high priority events for Canada[1].

The Canada First Defence Strategy (CFDS) states for domestic events that "the Forces will be prepared to effectively assist other government departments in providing security for major events at home, such as the 2010 Vancouver Olympic Games". For missions abroad it states that "In Afghanistan, for example, the Canadian Forces' contribution is only one component, albeit an essential one, of a 'whole-of-government' approach. Only by drawing upon a wide range of governmental expertise and resources will Canada be successful in its efforts to confront today's threats, [. . .] In addition, the Canadian Forces will participate, where circumstances dictate, in missions with like-minded states as a responsible member of the international community" (Government of Canada, 2008). Organizational Agility will be a key enabler for the success of both domestic and expeditionary complex endeavours.

Organizational Agility and Complex Endeavours

These above statements and CFDS as a whole contain three important implications about 1) complexity, 2) endeavours, and 3) coordinating complex endeavours. First, current and future events are and will continue to be complex. Complexity appears in both the environment and the collective (self). The SAS-065 Task Group on NATO Network Enabled Capability Command and Control Maturity Model (referred to as "SAS-065" in this paper) noted that environment complexity depends on the endeavour's (SAS-065, 2010):

- Nature (major events, natural disasters, conflicts, etc.)
- Clarity and unity of intent and strategy
- Entity number and nature (friendly, neutral, adversarial)
- Entity diversity and familiarity with each other
- Stability and predictability
- Entity interaction transparency and uncertainty
- Infrastructure
- Effects (change of state of physical, information, cognitive, and social variables)

"Self" complexity involves complexity amongst those entities that form the collective (i.e., friendly forces and partners), and depends on the entities' (SAS-065, 2010):

- Number
- Culture, values, and norms
- Trust between each other
- Language(s)

[1] Canada's Disaster Assistance Relief Team and other international partners responded within 48 hours after the Haitian Earthquake in January 2010 demonstrating signs of Organizational Agility. The challenge will be to govern and manage the situation as it unfolds.

- Information and communication capabilities
- Organization [Governance] and Management styles

Second, SAS-056 refers to "endeavours" while CFDS refers to "events", as opposed to "missions" or "operations", thus intentionally moving away from military-centric language and recognizing that current and future events, disasters, and conflicts will require a comprehensive (military, non-military, government, nun-government, domestic, and international) response. Organizational Agility is a critical attribute for such diverse groups to work effectively together towards accomplishing the collective's objectives for the endeavour.

Third, this diverse collective brings multiple skills and resources to the complex endeavour that requires some type of coordination (governance and management) to accomplish the strategic end - similar to sports teams where each team member (defence, offense, goal keeper, coach, trainer, *etc.)* has specific roles and responsibilities all working together towards winning the game. Players, referees, owners and fans all agree on the game rules (governance) otherwise penalties will ensue. However for complex endeavours, engagement rules are rarely pre-determined never mind agreed upon, except perhaps for physical rules that govern time, space, and matter. Never-the-less the multi-talented collective is expected to manoeuvre through (management) this 'rule-less' environment and achieve the objective.

Some teams within an organization stay for a term and rotate in new teams with the same skill set. Unfortunately, the new teams have little time to learn and adopt the governance and management approach being used by the collective. This lack of time puts additional pressure on Organizational Agility. Military collectives often meet their objectives because they have common equipment standards, doctrine, education, training, and mission rehearsal, all built on a common military culture and ethos. A military/non-military collective likely will not have a common work culture, making cohesive governance and management formidable and far from optimal.

Governance and Management (GM) set the conditions for effective and efficient [2]work. Governance places limitations on the organization's activities based on the stakeholders' global ends as well as organizational/societal values and ethics (Oliver, 2009). Management ensures that the organization's main activities get done, which include analysis, planning, execution, assessment, and decision-making (Farrell, 2007) for most events. In the context of this paper, Organizational Agility refers to organizational behaviours that enable governance and management as well as other organizational adjustments to be made in order to maintain effective work outcomes in lieu of the endeavour's complexities.

To illustrate GM adjustments, we return to the sports metaphor. A "play" is, in effect, a tool for managing the team's activities within the overall governance structure of the game, and the team uses well-practiced (learned) plays h m their 'playbook' (Miller & Parasuraman, 2007)[3]. If the initial (anticipatory) play does not work then team members need to quickly realize that the opposing team has responded unexpectedly and another pre-planned (compensatory) or instinctive (adaptive) play must be used. The team exhibits learning, anticipatory, compensatory,

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[2] For effectiveness and efficiency definitions see (SAS-065, 2010) and (Farrell, 2005)
[3] Miller and Parasuraman successfully applied the playbook metaphor to human-machine interactions with uninhabited vehicles. A similar analogy may be applied to entities within a complex endeavour.

and adaptive behaviours in this short example. In the same way, Organizational Agility is the ability to optimize its GM approach to the situation through compensatory, anticipatory, adaptive, and learning methods or behaviours.

Thus, Organizational Agility is critical for collectives engaged in complex endeavours. It is needed to cope with both complexity in the environment and complexity in the collective (self), coordinate (govern and manage) diverse entities' activities, manoeuvre through the nearly "rule-less" environment, and adopt the appropriate 'play' or GM approach as the situation dictates. Organization Agility involves strategic investments in several GM approaches (pre-determined "plays" and "rules") in anticipation of the range of situations that the collective may confront.

As the endeavour's complexity changes the collective must adopt the appropriate GM approach. However, moving from one GM approach to another does not happen instantaneously but over time. This paper focuses on the dynamic behaviour of a collective moving from one GM approach to another. We propose that the parameters that govern this dynamic behaviour are optimized using Organizational Agility.

Defining Organizational Agility

Organizational Agility is related to collectives adopting an appropriate GM approach as the situation demands during complex endeavours. But what is Organizational Agility specifically? The dictionary provides the following agility definition and synonyms (Merriam-Webster, 2009):

Agility: The quality or state of being agile: nimbleness, dexterity (played with increasing agility)
Nimble: Quick and light in motion: agile (nimble fingers)
Dexterity: Readiness and grace in physical activity; especially: skill and ease in using the hands (manual dexterity)

This agility definition is set in the context of working with one's hands. Wikipedia describes agility as the ability to change the body's position, and requires a combination of balance, coordination, speed, reflexes, and strength. This description is reminiscent of a gymnastic floor routine. From these perspectives, Organizational Agility is the collective's ability to nimbly reconfigure itself in response to a given situation.

The Focus Agility and Convergence Team (FACT) met in Washington in March, 2008 and invited the attendees to submit a 50-word definition of agility, and nineteen responses were collated in a draft document. Some definitions were from the dictionary, others were from the network-enabled capability and command and control literature, while still others were from other contexts. Of note, Jeremy M. Kaplan offered the following quantitative definition in response to the FACT request (Kaplan, 2008):

$$A = \sum_{i=1}^{N} \frac{P_i * E_i}{T_i / T_{c_i}} \log_2\left(\frac{1}{P_i}\right) \qquad (1)$$

where:
A - Agility
N - total number of configurations
P_i - probability that a configuration i is relevant (likely and important)

E_i - effectiveness of a system in configuration i
T_i - time for a system to reach the i^{th} configuration
T_c - time characteristic timescale for needed system response

Equation 1 has the same mathematical form as the information entropy equation developed as part of communications theory (Shannon, 1948), which borrowed the entropy concept from the second law of thermodynamics (Reynolds & Perkins, 1977). The logarithmic entropy equation describes the number of possible configurations that a system (collective, in this case) can occupy. For example, a two-sided coin with equal probability of heads or tails has an entropy value of 1 while a six-sided die with equal probabilities has an entropy value of 2.58. In other words, a die has more potential configurations (more entropy) than a coin. Similarly a collective, may have higher entropy than another collective (or the same collective at a different time).

Note that a two-headed coin has an entropy value of 0: that is, it has one potential configuration only. Most collectives operate with one configuration only, however, Organizational Agility requires more than one potential configuration as a minimum, and equation 1 provides a means to calculate that potential. The calculation challenge would be to identify the number and probability of relevant configurations, the effectiveness for each configuration, and the collective's characteristic time.

Although, entropy is a useful metaphor for describing organizational configuration potential, the entropy metaphor provides little insight into the organizational dynamics associated with Organizational Agility. "Agility, as explained in *Power to the Edge* (Alberts & Hayes, 2003), is the synergistic combination of robustness, resilience, responsiveness, flexibility, innovation, and adaptation. Each of these attributes of agility contributes to the ability of an entity (a person, an organization, a coalition, an approach to command and control, a system, or a process) to be effective in the face of a dynamic situation, unexpected circumstances, or sustaining damage. Effectiveness without agility is fragility" (Alberts, 2007). This agility definition implies that it is a compound attribute of six key organizational attributes required for an organization to be effective particularly during complex endeavours.

(Spaans, Spoelstra, Douze, Pienaman, & Grisogono, 2009) refer to agility in terms of the ability to change strategy when the situation calls for it, and they emphasize the need for an organization to take an "adaptive stance": that is creating the preconditions for adaptation with an emphasis on learning. Similarly, SAS-065 defines Command and Control[4] (C2) Agility as the ability to transition between C2 approaches as well as "Being able to choose among a larger set of C2 approaches is the essence of C2 agility" (SAS-065, 2010). Here we see that agility is more than a combination of other attributes but involves learning, adapting, and anticipating (choosing the right approach or 'play' for the situation).

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[4] The SAS-065 report was written for NATO, and C2 was the preferred term. However, C2 and Governance and Management (GM) are interchangeable for the purposes of this paper.

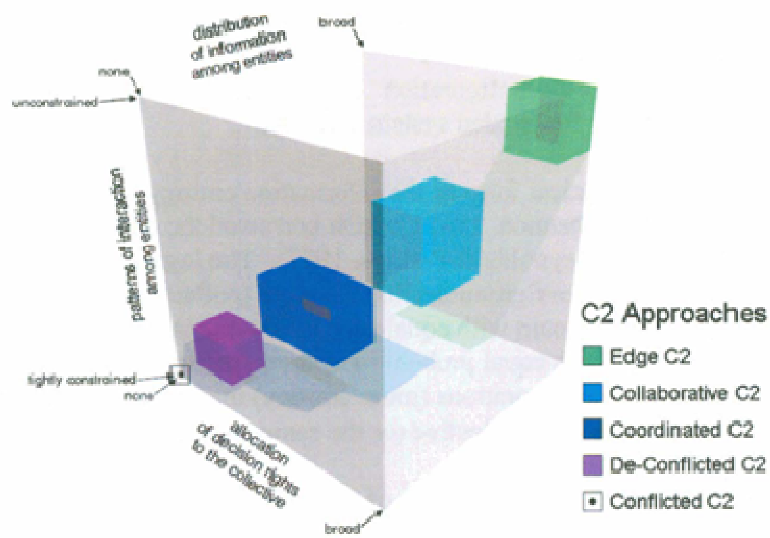

Figure 1: C2 Approaches and the C2 Approach Space – *Figure 16 in (SAS-065, 2010)*

This paper attempts to bring these agility definitions together first by using C2 approach space concept shown in Figure 1 to visualize transitions between C2 approaches. The space has three primary dimensions: Allocation of Decision Rights (ADR), Distribution of Information (DI), and Patterns of Interaction (PI). Decision rights, that are allocated and accepted by entities explicitly (formally verbalized or written down) or implicitly (assumed), range from none to broad. DI (or information sharing) amongst the entities also ranges from none to broad. PI refers to possible interaction configurations ranging from constrained (hierarchy) to unconstrained peer-to-peer) interactions. Note that DI and PI are related to each other. That is, if PI is peer-to-peer DI is likely to be broad, and conversely if the interaction is hierarchical, sharing information would be constrained to a single branch at times. Thus, DI and PI are not orthogonal to each other.

Even though the entire C2 approach space contains an infinite number of C2 approaches, most organizations maintain only a small number of relevant C2 approaches. SAS-065 identified five distinct C2 or Governance and Management (GM) approaches in this space: Conflicted C2, De-Conflicted C2, Coordinated C2, Collaborative *C2,* and Edge *C2.* Conflicted C2 exists at the origin of the space where ADR, DI, and PI are none, none, and tightly constrained, respectively, while Edge C2 is a region at the far edge of the space where ADR, DI, and PI are broad, broad, and unconstrained. The three other C2 approaches fall along the diagonal.

The transition from one C2 approach to another can be traced in the C2 approach space. Figure 2 shows a trajectory in the C2 approach space that represents the C2 approach position at various times throughout the complex endeavour. For illustrative purposes, consider the time units to be in months. At the beginning of the endeavour (t = 0), organizations bring their own version of governance and management to complex endeavour and conflicts arise. It quickly becomes obvious that some type of interaction coordination is needed. Some time later (t > 8) coordination exists, business rules are developed and agreed upon, and areas of responsibility and interest are established. At *t* = 20 months, the situation is stable and each entity works effectively within its designated area of responsibility. The collective adopts a De-conflicted approach to governance and management (note that the trajectory retraces itself).

