Annex A – DYNAMIC AIRBORNE MISSION MANAGEMENT: LESSONS LEARNT

A.1 DYNAMIC AIRBORNE MISSION MANAGEMENT

Fundamentally, DAMM is primarily concerned with adaptation of mission command, mission flow and effects delivery to changes in the mission context. In UK MOD operations, the mission context for tactical missions is customarily briefed in terms of the "4 Ts" – Tasks, Targets, Threats, Tactics – and the observed impact on timeliness for a co-ordinated and precision engagement mission. Thus, the 4T's provide an operationally relevant representation and high level decomposition of the key elements of the mission context. A simple representation of the functional flow model for DAMM in relation to the 4Ts is shown in Figure A-1 below.

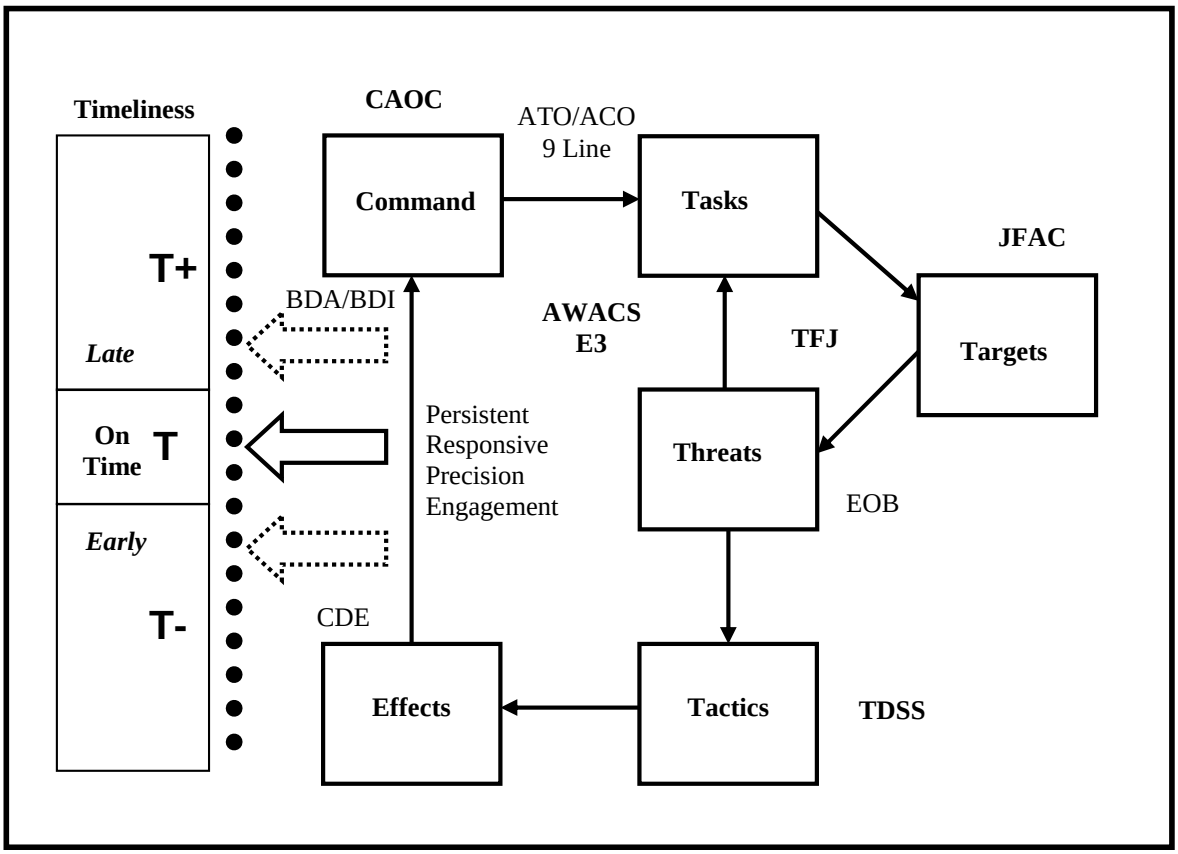

Figure A-1: Functional Model of DAMM.