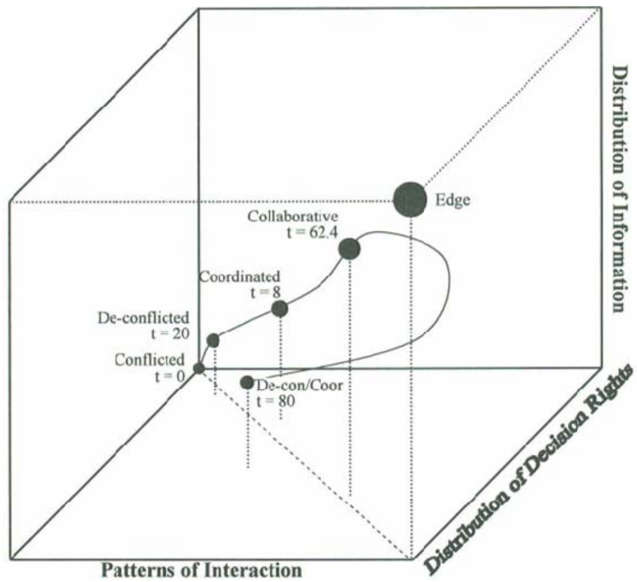

Figure 2: Notional Trajectory within the GM approach space

Five years from the start (t =60, not displayed) an unanticipated catastrophic event significantly increases the overall complexity and a De-conflicted approach no longer works. The collective must dynamically re-assess the governance and management structures to the point where ADR and DI are very broad and PI is unconstrained and the collective passes through a Collaborative approach a few months later (t = 62.4) but the trajectory never quite reaches the required Edge approach. Three months later (t = 63 not displayed), the event subsides and the GM approach settles somewhere between De-conflicted and Coordinated (t > 80). This fictitious vignette illustrates explicitly the SAS-065 Organizational Agility definition. However, it has elements of Kaplan's definition by the collective possessing multiple GM approaches, Alberts and Hayes' definition by the collective being responsive and flexible, and Spaans et al's definition by the collective having an adaptive *stance* and choosing appropriate approaches as the situation changes.

Summarizing the introduction, Organizational Agility is more than an oxymoron but a necessary aspect of a group of organizations as they work together to achieve common objectives during complex endeavours. Organizational Agility is required to cope with environment and collective (self) complexities, manoeuvre through a 'rule-less' environment, and adopt the appropriate GM approach. The entropy equation may be used to calculate configuration potential, and the GM approach space (ADR, DI, and PI as dimensions) is useful to visualize the time-evolution or dynamic nature of GM approaches. However, we are still left with the question, where does Organizational Agility fit in this view? In order to answer this question, a motion system dynamics model is used as a metaphor for transitions within the GM approach space. Then organizational attributes are related to the dynamics model. We discover that Organizational Agility involves improving organizational attributes using compensatory, anticipatory, adaptive, and learning methods.

GM Approach Dynamics Model

From SAS-065, Organizational Agility is the ability to recognize that the complexity of the situation may require a new GM approach (point in the approach space), and to transition from the current to the new approach (from one point to another). We assume that the transition from one point to another is not spontaneous, but follows a dynamic trajectory in time. That is, the transition varies as a function of time. Continuous changes are not readily observable as one GM approach morphs into another. On the other hand, we may be able to identify instantaneous nominal values of ADR, DI, and PI, and therefore place a point in the GM approach space at sampled intervals in time. A mathematical function is proposed that fits the sampled points and, in doing so, provides insight into the dynamic behaviour of the GM approach transitions.

Let x be a point in the GM approach space expressed as the following coordinates:

$$x = x(ADR, DI, PI) \qquad (2)$$

This paper does not attempt to find the relationship between ADR, DI, PI, and x, but is left for future research. We assume that ADR, DI, and PI values change continuously as a function of time rather than spontaneously (discontinuously). Thus, x is an implicit function of time:

$$x = x(ADR(t), DI(t), PI(t)) \quad \text{or} \quad x = x(t) \qquad (3)$$

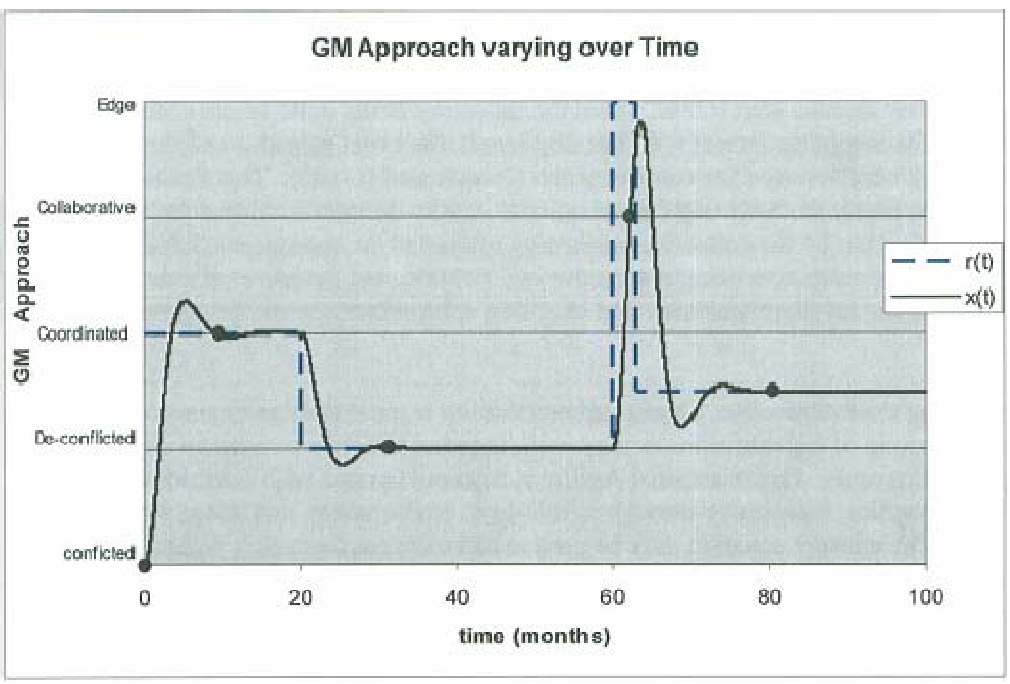

Figure 3: GM Approach Space sampled points transposed into the Time Domain

The sampled points in Figure 2 are transposed into the time domain as shown in Figure 3 and form the following set:

$$x(t_i) = \begin{Bmatrix} Conflicted & t_1 = 0 \\ Coordinated & t_2 = 1 \\ De-conflicted & t_3 = 30 \\ Collaborative & t_4 = 65 \\ Decon/Coord & t_5 = 68 \end{Bmatrix} \tag{4}$$

Figure 3 also includes a blue dashed line that represents the required GM approach, r(t), and a black solid line that is an approximate curve fit representing the proposed model, *x(t).* r(t) is a function of time since the situation varies with time. Recall from the vignette that the collective requires a Coordinated approach at the beginning of the endeavour ($0 \le t < 20$). For $20 \le t < 60$, the situation is fairly stable and only a De-conflicted approach is required. At $t = 60$, a catastrophic event occurs that requires an Edge Approach. Beyond t = 63, the situation has settled and the required approach is somewhere between De-conflicted and Coordinated. Thus, r(t) is a continuous series of step functions of the time-varying situation:

$$r(t_i) = \begin{Bmatrix} Coordinated & 0 \le t < 20 \\ De-conflicted & 20 \le t < 60 \\ Edge & 60 \le t < 63 \\ Decon/Coord & t \ge 63 \end{Bmatrix} \tag{5}$$

The third time plot in Figure 3 is a continuous and piecewise[5] smooth function, x(t), that passes through the sampled points and forms a reasonable approximation of the transition dynamics. For instance, the collective *can* not respond instantaneously to the changes in r(t) between $60 \le t < 63$ due to its size and momentum (mass × speed) even though it may be fully flexible and willing to change. The function x(t) is the solution to a 2nd-order differential equation and identical in form to a motion system's differential equation.

Motion System Differential Equation

The choice of fitting the sampled GM approach points with a solution of a 2nd-order differential equation is not immediately obvious unless the reader is familiar with systems that have similar differential equations including dynamic systems of motion, such as we see in plants, animals, humans, machinery, vehicles, robotics, water, air, and celestial bodies. This equation is wed as a metaphor to describe the movement from one GM approach to another.

For instance, the vertical displacement, x(t) of a shock absorber has the same characteristics of the generic spring-mass-damper system as shown schematically in Figure 4. The differential equation for a spring-mass-damper system is derived by applying Newton's second law of motion:

Σ Forces = mass (m) × acceleration (x)

= forcing function F(t) - damper (c) × velocity ($\dot{x}$) - spring (k) × displacement ($\ddot{x}$) (6)

[5] A piecewise smooth function means that the function and its derivatives are well-defined for the given interval.

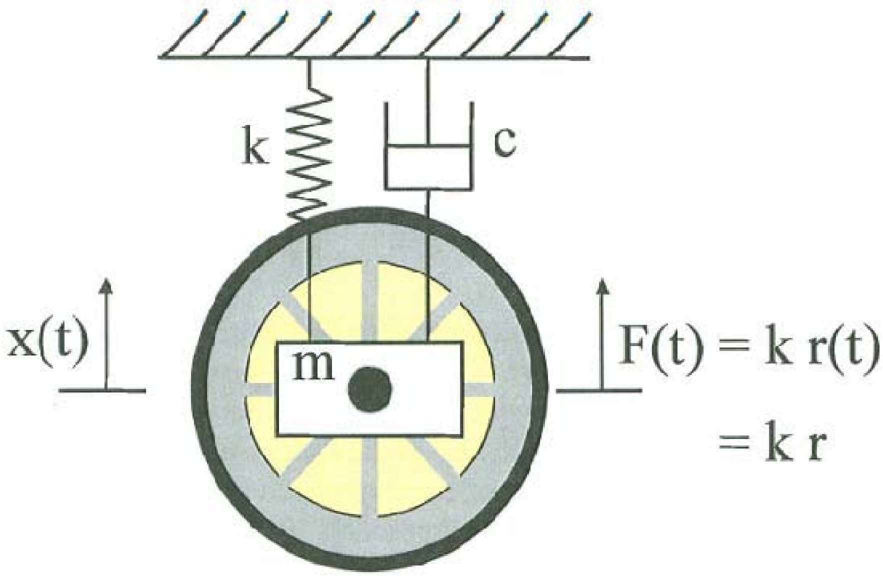

Figure 4: Wheel Shock Absorber is a Mass-Damper-Spring System

Note that the forces due to the damper and spring oppose the force due to acceleration and the forcing function, F(t). Let F(t) be a step function expressed as a scalar value of the required position (r_o), and the initial position is x_o. The 2nd-order differential equation becomes:

$$F(t) = k\, r_o = m\ddot{x} + c\dot{x} + k\, x \tag{7}$$

The general solutions for equation 7 are as follows (see Annex A for full derivation):

$$\text{Overdamped } (\xi > 1)\text{: } x(t) = r_o - (r_o - x_o)\frac{\exp(-\omega_n t)}{\sqrt{\xi^2 - 1}}\sinh\left(\omega_n\sqrt{\xi^2 - 1}t + \tanh\left[\frac{\sqrt{\xi^2 - 1}}{\xi}\right]\right) \tag{8}$$

$$\text{Critically damped } (\xi = 1)\text{: } x(t) = r_o - (r_o - x_o)\left(e^{-\omega_n t} + \omega_n t e^{-\omega_n t}\right) \tag{9}$$

$$\text{Overdamped } (\xi < 1)\text{: } x(t) = r_o - (r_o - x_o)\frac{\exp(-\omega_n t)}{\sqrt{1 - \xi^2}}\sin\left(\omega_n\sqrt{1 - \xi^2}t + \tan\left[\frac{\sqrt{1 - \xi^2}}{\xi}\right]\right) \tag{10}$$

$$\text{Meta-stable } (\xi = 0)\text{: } x(t) = r_o - (r_o - x_o)\cos(\omega_n t) \tag{11}$$

$$\text{Unstable } (\xi < 0)\text{: } x(t) \to \infty \text{ exponential exponent is positive} \tag{12}$$

where $\omega_n = \sqrt{k/m}$ is the system's natural frequency and $\xi = c/2\sqrt{km}$ is the damping ratio. Both ω_n and ξ determine the system's dynamic behaviour: stable, over-damped, critically damped, under-damped, response time, rise time, overshoot, meta-stable, and unstable. In other words, the mass, damper, and spring determine how the system will respond to a forcing function. From a design perspective, a designer can 'tune' these parameters or attributes so that the system responds optimally[6] or as best as it can (critically-damped, equation 9, has the fastest rise time with minimum overshoot).

[6] There are only three parameters to solve for multiple design requirements (rise time, overshoot, etc.). Optimal parameter values may be found using compensatory, anticipatory, adaptive, and learning control design techniques.

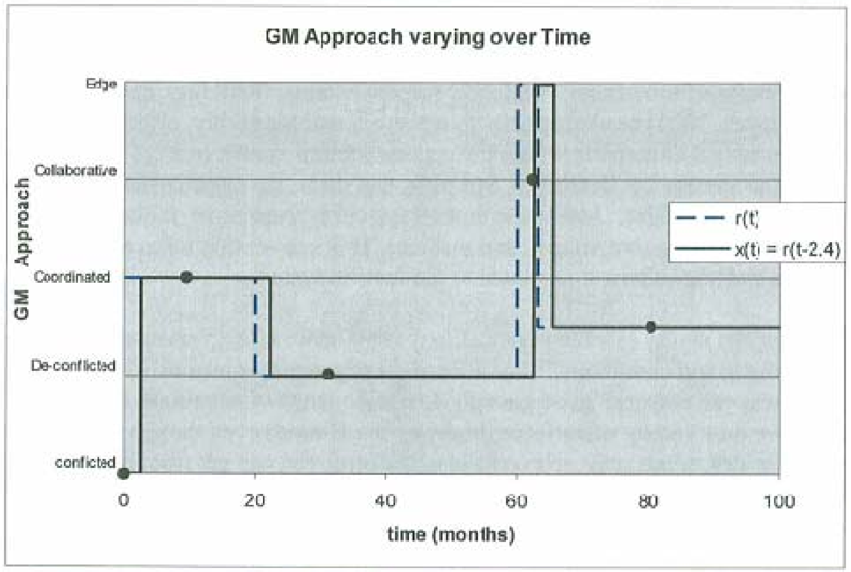

Figure 5: Approach space trajectory transposed into the time domain: Pure Time Delay

The solution to a 2nd-order differential equation is not the only possible curve fit to the sampled values in equation 4. Figure 5 shows an alternative continuous but non-smooth[7] curve fit for x(t):

$$x(t) = r(t - \tau) \qquad (13)$$

That is, x(t) is r(t) shifted by a pure time delay, $\tau = 2.4$ in this case. This time delay may correspond to the time it takes to recognize that the situation has changed and a new approach is required. Incorporating the time delay into equations 8 - 12 may better represent the underlying dynamics involved in moving from one approach to another.

So far, the GM approach space trajectory was transposed into the time domain to visualize the time dynamic behaviour as the collective transitions from one approach to another. The required GM approach r(t) was introduced as well as a continuous function x(t) that fits the sampled data and approximates the underlying dynamics of the transition.

So where does Organizational Agility fit in? We would argue that in the same manner a designer has the ability to 'tune' motion system parameters (m, *c*, k, and τ), Organizational Agility involves tuning (optimizing, improving) organizational parameters or attributes though compensatory, anticipatory, adaptive, and learning methods.

[7] A non-smooth (and therefore nonlinear) function has undefined derivatives (e.g., corners of a step function).

Organizational Attributes

The agility attributes of robustness, resilience, responsiveness, flexibility, and adaptation defined in (Alberts & Hayes, 2003) implicitly refer to an organization's ability, characteristic or attribute. These attributes have counterparts within the generic motion system (except for innovation). Just as the motion system has flexibility, damping, and mass, the organization has flexibility, resistance to change, and size. Just as the motion system is responsive, robust and resilient, an organization can be responsive, robust, and resilient. This sub-section takes each organization attribute in turn and shows how it is related to the motion system.

1. "Robustness: the ability [for the organization] to maintain effectiveness across a range of tasks, situations, and conditions." For a fixed set of properly tuned m, c, and k values, the motion system can respond 'good enough' to a wide range of situations. For example, minivan can drive on a variety of surfaces (highway to off-road) even though c and k were optimized for dry streets only. Nevertheless, the mini-van can get from point A to B in most cases, and therefore exhibits robustness. In a similar way, an organization may exhibit robustness for a given 'tuned' set of organizational attributes (e.g., size, willingness, and flexibility). Moreover, feedback or compensatory methods are used to produce stable and robust system dynamics.

2. "Resilience: the ability [for the organization] to recover from or adjust to misfortune, damage, or a destabilizing perturbation in the environment." For motion systems, resilience is related the system being able to continue to function despite damage to itself. The 2^{nd}-order differential equation 7 is resilient in that if the mass, damper, or spring term were to be removed (most severe self-damage), the system would still respond although sub-optimally. For instance, a shock absorber might cease up, but the car is still drivable albeit very bumpy and uncomfortable. There is a limit to resilience and if the environment changes substantially (e.g., off-road) the damaged car may become un-drivable. In the same manner, organizations may lose their internet connection and yet may use telephones to communicate. However, if telephones also fail, organizations might not be able to function any longer.

3. "Responsiveness: the ability [for the organization] to react to a change in the environment in a timely manner." Note that the motion system time constant is $(\xi\omega_n)^{-1}$, which decreases as c and k increase, and m decreases. However, in real systems where time delays exist, there is a high probability of generating limit cycles or unstable responses as the time constant approaches and becomes less than the time delay. Thus, there is a limit to responsiveness. Race cars have very small time constants and operate at the edge of stability. Similarly organizations may be very responsive by operating at the edge of stability. Most government organizations stay far away from the edge of stability because they must absorb all liabilities.

4. "Flexibility: the ability [for the organization] to employ multiple ways to succeed and the capacity to move seamlessly between them." For motion systems, the spring represents the system's flexibility. Sometimes a flexible system is required to conform to the uneven shape of the environment. In fact, Navigational intelligence is a relatively new term when referring to 21^{st} century ground robots. Ground robots encounter all sorts of terrains (rocks, sand, stairs, sewer grids, potholes, etc.) that humans take for granted. Very sophisticated algorithms are used to dynamically change the spring constant and conform to the terrain

wing compensatory, anticipatory, adaptive, and learning methods, and thus manoeuvre successfully through the environment. Management of DI (all the aspects within Figure 6) and PI (Figures 7a, b, and c) helps the organization conform to the situation. That is, organizational flexibility is related to management.

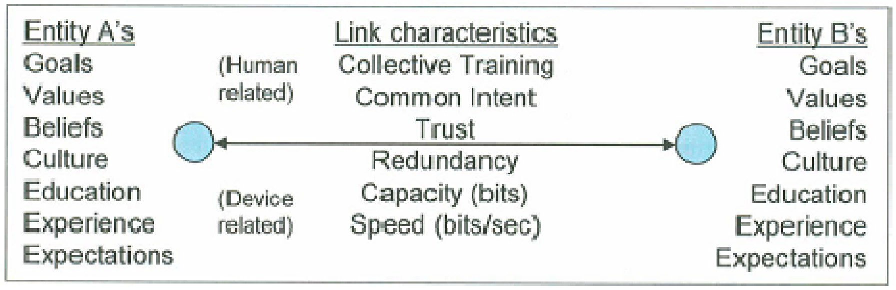

Figure 6: Node and Link Characteristics for Two interacting Entities

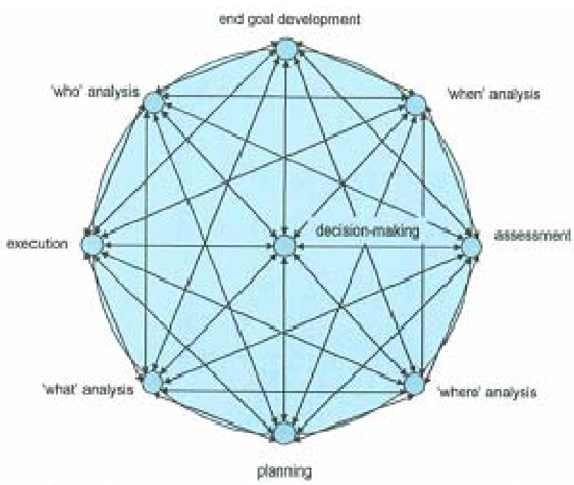

Figure 7a: Peer-Peer Patterns of Interaction

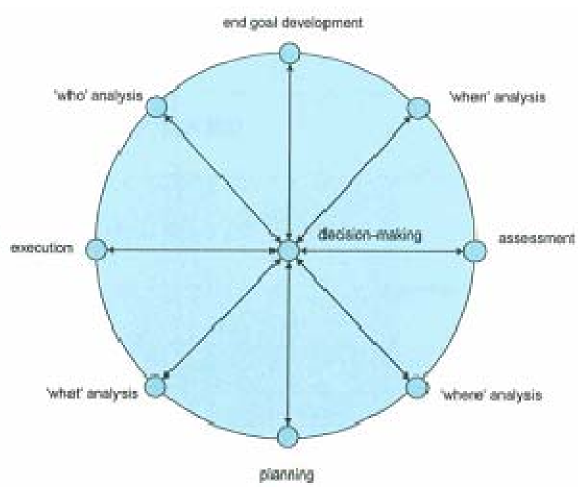

Figure 7b: Hub-and-Spoke Pattern of interaction

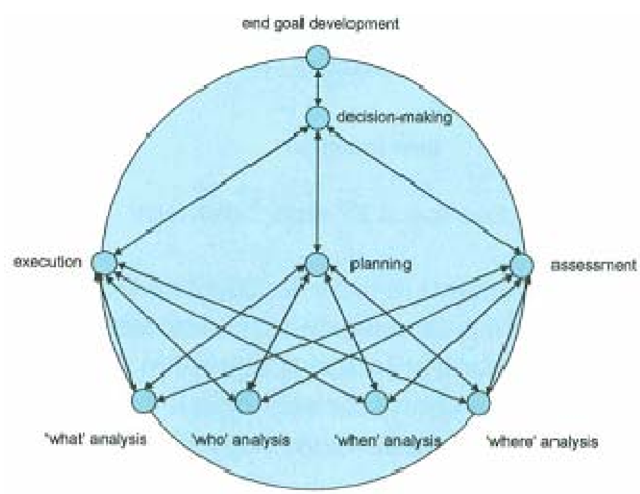

Figure 7c: Hierarchy Pattern of Interaction

Organizational flexibility is the organizational equivalent to the motion system spring constant. If an organization is too stiff the GM transition will be very quick but may easily become unstable with any inherent time delays. If the organization is too flexible it might respond better to relatively smooth and slow undulations but not to rapid situation changes. Organizational flexibility must be 'tuned' to achieve optimal GM transition performance.

5. "Innovation: the ability [for the organization] to do new things and the ability to do old things in new ways." Innovation is a uniquely human quality that does not have an obvious counterpart in the motion system metaphor. Attempts have been made to mimic innovation in robotic systems using a combination of learning and genetic algorithms (e.g., artificial intelligence) Nevertheless, innovation in human systems seems to be critical when 'eureka' moments are needed to solve complex problems and to be successful in complex situations.

6. "Adaptation: the ability [for the organization] to change work processes and the ability to change the organization." The adaptive expression for the motion differential equation is one where the coefficients vary with time as follows:

$$F(t) = m(e)\,\ddot{x} + c(e)\,\dot{x} + k(e)\,x \;\ldots\; e(t) = r(t) - x(t) \qquad (14)$$

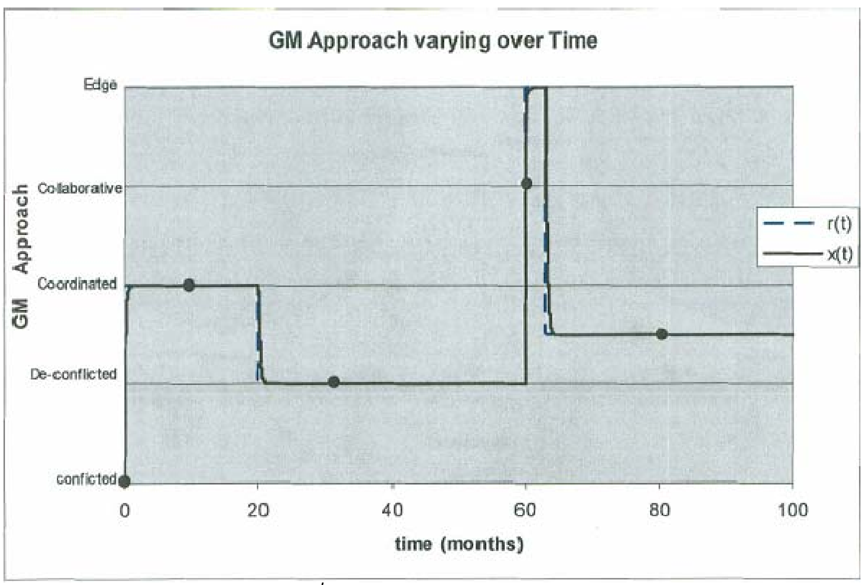

Figure 8: Solution to 2nd-order differential equation with adaptation

Equation 14 implies feedback control in order to calculate the error, and adaptive feedback control is used to change system parameters to maximize system performance. Figure 8 shows the response when this adaptive feedback algorithm is used for $c(e) = c \times e$ and constant m and k. This algorithm allows for very high k values and therefore quick response times, however, as e $\rightarrow 0$ a limit cycle develops (very high frequency vibrations). The limit cycle may be nullified by setting $e = 0$ once within a control threshold ($|e| < \varepsilon$), which is called Variable Structure Control (Farrell, 1992; Slotine & Li, 1991). Applying adaptive feedback control to an organization is equivalent to optimizing its parameters "online" or as the situation unfolds.

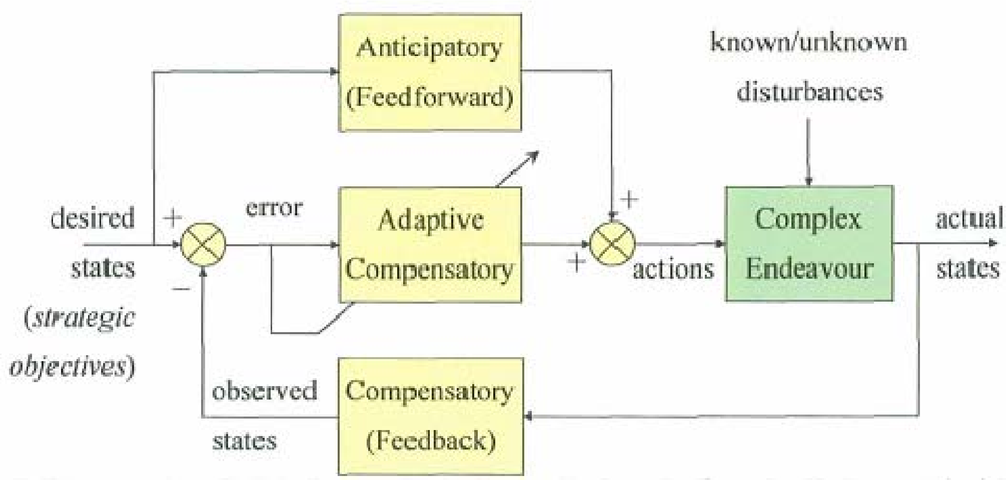

Figure 9: Compensatory, Anticipatory, and Adaptive methods along with a Complex Endeavour depicted as a functions within a generic feedback control loop.