The functional flow model of DAMM illustrated in Figure A-1 provides a useful framework for planning of DAMM test and evaluation studies. This framework has utility for defining test variables and metrics, with potential discriminative power for diagnostic and prognostic analysis. All 4T's, coupled with command intent and the timeliness of effects, should be considered as essential mission variables and sources of metrics for comprehensive studies of DAMM advanced digital networking and mission enabling technologies.

A.2 MISSION CONTEXT

Measurement and control of the complexity of the mission context provides a basis for standardisation, comparison and balance in test design. The "4 T's" – Tasks, Targets, Threats, Tactics – with timings of effects, provide an operationally relevant framework for the description, decomposition, and measurement of the mission context. The frequency of individual tasks, targets, threats, tactics (and affected timings) can be controlled, observed and measured directly. Additionally, given the familiarity of operators with the 4T's framework for briefing missions, it seems sensible and potentially useful to try to elicit from participant operators, or from observer subject-matter experts, estimates of the demands on operators workload arising from changes in mission T's. Accordingly, in the both 1st and 2nd US-UK Strike Warrior SE Trials, rating scale estimates (using 7-point Likert scales) of Change Management Demand for Tasks, Targets, Threats, and Tactics (Times 1st Trial only) were obtained from the participants for individual trial runs. The mission T's change demand ratings data showed evidence of systematic and sensible trends (Tasks>Targets>Threats>Tactics>Times) and some statistically significant beneficial effects of advanced system architectures (Baseline>Threshold>Objective). It was noted that Target and Threat demands arose directly from the external environment and mission scenario. In contrast, Tasks, Tactics and Times were mitigation responses mediated by the system architectures and mission management.

A.3 SCALE

In the operational environment, DAMM involves complex interactions and interfaces between air packages, C2 elements and air-land co-ordination. In planning realistic technology demonstrations and operational testing, the scale of the tested operations and architectures, and the degree of uncertainty or volatility in test missions, are major determinants of the validity, reliability and generalisability of test findings. Scale is a major study cost driver. More affordable small-scale, sub-system studies provide simpler effects and easier measurement, but risk low generalisability of findings. More costly large scale, system-of-system realistic demonstrations can be convincing and impressive, but the more complex effects arising can be difficult to quantify and verify, in particular with regard to repeatability and reliability. A mixed approach is probably preferable, using progressive development and testing of prototypes, for better managing the risks and costs of scale. This can be provided by a series of development and test phases, with increasing complexity, and prioritisation of core capabilities, critical interactions and essential interfaces. A progressive approach can be facilitated by exploiting any inherent scalability in the technical system and testing scenarios. The DAMM architecture afforded progressive building and extension of the horizontal (effectors packages) and vertical (tactical/operational command) C2-MM system components. The DAMM scenario afforded incremental development of mission complexity by the addition of tasks, targets, and threats.

A.4 VOLATILITY AND UNCERTAINTY

DAMM seeks to enable adaptation and stability in a dynamic environment. The scenario and missions were designed to allow White Force to vary volatility and create uncertainty through injection of unexpected and disruptive information and events via tasks, targets and threats. Variability in the volatility and uncertainty of the missions is necessary to stress and test human component capabilities:

- To exercise and challenge the operator's use of DAMM tools, and application of skills, rules knowledge underpinning Mission Essential Competencies (MEC);
- To mitigate operator learning;

- To provide military operational variety and realism; and
- To enable participant engagement and immersion.

Control of the scale of volatility and uncertainty in the test scenario missions provides a further basis for standardisation, comparison and balance in test design. The frequency of injections of changes affecting tasks, targets, threats, and tactics afforded by the vignettes can be observed and measured directly to provide direct measurement of the mission volatility. Estimates of Change Management Demands associated with the 4Ts provide indirect measurements of the resulting uncertainty. However, these are confounded with the mitigating effects of the DAMM system architectures. The scenarios were designed with a set of vignettes (typically 3+) to provide variety and challenge, with progressive complexity and volatility. In practice, the degree of volatility and uncertainty appropriate for stressing and testing effectively the DAMM tools relied heavily on military judgement. Generally, vignette complexity was matched to the DAMM capability under test. White Force used more complex vignettes and injected more volatility and uncertainty on Objective architecture runs, expecting better mitigation and adaptation. The Baseline architectures were tested with relatively simpler vignettes.