7. Feedback or compensatory control is needed, as a minimum, to bring stability to a situation (see Figure 9). Most organizations adopt a compensatory approach to achieve the mission objectives. In fact, Powers asserts that all human behaviour results in the control[8] of perceptions (Powers, 1973). Complex endeavours have similar feedback control loops as do most military operations (Farrell, 2007), only that there will continue to be a demand for faster and faster loop times in order to maintain stability and to mitigate unknown disturbances. Compensatory behaviours are a key organizational attribute.

8. Again from control theory and robotics, feedforward or anticipatory algorithms (Spong & Vidyasagar, 1989; Van de Vegte, 1990) provide optimized performance by ‘cancelling out’ known situation dynamics. Although the algorithm is executed during the event, the situation dynamics model is developed before the event occurs. Mission Analysis is an example of the development of anticipatory models used within operational level headquarters.

9. Another organizational attribute is learning. (Spaans, et al., 2009) argue that organizations should possess an ‘adaptive stance’ by learning to be adaptive in order to meet the challenges of complex endeavours. For robotics, learning may be an “offline”[9] method for optimizing system parameters (Spong & Vidyasagar, 1989). In the same way, key organizational attributes (size, governance/willingness to change, management/flexibility, responsiveness, etc.) may be improved by training and education techniques. Figure 10 shows a simplified view of where learning generally fits with respect to subsequent endeavours, although learning may occur throughout the endeavour by various people, teams, and organizations.

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[8] … in the cybernetics or Classical Control Theory sense of the word …

[9] Given today’s computing power, learning algorithms can operate between robot manoeuvres, making it seem like learning happens concurrently. Learning is indistinguishable from adaptation, except by examining computer code.

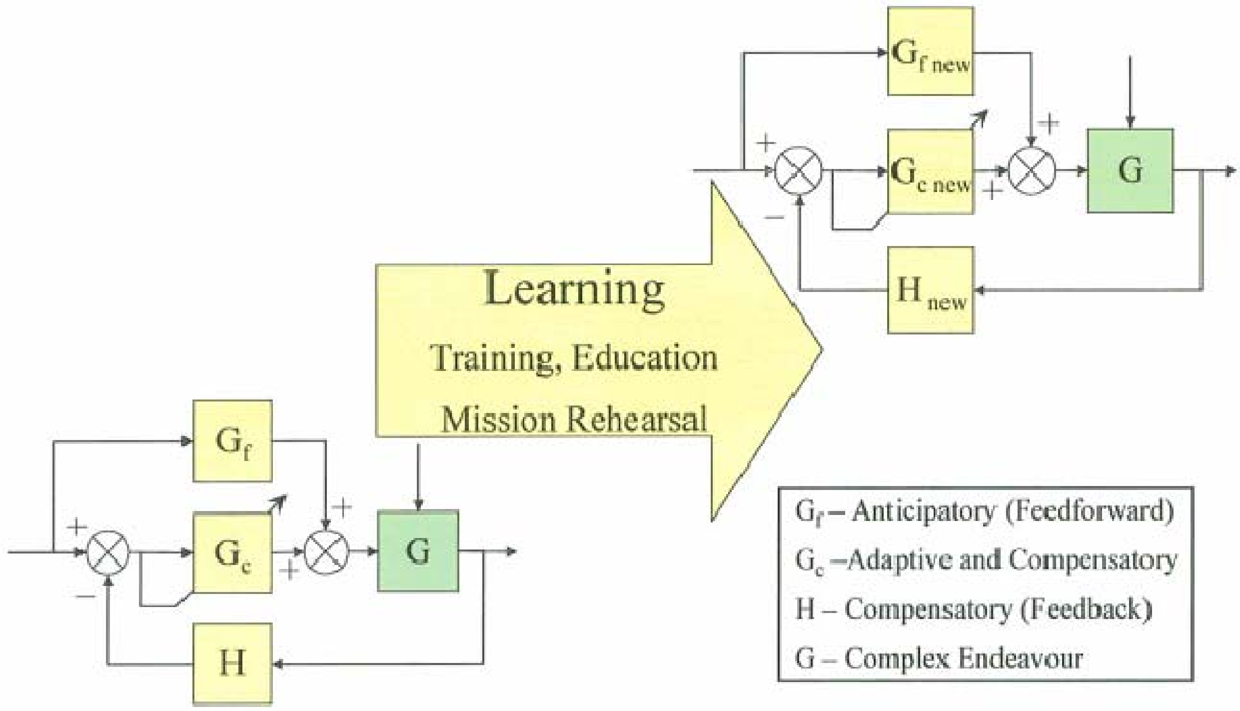

Figure 10: "offline" Learning method yields improved organizational attributes.

10. From the motion system metaphor, we see that organizational size is equivalent *to* mass. Intuitively, an organization's size impacts a number of attributes, particularly responsiveness. As m increases, the bandwidth, $\omega_n = \sqrt{k/m}$, decreases and it becomes harder for the system to keep up with quick changes in r(t). In other words, it is much harder for a large 1000-person bureaucracy to switch quickly from one GM approach to another, compared to a small 10- person company. Also, as m increases, the damping ratio, $\xi = c/2\sqrt{km}$, decreases and the system becomes less damped and tends to overshoot due of its large momentum. Finally, as m increases, the characteristic time, $2m/c = (\zeta\omega_n)^{-1}$, increases thus the system is slow to respond. Conversely, as the entity's size gets smaller, then it would respond faster with smaller overshoot and it would be able to keep up with quick changes in r(t). Therefore, a small organization is more responsive than a larger one. Organizational size may be expressed as the total sum of the entity's assets (people, equipment, infrastructure, financial, etc.) in monetary terms. This total "size" would be useful when comparing agility across different collectives or the same collective in different situations.

11. Lastly, from the motion system metaphor, we see that organizational resistance to change is equivalent to the damping factor. A mechanical damper causes resistance[10] to motion only when the object is moving. In a similar manner, organizational 'resistance to change' refers to those aspects within the organization that resist the transition from one GM approach to another. Organizational resistance to change may come from externally imposed governance limitations as well as an internal and personal unwillingness to change. This notion is borrowed from the Balanced Command Envelop concept (Pigeau & McCann, 2002) where

[10] Resistance is also the second term in a capacitor-resistor-inductor system (alliday & Resnick, 1978).

legal authority and extrinsic responsibility (formal governance) exist simultaneously with personal authority and intrinsic responsibility (informal governance). They must balance with each other to produce effective command. Thus, when formal and informal governance are aligned there is less resistance to change.

Governance provides hard limits to an otherwise highly responsive system operating at the edge of stability. The F16 fighter aircraft is a good example of such a system. It requires three computers to ensure a controlled and stable response even though the aircraft is inherently unstable. The controlling algorithm allows the aircraft to always respond as fast as possible (i.e., full throttle, full flaps, etc.) until the error between desired and actual responses is within certain tolerances (to account for actuator time delays), then the throttle (control surface, etc.) is automatically pulled back to a neutral position synchronously as the error approaches zero: that is, variable structure control (Farrell, 1992).

In the same way, the Carver governance model promotes a governance style by limitation (Oliver, 2009). That is, the CEO may do whatever it takes to reach the stakeholder's end goal within the explicit pre-determined limitations that reflect the company's values and ethics. Carver's model was conceived for a single organization and a single CEO. However, it may not be applicable for collectives with multiple CEOs where the governance limitations would be implicit at best. Nevertheless, the notion of governance by limitation (passive) is actually more liberating than governance by regulation (active) where written policy gives permission for each and every possible action under all conceivable circumstances.

Governance Balance (formal and informal) and Governance Style (passive and active) are two aspects that contribute to organizational resistance to change. Other aspects may be thought of that also contribute to resistance to change, and can be added as dimensions in a Governance sub-space (see Annex B). Determining a value for resistance to change is not immediately obvious, although an ADR value may be used as a surrogate. However, using the model and having sampled points for a given scenario, a value for c can be derived.

Organizational Agility Alternative Perspective

Several Organizational Agility perspectives, including that of Kaplan, Alberts and Hayes, and Spaans et al. can be related to each other using entropy and motion system metaphors. That is, Organizational Agility has potential and dynamic components. The potential component focuses on the number of configurations, patterns of interaction, and GM approaches that an organization or collective possesses. The dynamic component focuses on methods that improve transitions over time from GM approach to another. Thus, Organizational Agility is the ability for an organization to optimize its parameters or attributes - configuration potential, robustness, resilience, responsiveness and time delays (τ), innovation, adaptation and limits (ε), flexibility (k), resistance to change (c), size (m), and even itself, to name a few - through strategic investment, compensatory (feedback), anticipatory, adaptive, and learning methods or behaviours. Organizational Agility is still a compound attribute, but this perspective focuses on those methods that improve other organizational attributes and ultimately achieve the endeavour's objectives. Figure 10 provides a snapshot of this Organizational Agility perspective.

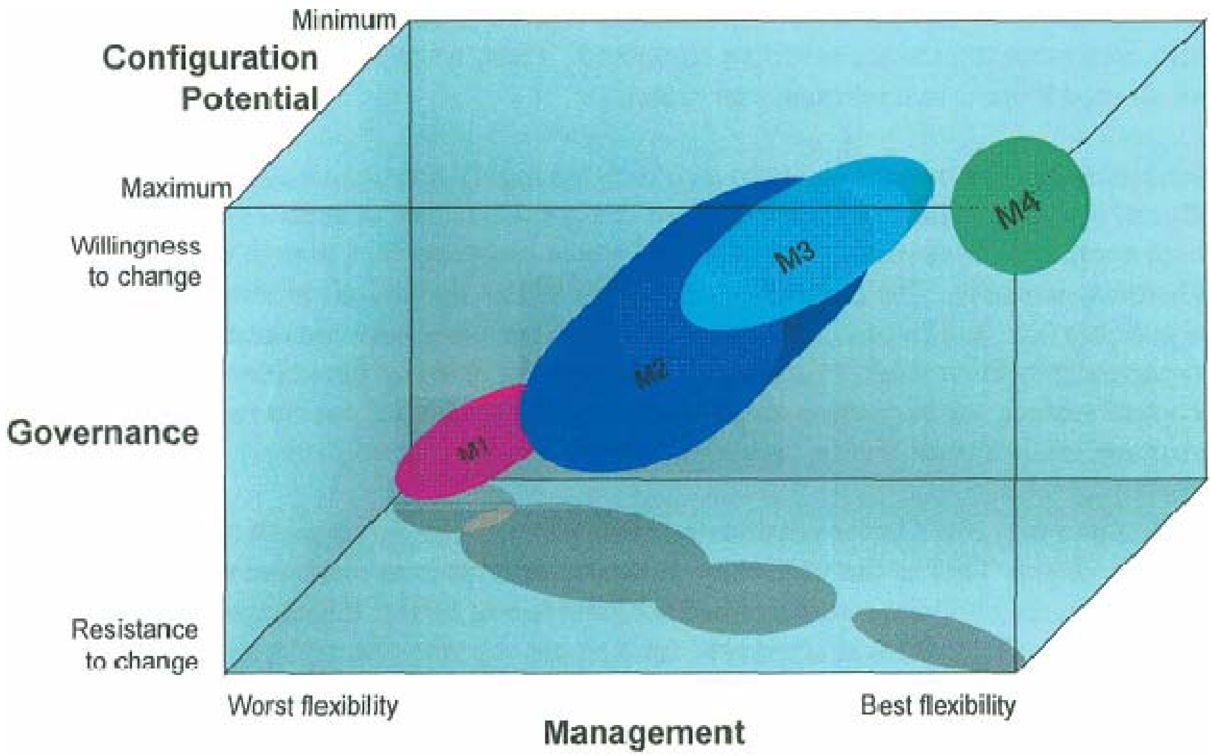

Figure 11: GM Maturity Levels located in the Organizational Attribute Subspace

From this perspective, Organizational Agility is a key attribute that a collective needs to obtain high GM Maturity Levels (ML) [11]. That is, as organizational attributes are 'tuned', improved, or optimized, Governance and Management is said to have matured. Figure 11 locates the maturity levels within a subspace for three organizational attributes: Configuration Potential (entropy), Governance (resistance to change), and Management (flexibility). Maturity levels are independent of Organizational Size (mass), and so it is not shown in Figure 11 . The maturity levels increase as the number of configurations increase. The maturity levels increase as the Governance decreases, or the willingness to change increases. Maturity levels increase as the Management improves[12]. Putting these dimensions together, maturity level increases diagonally from the origin to the farthest vertex of the organizational attribute subspace.

Strategic investment is a method for increasing the configuration potential, which is a prerequisite for higher GM ML. That is, a collective must make a conscious choice regarding the level of GM maturity they desire to be at, understanding the benefit-cost tradeoffs. The benefits of higher maturity levels include an increased chance of successfully accomplishing strategic objectives during complex endeavours. The costs include communication and information sharing equipment and infrastructure costs, human resources, training, and education costs, policy-making costs, and so on. A collective must also consider the strategic investments related to the dynamic component of Organizational Agility. That is, most organizations have already adopted compensatory and initial learning behaviours. However, there are additional benefits and costs associated with anticipatory, adaptive, and continuous learning methods.

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[11] See (SAS-065, 2010) for full descriptions of GM ML. In the SAS report, GM ML is referred to as C2 ML.
[12] Note that "Best" flexibility is likely between no flexibility and complete flexibility. Flexibility is optimized for the situation

Compensatory methods involve adopting a feedback-oriented work flow in order to achieve, at least, a stable response. In other words, if an organization were to emit actions without assessing the effects resulting from those actions (open loop control), then there would be no way to know whether the organization is moving toward meeting the mission objectives.

Anticipatory methods involve modeling the situation to some level of fidelity, and using the model to determine the initial actions that should be done for the situation. Costs increase as fidelity increases.

Adaptive methods involve "online" attribute changes as the situation unfolds. During humanitarian endeavours, morphing from peer-to-peer to hierarchical patterns of interaction (due to increasing security risks, for instance) would be an example of an adaptive "online" change.

Learning methods (lessons learned, training, education, etc.) involve "offline" improvements for the next time a similar situation arises. Learning and Adaptive methods are very much the same, and the distinction between "online" and "offline" somewhat arbitrary and depends on the time scale context. That is, learning may occur during significant activity pauses within the situation, or by another person, team, or organization as the situation unfolds. Just as there are significant computational costs associated with learning robots, there are costs associated with continuous learning.

Anecdotal Evidence for Organizational Agility

A conceptual model is being proposed for Organizational Agility that is analogous to a motion system that exhibits compensatory, anticipatory, adaptive, and learning behaviours. The next research step would be to evaluate the model by collecting empirical evidence from modelling and simulation, experimentation, and case studies. Modelling and simulation were used to generate Figures 3, 5, and 8 in order to demonstrate compensatory and adaptive methods. The simulation will expand to demonstrate other aspects of the concept. Although no experiments are currently planned, a controlled environment is required to separately manipulate situation complexity and various organizational attributes so to fully test the model. In terms of case studies, The Vancouver 2010 Olympics and the Canadian experience in Afghanistan are being examined for evidence of Organizational Agility. However, the reader may appreciate that there are many aspects of these major events that are sensitive. Thus, only anecdotal evidence is presented below from the Vancouver 20 10 Olympics and as well as from an analyst in embedded in the Afghanistan mission.

Organizational Agility Survey for 2010 Olympics

An Organizational Agility survey (Annex C) was developed specifically for the security collective responsible for the 201 0 Olympics (Allen, Chow, Trinh, & Farrell, 2009). The collective comprised of police forces at the municipal, provincial, and federal levels, all services of the Canadian Forces, border patrol, international affairs, coast guard, US partners, etc. The survey solicits opinions on ADR, DI, PI, organizational size, resistance to change, flexibility, and situation complexity needed to estimate r(t). Preferably, the survey should be administered multiple times throughout an event and by actual participants. But the survey was considered a low priority. As a compromise, scientists assigned to the Olympics were asked to fill out the survey twice, once for a pre-Olympic exercise and again for the Olympics itself, thus trialing the survey and providing constructive comment. Data analysis is ongoing.

Anecdotal Evidence from Afghanistan

Organizational Size

An analyst was embedded in the Afghanistan mission and was asked to comment on the impact of Organizational Agility on organizational size, resistance to change, and flexibility in this context. In Afghanistan, there are over 50 donor Nations, 34 contributing Nations within International Security Assistance Force (ISAF), 5 lead Nations for Security Sector Reform including Afghan National Army (ANA) development, Afghan National Police *(*ANP*)* development, Governance, Counter Narcotics, and Judicial reform, 24 Provincial Reconstruction Teams (PRTs) the United Nations, and several dozen non-government organizations. Typically a large collective reacts slowly due to its inherent 'momentum' related in part to their:

- Complex command and control structures;
- External (military , government, civil and public/private) interrelationships;
- Internal and external information and reporting requirements;
- Governance and international rules for conduct; and
- Associated management overhead for all of these influences.

The number and variety of relationships and inter-relationships can impede this larger collective from being agile with respect to their GM approach which in turn restricts freedom of action due to the limited ability for creative solutions to survive the staff planning action cycle. In contrast, former Chief of the Defence Staff General Rick Hillier's original and innovative establishment of the Strategic Advisory Team (SAT) in Kabul was a small entity within the larger one that had an effective and efficient GM approach (nearly Edge). SAT was directly supported with integral capabilities, had freedom of movement and independent action, and was established separately from Canadian, NATO and US military commands. SAT consisted of a small group of officers and Department of National Defence civilians embedded inside key ministries of the Afghan Government, including Afghan President Karzai's office. These 'working level' officers had unparalleled access to information and people, and they had influence on policy well beyond the security sphere[13]. The team had tremendous depth and breadth of experience and demonstrated performance.

SAT reported directly to the national diplomatic and strategic chains of command. Owing to their small size, officers typically had responsibility which cut across the Lines of Operation (Security, Governance and Development) and permitted the application of their expertise in dynamic and creative ways which resulted in successes far surpassing their inputs. Knowing that they were fully agile, SAT efforts could be concentrated or disbursed rapidly in reaction to identified priorities such as the development of the Afghan National Development Strategy (ANDS). ANDS was a key deliverable which set the conditions for all future development and reconstruction within the country and was a key enabler to secure international support and commitments. Thus, the small size of the SAT allowed them to identify priorities and respond quickly. The larger US, NATO and Canadian organizations did eventually adopt and support the implementation of the ANDS objectives, but not as quickly.

Organizational Resistance

Organizational cultures, policies and structures created conditions for high resistance to change within the ISAF mission. Military planners do not have the requisite skills to include the vast majority of diplomatic, information, and economic effects and actions necessary to engage in nation building. The complexities involved in a military coalition of approximately 34 nations with different national mandates, limiting caveats and rules of engagement (ROES), and complex command and control relationships are once again beyond the capacity of the military planners. Therefore commanders cannot adequately represent the situation as it exists, nor adequately accommodate the ends, ways and means necessary to achieve the overall objective and end state.

National caveats introduce several C2 complexities due to the requirement to cater to multiple, sometimes conflicting, restrictions on the ability to utilize and apply capabilities. Caveats relating to equipment and personnel unduly restrict their employment due to distance, movement, type of operation, capability, type of forces, mission and C2. These caveats are further complicated by national, bi-lateral and or multilateral agreements and treaties as well as culture or religion. Canada confronted this situation when forces were positions in Kandahar in 2004 with the review of its ROEs. The Kandahar Task Force required very robust ROEs to respond agilely to threats and opportunities within the operational mission space. Previous ROEs were

[13] "A Civilian Surge From Afghanistan", by Eugene Lang, The Ottawa Citizen, Ottawa ON, 28 January 2010.

deemed too restrictive and potentially would impose greater risk on Canada's forces and their close partners because the ROES did not support the flexible capability employment in response to threats encountered.

Force Protection (FP) measures are policy restrictions aimed at decreasing casualties through the enforcement of personal and vehicle movement measures and procedures within the theatre of operations. Unfortunately, highly restrictive FP measures can create a false sense of security and potentially impede mission accomplishment. For example, restrictive force protection insulates military forces from the local population, impedes our ability to work directly with the indigenous population, can unduly restrict M o m and patterns of movement, reinforces the requirement for Afghans to keep and bear arms, and impedes winning hearts and minds (a key counter-insurgency mission objective). A Canadian diplomat was killed in 2005 by an improvised explosive devise in Kandahar, which resulted in severe limitations being placed on all civilians. This imposition created significant resistance for non-military personnel as they conducted their reconstruction and development roles thereby creating significant organizational resistance and impeding the attainment of mission objectives.

Organizational Flexibility

Organizational Flexibility relates to the node and link characteristics identified earlier in Figure 7 (goals, values, beliefs, culture, education, experience and expectations) as well as the choice and management of the patterns of interaction. The ISAF mission involves the development of the Afghan National Security Forces (ANSF) and the eventual transition of the security role. Despite this goal and mission objective, lack of trust would appear to be the dominant interfering characteristic, particularly for the Afghan national Police *(ANP).* The Afghan National Army (ANA) has worked extensively with ISAF forces and has earned a greater sense of trust as a result. Several differences still exist which impede smooth interaction, which is a minimum requirement for organizational stability as well as organizational flexibility.

New management solutions were conceived (evidence of learning and adaptive behaviours) and implemented to address these differences by 1) introducing national level recruitment that facilitate common tactics, training, and procedures, and 2) using regional and sub-regional Operational Mentoring and Liaison Teams (OMLTs) embedded with the ANSF to develop common culture, experience, values and expectations in the planning and execution of operations. These management solutions *seem* to be working because OMLT-enabled ANA units are more flexible when employed within the operational theatre.

The ISAF HQ staff employs a Napoleonic staff *structure* irrespective of the operating environment and the operational plan bang followed. Although relatively simple to execute and manage, this structure is overly dependent on leadership personalities, and it is not optimized to address the longer term ISAF and NATO mission objectives. A multidisciplinary approach (i.e., military and non-military organizations) is needed for the longer term mission objectives (anticipatory). Therefore, each organization will need to understand each other's work culture (Lichacz, 2009).

Conclusions

Organizational Agility is a key enabler for a collective as they work effectively and efficiently towards common objectives during a complex endeavour. It is an organization's inherent ability to optimize its own attributes using compensatory, anticipatory, adaptive, and learning methods – which are organizational attributes themselves. Thus, 'learning to learn' is a valid construct from this perspective. Also from this perspective, we see that the agility dictionary definition is related to an organization's ability to 'nimbly' adjust organizational parameters for a given complex situation.

A hierarchical policy-driven collective may be optimal in some situations, while in others, an 'Edge' organization may be optimal. An Edge approach would be costly and inefficient if the situation requires a De-conflicted approach, and a De-conflicted approach would be insufficient if the situation requires an Edge approach. Organizational Agility is the ability to recognize the required approach and subsequently 'tune' (whether 'online' or 'offline') the organizational attributes accordingly.

The 2nd-order differential equation of a mechanical motion system was used as a metaphor for an organization's dynamic behaviour. That is, a robot has mass, damping, and a spring constant, and an organization has size, resistance to change and flexibility, respectively. This metaphor provided insight into organizational attributes and led to the notion of attribute optimization. Twelve organizational attributes related to agility were identified and discussed in this paper: configuration potential, robustness, resilience, responsiveness, innovation, flexibility, size, resistance/willingness to change, compensatory, anticipatory, adaptive, and learning methods. The first attribute involves an organization's potential component. The next seven attributes is related to the organization's dynamic component. Organizational Agility comprises of the last four that help to improve all organizational attributes. These twelve are not an exhaustive list but allow us to begin to understand Organizational Agility in relation to organizational attributes. The relationship between Organizational Agility and Governance and Management Maturity Levels was briefly discussed in this paper. As the organizational attributes – including Governance and Management - improve using Organizational Agility, the organization is said to 'mature'.

The Olympics Organizational Agility survey and data collection will be used in future research to evaluate the model. Anecdotal evidence from the Afghanistan experience provides some confidence that this research is moving in the right direction. Once the model is "validated" it can be used proactively to inform strategies and make strategic investment decisions for the governance and management teams, organizations, or collectives. A Defence R&D Canada project has been approved to continue this research and work collaboratively within the new SAS-085 Task Group on C2 Agility and Requisite Maturity.

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Annex A

Solution(s) to 2nd-order Linear Differential Equation

(Thomson, 1981) gives the general solution to a 2nd-order linear differential equation. However, it does not show the full derivation of the solution. This Annex provides the full derivation using a substitution method. Laplace or graphical methods can also be used to find the function's coefficients and exponent expressions.