A.5 DECISION MAKING

In the development of the DAMM CMDM assessment approach, it was useful to consider how DAMM CMDM task MECs were structured with reference to existing cognitive frameworks. Figure A-2 illustrates the structure of individual CAS/TST CMDM task MEC examples within a Skills–Rules–Knowledge (SRK) cognitive framework.

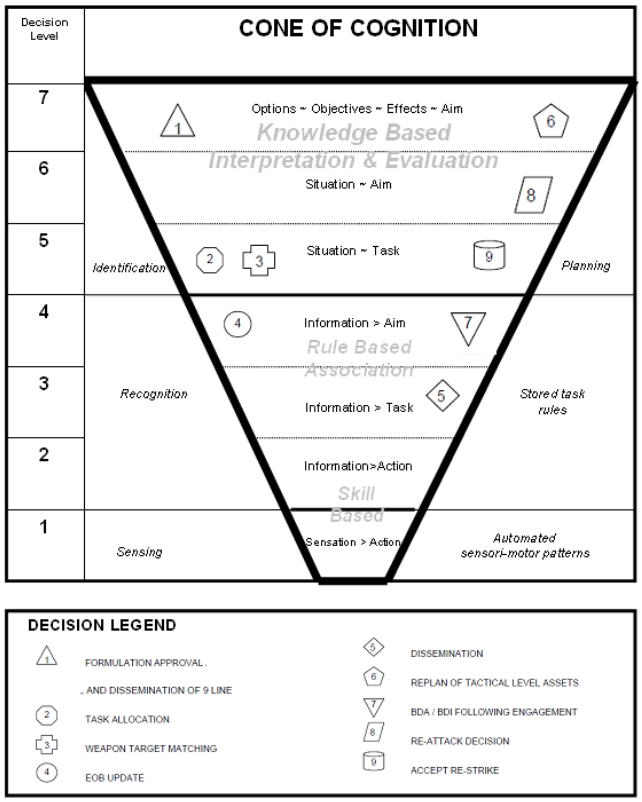

Figure A-2: DAMM Decisions in the SRK Cognition Framework.

The SRK framework draws distinctions between automatic and naturalistic or recognition-primed decision making decision making, and deliberative, analytical and evaluative decision making. In Figure A-9, the nine CAS/TST CMDM task MECs are shown as residing at the rule-based association level, and at the knowledge-based interpretation and evaluation level.

The SRK framework concerns cognition at the level of the individual. DAMM concerns individuals working collaboratively within a distributed, hierarchical C2 process. So, it was also considered useful to examine how DAMM CMDM task MECs were structured with reference to C2 framework. Cognitive control theory represents cognition as a layered process of multiple control loops. Figure A-3 illustrates a representation of the structure of the CAS/TST CMDM task MEC examples within the Operational and Tactical C2 architecture C2 OODA (Observe>Orient>Decide>Act), or "COODA loop" layered control system. Here, the REMDAER* framework provides the components for multi-player, distributed, or team, decision making cycle.