Let x(t) be a linear combination of exponential functions:

$$x(t) = A\,e^{at} + B\,e^{bt} + D \qquad \text{A.1}$$

The first derivative is:

$$\dot{x}(t) = a\,A\,e^{at} + b\,B\,e^{bt} \qquad \text{A.2}$$

Assume that the first derivative is zero when t = 0. That is:

$$\dot{x}(0) = 0 = a\,A + b\,B \qquad \text{A.3}$$

A.3 yields the following relationship between A and B:

$$B = -a\,A / b \qquad \text{A.4}$$

The second derivative is:

$$\ddot{x}(t) = a^2\,A\,e^{at} + b^2\,B\,e^{bt} \qquad \text{A.5}$$

The 2nd-order differential equation is expressed as follows:

$$F(t) = m\,\ddot{x} + c\,\dot{x} + k\,x \qquad \text{A.6}$$

Where m, c, and k are the mass, damping factor, and spring constant, respectively, for a spring-mass-damper system. x, $\dot{x}$, and $\ddot{x}$ are the position, velocity, and acceleration of the mass. Let F(t) = k r_o, where r_o represents the reference or required position:

$$k\,r_o = m\,\ddot{x} + c\,\dot{x} + k\,x \qquad \text{A.7}$$

Substituting equations A.1, A.2, and A5 into A.6 yields:

$$k\,r_o = m\,(a^2\,A\,e^{at} + b^2\,B\,e^{bt}) + c\,(a\,A\,e^{at} + b\,B\,e^{bt}) + k\,(A\,e^{at} + B\,e^{bt} + D) \qquad \text{A.8}$$

Expanding yields:

$$k\,r_o = m\,a^2\,A\,e^{at} + m\,b^2\,B\,e^{bt} + c\,a\,A\,e^{at} + c\,b\,B\,e^{bt} + k\,A\,e^{at} + k\,B\,e^{bt} + k\,D \qquad \text{A.9}$$

Therefore:

$$D = r_o \qquad \text{A.10}$$

D represents the steady state or asymptotic response of the system. By substituting A.10 back into A.9, one can find relationships for the exponents a and b in terms of m, c, and k as follows:

$$0 = m\,a^2\,A\,e^{at} + m\,b^2\,B\,e^{bt} + c\,a\,A\,e^{at} + c\,b\,B\,e^{bt} + k\,A\,e^{at} + k\,B\,e^{bt} \qquad \text{A.11}$$

$$0 = m\,a^2\,A\,e^{at} + c\,a\,A\,e^{at} + k\,A\,e^{at} + m\,b^2\,B\,e^{bt} + c\,b\,B\,e^{bt} + k\,B\,e^{bt} \qquad \text{A.12}$$

$$0 = (m\,a^2 + c\,a + k)\,A\,e^{at} + (m\,b^2 + c\,b + k)\,B\,e^{bt} \qquad \text{A.13}$$

The equation is true when:

$$m\,a^2 + c\,a + k = 0 \quad \text{and} \quad m\,b^2 + c\,b + k = 0 \qquad \text{A.14}$$

or

$$a^2 + c/m\,a + k/m = 0 \quad \text{and} \quad b^2 + c/m\,b + k/m = 0 \qquad \text{A.15}$$

or:

$$a = -\tfrac{c}{2m} \pm \sqrt{\left(\tfrac{c}{2m}\right)^2 - \tfrac{k}{m}} \quad \text{and} \quad b = -\tfrac{c}{2m} \pm \sqrt{\left(\tfrac{c}{2m}\right)^2 - \tfrac{k}{m}} \qquad \text{A.16}$$

There are four solutions: a = b account for two of the solutions, but when these solutions are substituted into equation A.13, A = B = 0 is the trivial solution. When a and b are conjugate pairs, a non-trivial symmetrical\

solution emerges (identical solution for both conjugate pairs):

$$a = -\tfrac{c}{2m} + \sqrt{\left(\tfrac{c}{2m}\right)^2 - \tfrac{k}{m}} \quad \text{and} \quad b = -\tfrac{c}{2m} - \sqrt{\left(\tfrac{c}{2m}\right)^2 - \tfrac{k}{m}} \qquad \text{A.17}$$

or:

$$a = -\tfrac{c}{2m} - \sqrt{\left(\tfrac{c}{2m}\right)^2 - \tfrac{k}{m}} \quad \text{and} \quad b = -\tfrac{c}{2m} + \sqrt{\left(\tfrac{c}{2m}\right)^2 - \tfrac{k}{m}} \qquad \text{A.18}$$

Given $c = 2\,\xi\omega_n\,m$, $k = \omega_n^{\,2}\,m$, and $c^2 = 4\,\xi^2\,k\,m$ equation A.17 is rewritten in terms of the natural frequency, ω_n, and the damping ratio, ξ, as follows:

$$a = -\xi\omega_n + \omega_n\sqrt{\xi^2 - 1} \quad \text{and} \quad b = -\xi\omega_n - \omega_n\sqrt{\xi^2 - 1} \qquad \text{A.19}$$

So far, $B = -a\,A / b$, $D = r_o$, and a and b are expressed in terms of the differential equation parameters that are, in turn, expressed as the system's natural frequency and damping ratio as shown in equation A.19. Equations A.4 and A.10 are substituted into equation A.1:

$$x(t) = A\,e^{at} - a/b\,A\,e^{bt} + r_o \qquad \text{A.20}$$

$$x(t) = A\,(\,e^{at} - a/b\,e^{bt}\,) + r_o \qquad \text{A.21}$$

Substituting equation A.19 into equation A.21 yields:

$$x(t) = A\left(e^{-\xi\omega_n t + \omega_n\sqrt{\xi^2-1}t} - \frac{-\xi\omega_n + \omega_n\sqrt{\xi^2-1}}{-\xi\omega_n - \omega_n\sqrt{\xi^2-1}}\,e^{-\xi\omega_n t - \omega_n\sqrt{\xi^2-1}t}\right) + r_o \qquad \text{A.22}$$

$$x(t) = r_o - A\,\frac{e^{-\xi\omega_n t}}{\xi + \sqrt{\xi^2-1}}\left(\left(\xi + \sqrt{\xi^2-1}\right)e^{\omega_n\sqrt{\xi^2-1}t} - \left(\xi - \sqrt{\xi^2-1}\right)e^{-\omega_n\sqrt{\xi^2-1}t}\right) \qquad \text{A.22}$$

$$x(t) = r_o - A\,\frac{e^{-\xi\omega_n t}}{\xi + \sqrt{\xi^2-1}}\left(\xi\left(e^{\omega_n\sqrt{\xi^2-1}t} - e^{-\omega_n\sqrt{\xi^2-1}t}\right) + \sqrt{\xi^2-1}\left(e^{\omega_n\sqrt{\xi^2-1}t} - e^{-\omega_n\sqrt{\xi^2-1}t}\right)\right) \qquad \text{A.23}$$

The exponential terms are replaced with their hyperbolic sine and hyperbolic cosine identities:

$$x(t) = r_o - 2A\,\frac{e^{-\xi\omega_n t}}{\xi + \sqrt{\xi^2-1}}\left(\xi\sinh\left(\omega_n\sqrt{\xi^2-1}t\right) + \sqrt{\xi^2-1}\cosh\left(\omega_n\sqrt{\xi^2-1}t\right)\right) \qquad \text{A.24}$$

Given $\cosh^2\phi - \sinh^2\phi = 1$, let $\cosh\phi = \xi$ and $\sinh\phi = \sqrt{\xi^2-1}$, and therefore $\phi = \tanh^{-1}\left[\frac{\sqrt{\xi^2-1}}{\xi}\right]$.

Substituting these relationships into A.24 yields the following:

$$x(t) = r_o - 2A\,\frac{e^{-\xi\omega_n t}}{\xi + \sqrt{\xi^2-1}}\left(\cosh\phi\sinh\left(\omega_n\sqrt{\xi^2-1}t\right) + \sinh\phi\cosh\left(\omega_n\sqrt{\xi^2-1}t\right)\right) \qquad \text{A.25}$$

Given the hyperbolic relationship coshα sinhβ + sinhα coshβ = sinh($\alpha + \beta$), equation A.25 simplifies to:

$$x(t) = r_o - 2A \frac{e^{-\xi\omega_n t}}{\xi + \sqrt{\xi^2 - 1}} \sinh\left(\omega_n \sqrt{\xi^2 - 1}t + \phi\right) \qquad \text{A.26}$$

Assume that the initial position is x_o when t = 0. That is:

$$x(0) = x_o = r_o - 2A \frac{1}{\xi + \sqrt{\xi^2 - 1}} \sinh\phi \qquad \text{A.27}$$

$$r_o - x_o = 2A \frac{\sqrt{\xi^2 - 1}}{\xi + \sqrt{\xi^2 - 1}} \qquad \text{A.28}$$

$$A = (r_o - x_o) \frac{\xi + \sqrt{\xi^2 - 1}}{2\sqrt{\xi^2 - 1}} \qquad \text{A.29}$$

Therefore the full expression for the position in terms of the natural frequency and the damping ratio is:

$$x(t) = r_o - (r_o - x_o) \frac{\exp(-\xi\omega_n t)}{\sqrt{\xi^2 - 1}} \sinh\left(\omega_n \sqrt{\xi^2 - 1}t + \tanh^{-1}\left[\frac{\sqrt{\xi^2 - 1}}{\xi}\right]\right) \text{ for } \xi > 1 \qquad \text{A.30}$$

Equation A.30 is the solution for a 2nd-order differential equation for $\xi > 1$. The first term represents the steady state response while the second term is the transient response. The exponential term contains the characteristic time constant for the system ($\tau = \xi\ \omega_n$). This response is called over-damped because there are no oscillations: that is, the damping factor dominates and effectively over-powers any possible force contribution of the spring term.

For $\xi < 1$, the solution includes imaginary terms as follows:

$$x(t) = r_o - (r_o - x_o) \frac{\exp(-\xi\omega_n t)}{i\sqrt{1 - \xi^2}} \sinh\left(i\omega_n \sqrt{1 - \xi^2}t + \tanh^{-1}\left[i\frac{\sqrt{1 - \xi^2}}{\xi}\right]\right) \qquad \text{A.31}$$

However, it is not clear whether the solution is imaginary or real at the moment. First, we convert the hyperbolic tan function with an imaginary argument to a tan function using the identity tanh ϕ = $-$ i tan i ϕ. Let:

$$\tanh^{-1}\left[i\frac{\sqrt{1 - \xi^2}}{\xi}\right] = \phi \qquad \text{A.32}$$

Thus:

$$\tanh\phi = i\frac{\sqrt{1 - \xi^2}}{\xi} = -i \tan i\phi \qquad \text{A.33}$$

Multiply both sides by i yields:

$$-\frac{\sqrt{1 - \xi^2}}{\xi} = \tan i\phi \qquad \text{A.34}$$

Taking the inverse tan of both sides yields:

$$\tan^{-1}\left[-\frac{\sqrt{1-\xi^2}}{\xi}\right] = i\,\phi \qquad \text{A.35}$$

Multiply both sides by i and applying the identity that tan (–α) = – tan α:

$$-i\tan^{-1}\left[\frac{\sqrt{1-\xi^2}}{\xi}\right] = -\phi \qquad \text{A.36}$$

Therefore, we have an expression for ϕ in terms of tan or tanh as follows:

$$i\tan^{-1}\left[\frac{\sqrt{1-\xi^2}}{\xi}\right] = \phi = \tanh^{-1}\left[i\frac{\sqrt{1-\xi^2}}{\xi}\right] \qquad \text{A.37}$$

Equation A.37 is substituted into A.31

$$x(t) = r_o - (r_o - x_o)\frac{\exp(-\xi\omega_n t)}{i\sqrt{1-\xi^2}}\sinh\left(i\omega_n\sqrt{1-\xi^2}\,t + i\tan^{-1}\left[\frac{\sqrt{1-\xi^2}}{\xi}\right]\right) \qquad \text{A.38}$$

Another identity, sinh (i α) = i sin (α), is applied to equation A.38 as follows:

$$x(t) = r_o - (r_o - x_o)\frac{\exp(-\xi\omega_n t)}{\sqrt{1-\xi^2}}\frac{i}{i}\sin\left(\omega_n\sqrt{1-\xi^2}\,t + \tan^{-1}\left[\frac{\sqrt{1-\xi^2}}{\xi}\right]\right) \qquad \text{A.39}$$

$$x(t) = r_o - (r_o - x_o)\frac{\exp(-\xi\omega_n t)}{\sqrt{1-\xi^2}}\sin\left(\omega_n\sqrt{1-\xi^2}\,t + \tan^{-1}\left[\frac{\sqrt{1-\xi^2}}{\xi}\right]\right) \qquad \text{A.40}$$

Equation A.40 is the solution for a 2nd-order differential equation for $\xi < 1$. Like before, the first term represents the steady state response while the second term is the transient response. The exponential term contains the characteristic time constant for the system ($\tau = \xi\,\omega_n$). This response is called under-damped because there are oscillations: that is, the spring constant dominates and effectively over-powers any possible force contribution of the damping term.

For $\xi = 1$, equations A.30 and A.40 are undefined (the simple exponentials are not a solution to the differential equation). Another form of the solution is required to solve the differential equation. Let the solution be of the following form:

$$x(t) = A\,e^{at} + B\,t\,e^{at} + D \qquad \text{A.41}$$

Note that the exponents in both terms are the same. Following the same procedure as before, the coefficients and exponent can be found in terms of the natural frequency and damping ratio as follows:

$$\dot{x}(t) = a\,A\,e^{at} + B\,e^{at} + a\,B\,t\,e^{at} \qquad \text{A.42}$$

$$\dot{x}(0) = 0 = a\,A + B \qquad \text{A.43}$$

Therefore:

$$B = -a\,A \qquad \text{A.44}$$

$$\ddot{x}(t) = a^2\,A\,e^{at} + a\,B\,e^{at} + a\,B\,e^{at} + a^2\,B\,t\,e^{at} \qquad \text{A.45}$$

$$\ddot{x}(t) = a^2 A e^{at} + 2 a B e^{at} + a^2 B t e^{at} \quad \text{A.46}$$

$$F(t) = m\ddot{x} + c\dot{x} + k x \quad \text{A.47}$$

$$F(t) = k r_o \quad \text{A.48}$$

$$k r_o = m\ddot{x} + c\dot{x} + k x \quad \text{A.49}$$

$$k r_o = m (a^2 A e^{at} + 2 a B e^{at} + a^2 B t e^{at}) + c (a A e^{at} + B e^{at} + a B t e^{at}) + k (A e^{at} + B t e^{at} + D) \quad \text{A.50}$$

Therefore:

$$D = r_o \quad \text{A.51}$$

$$0 = A e^{at}(a^2 m + c a + k) + B e^{at} (2 a m + c) + B t e^{at} (a^2 m + c a + k) \quad \text{A.52}$$

$$a = -\frac{c}{2m} \quad \text{A.53}$$

$$k = \frac{c^2}{4m} = \omega_n^2 m \quad \text{A.54}$$

Therefore

$$a = -\omega_n \quad \text{A.55}$$

$$x(t) = A e^{-\omega nt} + \omega_n A t e^{-\omega nt} + r_o \quad \text{A.56}$$

$$x(0) = x_o = A + r_o \quad \text{A.57}$$

$$A = -(r_o - x_o) \quad \text{A.58}$$

$$x(t) = r_o - (r_o - x_o)(e^{-\omega nt} + \omega_n t e^{-\omega nt}) \quad \text{A.59}$$

Equation A.59 is the solution for a 2^{nd}-order differential equation for $\xi = 1$. Like before, the first term represents the steady state response while the second term is the transient response. The exponential term contains the characteristic time constant for the system ($\tau = \xi \omega_n$). This response is called critically-damped because it is on the cusp of oscillating: that is, the spring constant and damping factor have equal contribution as resorting forces. This is the fastest rise time possible without oscillations. Designers call this an optimal response. In terms of governance and management, Organizational Agility would be considered optimal when these organizational attributes equally compliment each other.

Annex B

Organizational Agility and GM Maturity

Organizational Agility is an attribute of a collective. It does not dictate which GM approach a collective may adopt in a particular situation, but it does determine whether the collective is mature enough (or has the capability) to maintain and transition to a number of GM approaches. The notion of Maturity Levels is provided in detail in (SAS-065, 2010).

Maturity Level 1 (ML 1) means that the collective is only capable of maintaining and reaching a De-conflicted GM approach. ML 2 means that the collective is capable of maintaining and transitioning between De-conflicted and Coordinated GM approaches. ML 3 includes ML 2 plus the Collaborative GM approach. ML 4 is the most mature state that a collective may have, and includes the ability to maintain and transition to the Edge GM approach in addition to the other three approaches.

The relationship between Organizational Agility and GM Maturity Levels is developed here pictorially. Figure B1 shows that maturity levels are directly related to configuration potential. That is, it is said that a collective is more mature as the number of potential configurations increases. The gap between ML3 and ML4 denotes a qualitative difference between ML4 and all other maturity levels as observed by SAS-065.

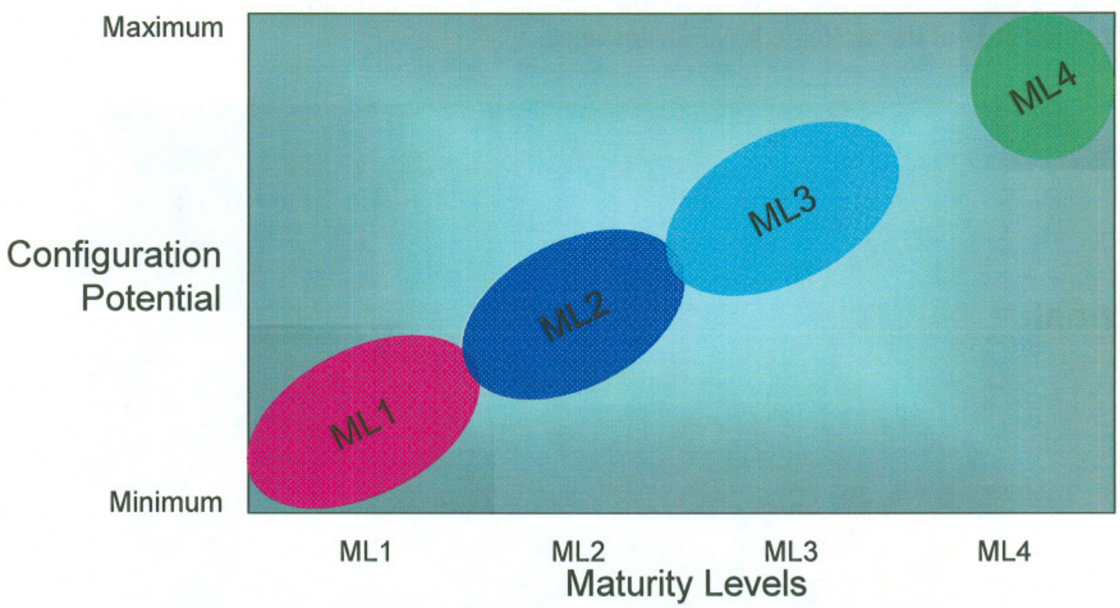

Figure B1: Configuration Potential (Entropy) and Maturity Levels

Figure B2 shows Organizational Size as a linear function of the transition responsiveness. That is, the characteristic time of the transition varies linearly with the size of the collective. Note that size is independent of maturity level. In other words, to say that an organization is more or less mature, or has the same level of maturity because of its size does not make sense.

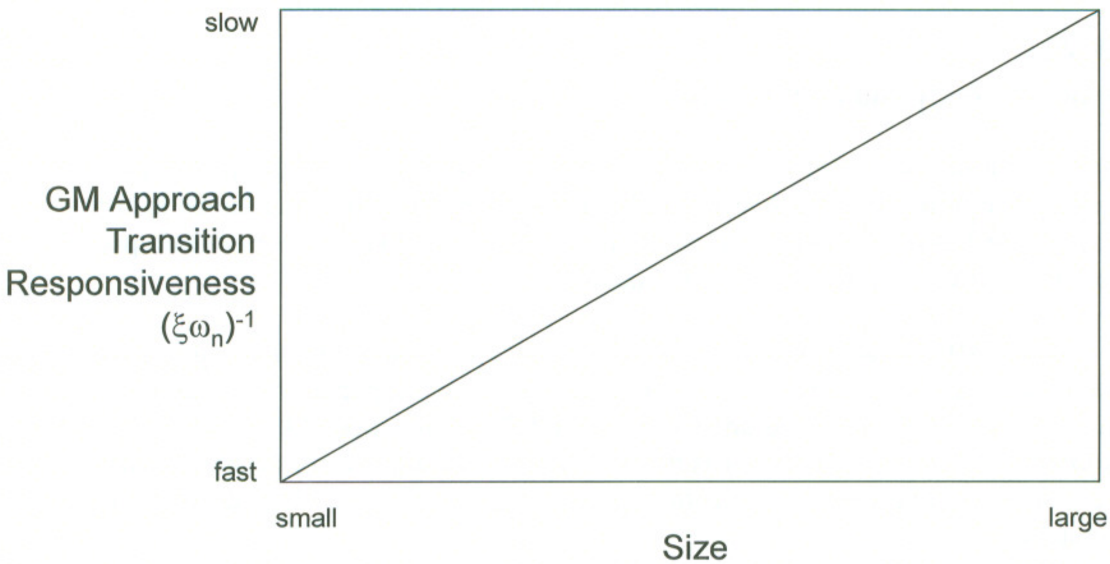

Figure B2: Organizational Size and Transition Responsiveness

Figure B3 shows pictorially the formal and informal governance space. The maturity levels may be positioned along the diagonal, but the off-diagonal areas may result in conflicted governance and management. Note that all the maturity levels are balanced between formal and informal. The difference is that ML4 has balanced governance throughout all collective entities (at the strategic, organizational, team, and individual levels), while in contrast ML 1 may have balanced governance only at the strategic level for instance.

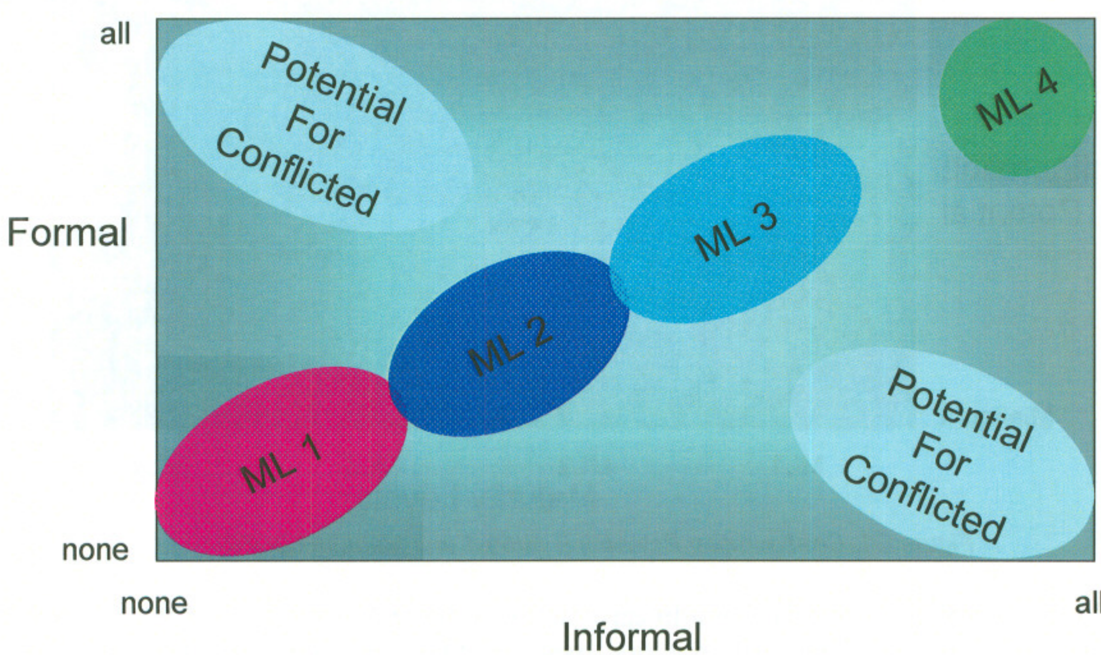

Figure B3: Formal and Informal Governance and Maturity Levels

Balanced Governance is one of many aspects of Governance that impacts the resistance to change. Another aspect the Governance Style – that is, by regulation (active) or by limitation (passive). Figure B4 positions the maturity levels in this two dimensional Governance Space. As more aspects of Governance are determined, they can be added dimensionally to the space. Note that M1 is the most resistant to change while M4 is the most willing to change.

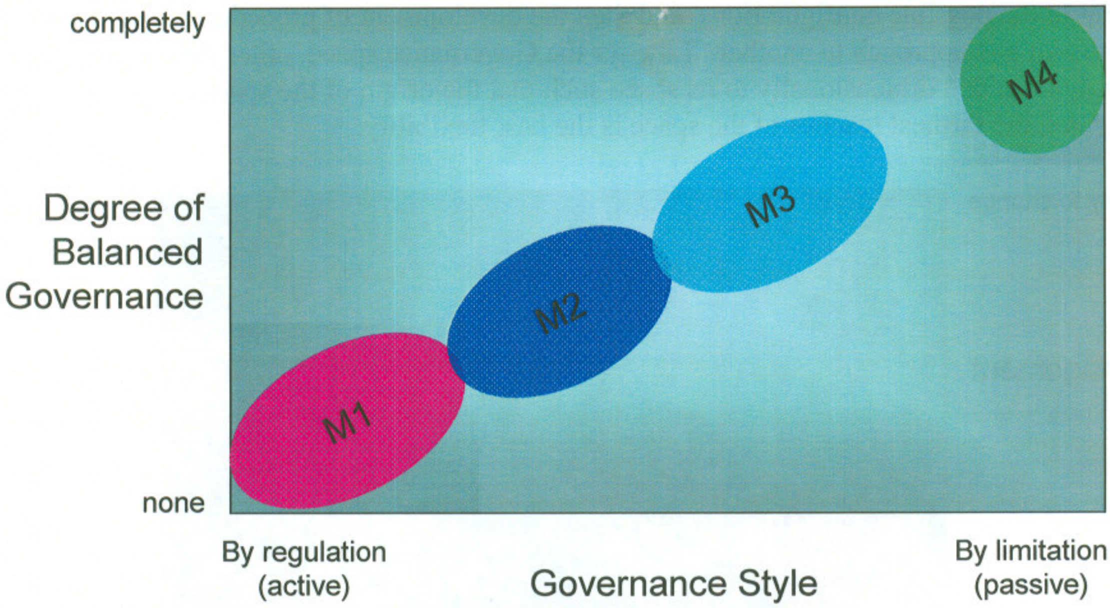

Figure B4: Two-Dimensional Governance Space and Maturity Levels

Figure B5 shows the relationship between distribution of information (or information sharing) and the maturity levels. The node characteristics similarity is on the horizontal axis and the link characteristics capacity is on the vertical axis. For example, if trust is at full capacity (i.e., complete trust between two nodes) then the maturity level is high. The axes are labelled such that the maturity levels fall on the diagonal of the space going from ML 1 to ML 4.