**Recognise>Evaluate>Mitigate>Disseminate>Acknowledge>Decide>Execute>Report.*

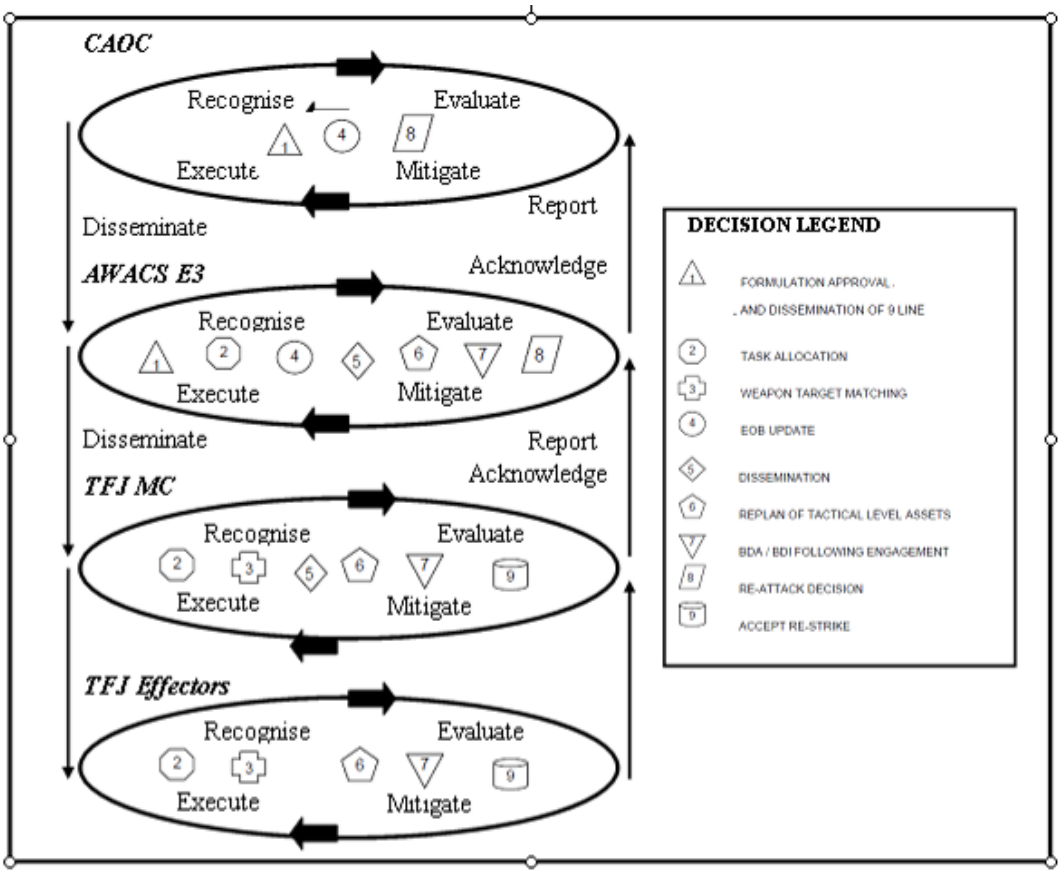

Figure A-3: DAMM Decisions in the REMDAER Framework.

In the development of DAMM capability, and in planning and reporting of trials, it was found to be useful to provide system-of-systems views and system architecture representations of DAMM CMDM derived from MODAF/DODAF system architect tools. Figure A-4 illustrates a representation of the structure of decision making using a systems architecture framework view approach (MODAF/DODAF), with CAS/TST CMDM

examples depicted in sequential order, with the *Command Flow* across the architecture tiers (CAOC White Force; E3 OpTEAM; TFJ TacTEAM and TDSS), and with the *Mission Flow* within Tiers. This approach is more suitable for identifying CMDM characteristics such as influencing factors, prioritisation, and alternative Courses of Action (CoA).