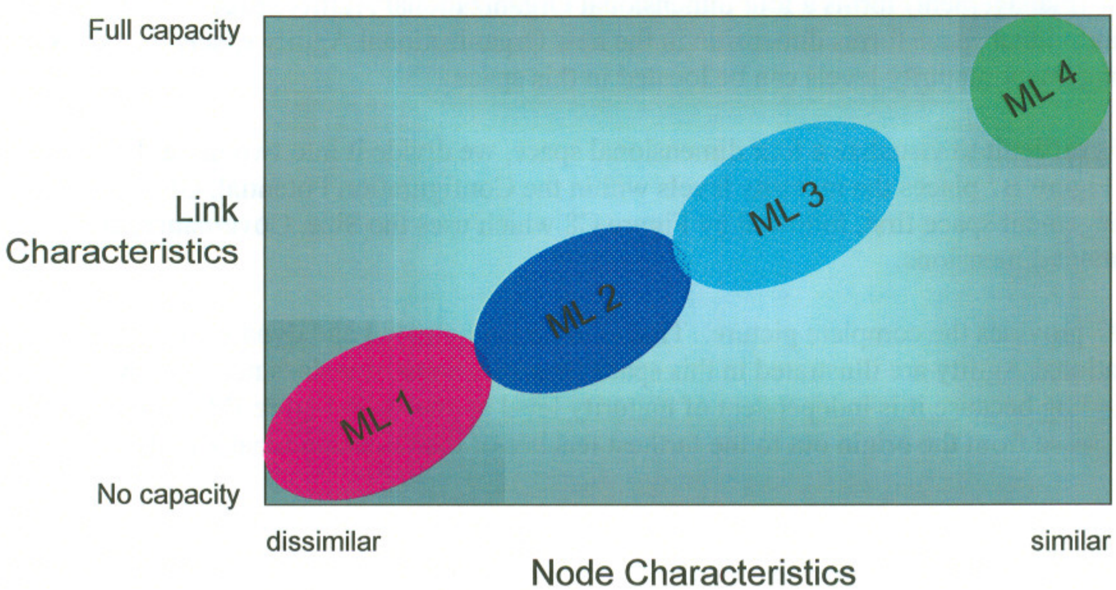

Figure B5: Distribution of Information Characteristics and Maturity Levels

Figure B6 depicts a two-dimensional management space where the x-axis shows DI management and the y-axis shows PI management. The PI management dimension is different from the configuration potential dimension. PI management are those activities that enable the transition from one pattern of interaction to another. Many of these activities would involve strategic investment in the possible configurations, and then the development of procedures needed to transition from one approach to another. Like for the Governance space, other management aspects may be added dimensionally to its space such that the origin of the space is the worst flexibility and the farthest reaches of the space is the best flexibility.

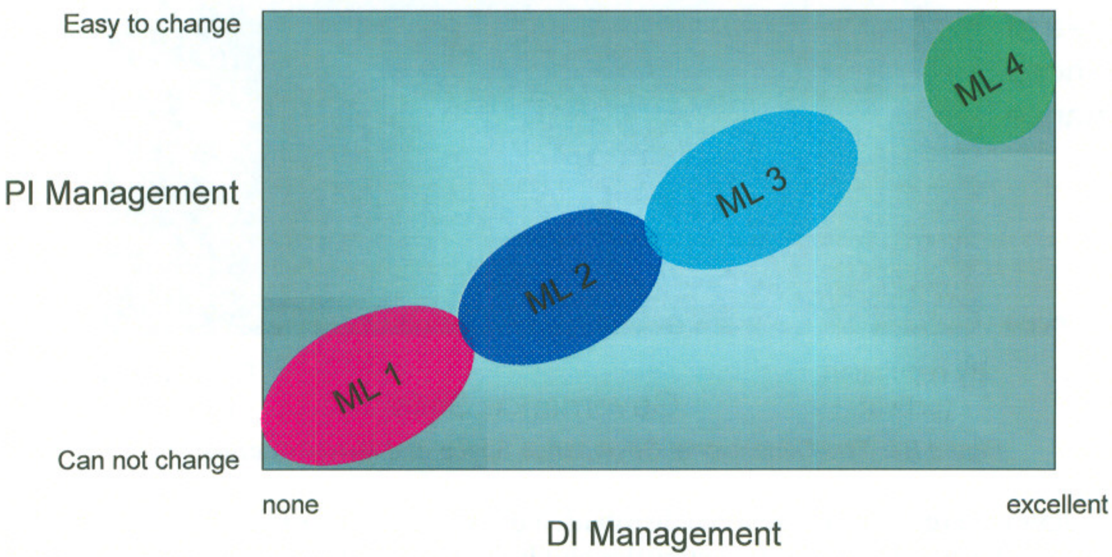

Figure B6: Two-Dimensional Management Space and Maturity Levels

Bringing together the dimensions of organizational configuration potential (entropy), organizational size, organizational resistance to change (governance), and organizational flexibility (management) forms a four dimensional Organizational Agility space. The diagonal of each individual space forms dimension in the new Organizational Agility space. Governance and Management maturity levels can be located in this space.

Since it is difficult to visualize a four dimensional space, we divide it into two three-dimensional spaces. Figure B7 places the maturity levels within the Configuration Potential, Governance, and Management space first, followed by Figure C8 which uses the Size, Governance, and Management dimensions.

Figure B7 provides the complete picture. That is, both the potential and dynamic aspects of Organizational Agility are illustrated in this space (organizational size does not add any further understanding because it is independent of maturity level as shown in Figure B8). The maturity levels increase from the origin out to the farthest reaches of the Organizational Agility space.

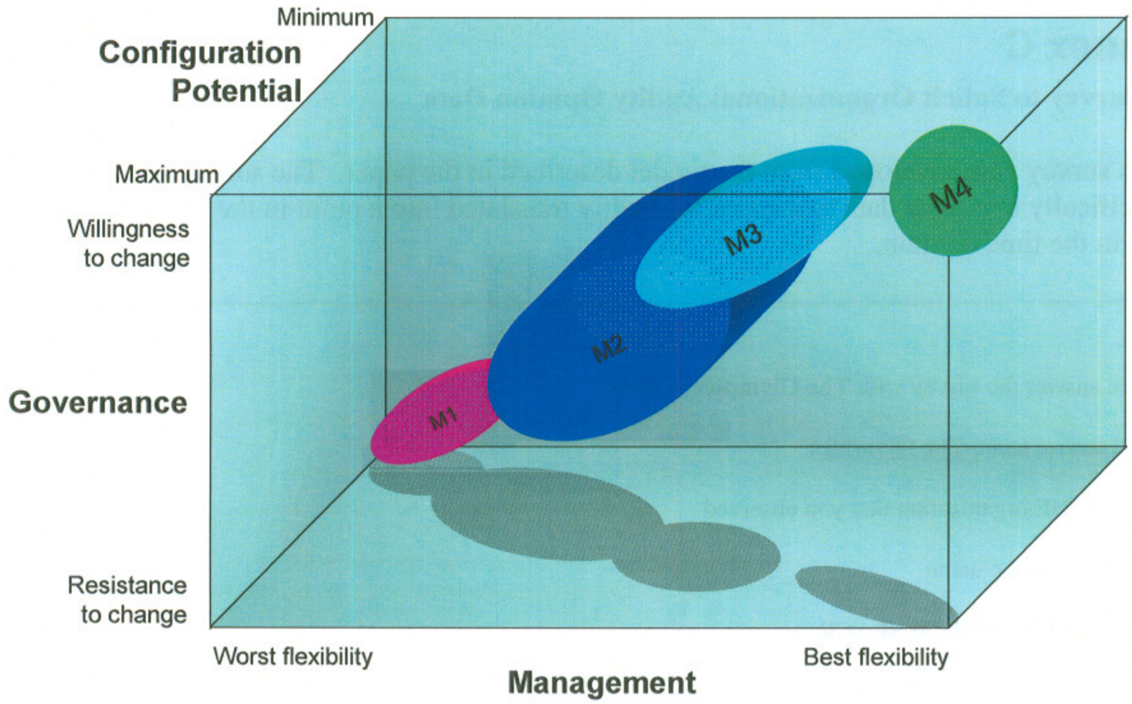

Figure B7: Organizational Agility Space (Configuration Potential and GM) and Maturity Levels

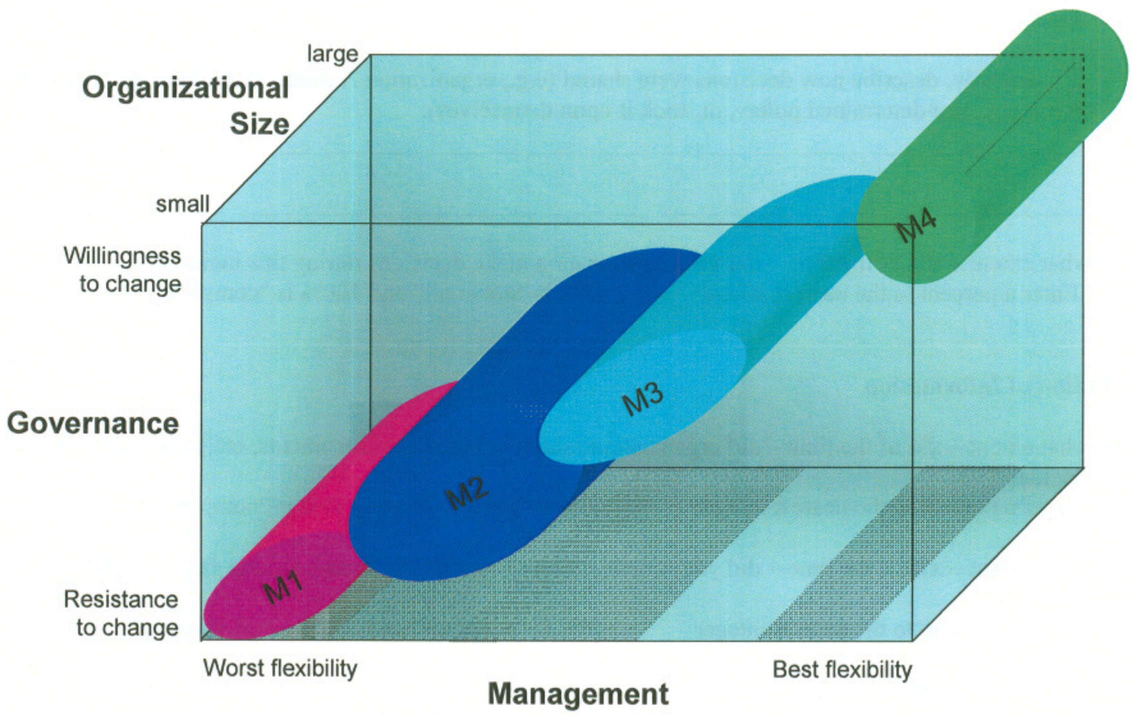

Figure B8: Organizational Agility Space (Organizational Size and GM) and Maturity Levels

Annex C

A Survey to Solicit Organizational Agility Opinion Data

This survey was developed from the model described in the paper. The survey was designed specifically to collect data that could be readily translated into a point in the GM approach space and in the time domain.

Please answer the survey with **The Olympics** in mind.

1. Exercise name **The Olympics**

Choose ONE organization that you observed

2. Organization name ____________

THE GM APPROACH SPACE

Allocation of Decision Rights

3. Describe the distribution of decision rights amongst the organizations:
   Equal _______
   Unequal _____

   If unequally, describe how decisions were shared (e.g., organization A made 75% of the decisions) and why (e.g., pre-determined policy, or, took it upon themselves).

   ____

   ____

4. To what extent – x% of the time – did your organization make decisions during this incident?
   Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

Distribution of Information

5. To what extent – x% of the time – did organizations share information (documents, etc.) with each other during this incident?
   Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

6. To what extent – x% of the time – did your organization communicate (email, face-to-face, telephone) during this incident?
   Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

Patterns of Interaction

7. Approximately how many organizations were involved in this event?
   Enter a number ______ (e.g., 1, 5, 21, etc.)

8. Select the pattern of interaction that best describes the interaction observed in the Olympics?
   Hierarchical _____
   Peer-to-Peer _____

Hub & Spoke ____
Other (please describe) ____

ORGANIZATIONAL PARAMETERS

Size

9. Estimate total number of security people in the collective that participated in the incident to the nearest 50 people.
   Enter a number ______ (e.g., 0, 50, 100, 150, etc.)

Willingness

10. To what extent – x% of the time – are organizations willing to change GM approaches as required?
    Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

11. Why (select one or more)?
    Policy _____
    Situation Awareness _____
    Personal ____
    Other (please describe) ____

Flexibility

12. To what extent – x% of the time – was the collective flexible during the incident?
    Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

ENDEAVOUR COMPLEXITY

Question 13 is an overall question. The other questions are optional.

13. To what degree was the Olympics **complex** compared to the most complex situation you can think of?
    Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

14. To what degree was the Olympics **complicated**?
    Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

15. To what degree did the Olympics have a lot of **physical nodes** (infrastructure, physical hardware, vehicles, bodies, etc.)?
    Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

16. To what degree did the Olympics have a lot of **information nodes** (computer networks, telephone networks, radio networks, data transfer networks, etc.)?
    Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

17. To what degree did the Olympics have a lot of **cognitive nodes** (people)?
    Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

18. To what degree did the Olympics have a lot of **social nodes** (teams, organizations, collectives, groups, populations)?
    Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

19. To what degree did these nodes **inter-connected**?
    Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

20. To what degree was the Olympics disorderly (**chaos amplitude**)?
    Enter a percent to the nearest integer ______ (0% is "orderly" and 100% is "chaotic")

21. What was the frequency of the disorderly events within the exercise (**chaos frequency**)?
Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "continuous")

22. To what degree were the exercise's events and their outcomes predictable?
Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

23. To what degree were the exercise's events stable?
Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

24. To what degree was the exercise multi-dimensional?
Enter a percent to the nearest integer ______ (0% is "not at all" and 100% is "completely")

General Comments

There are eleven complexity questions that come from several complexity definitions. Question 10 "To what degree is the endeavour complex?" solicits an overarching opinion regarding complexity. The other questions are various dimensions of complexity. Thus, a set of ten responses (each response is a number between 0 and 100) represents a point or a vector in a ten-dimensional complexity space. The questions are designed such that the farthest reaches of the space (ten 100's) would be the most complex while the origin (ten 0's) would be the least complex. Vector algebra (Farrell, 2005) can be used to compare the response vector to a representative vector, other participant's response vector, or response vectors at different times. The plan is to pursue this line of research and find opportunities to use the survey's data to evaluate the model. But for now anecdotal evidence provides some confidence that this line of investigation is moving in the right direction.