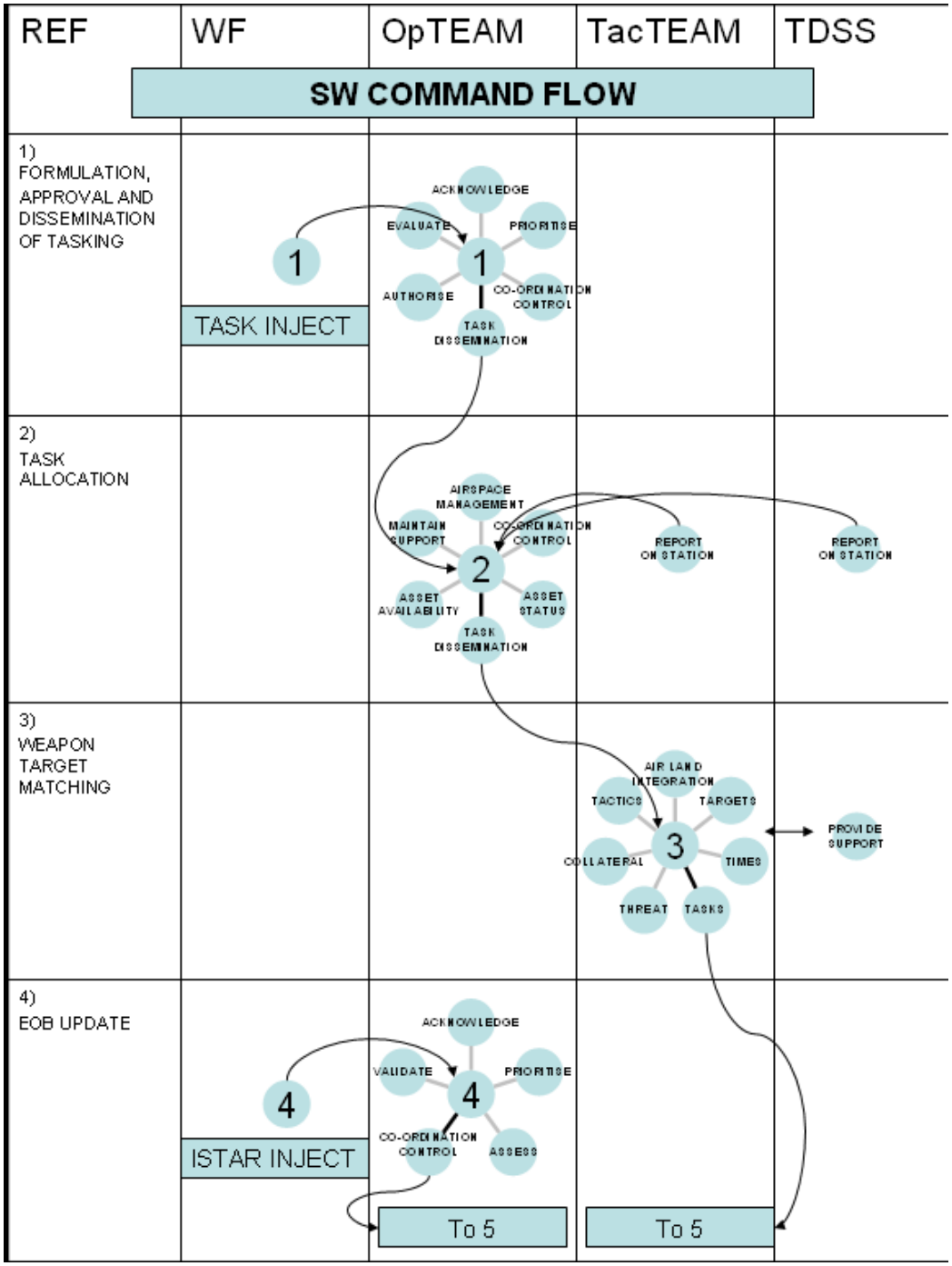

Figure A-4: DAMM Decisions in Command and Mission Flow Framework.

In DAMM SE trials workshops, the impact of DAMM on mission command flow was frequently discussed and debated, in particular the increased potential for distributed adaptive decision making providing support for the role of Mission Commander. It was hypothesised that in more highly networked collaborative architectures, SSA might be more widely and better distributed, and that mission command decision making processes might not necessarily need to be centralised, as illustrated in Figure A-5. As reported earlier, in the 2nd Joint US-UK SE Trial, September 2010, four different MC positions were tested, and the Objective architecture provided relatively good adaptability proficiency with the MC in all four positions, consistent with good communications and SA. Individual runs showed benefits of distributed and adaptive decision making, afforded most by the networked Objective architecture. Further work is needed to more fully understand the implications of DAMM for Mission Commander MECs.

MISSION COMMAND	*BASELINE*	*THRESHOLD*	*OBJECTIVE*
DECISION HOLD PACT In Command Participants provide MC with information and advice, and MC decides course of action	★	☆	☆
DECISION TIGHT By Consent PACT In Support Participants provide MC with advice and action information, and if approved by MC, participants perform advised Action	☆	★	☆
DECISION FREE By Exception PACT Direct Support Participants provide MC with advice and action information, and perform advised action, unless revoked by MC Dynamic Adaptive	☆	☆	★

Figure A-5: Effect of DAMM Network Architecture on Mission Command.

A.6 DYNAMIC MISSION ACTIVITY REPRESENTATION

In analysis and reporting of successive trials, the need was recognised to develop improved methods for the representation of the missions. Mission representations needed to highlight the important relationships between system components, participants, tasks, goals, events, decisions and outcomes. This was needed in a manner that captured the structure of the dynamics and flow and afforded measurement of performance. Illustrations of the forms of representation that evolved under DAMM, and that were found to be useful, is shown in Figure A-6 to Figure A-8 below.

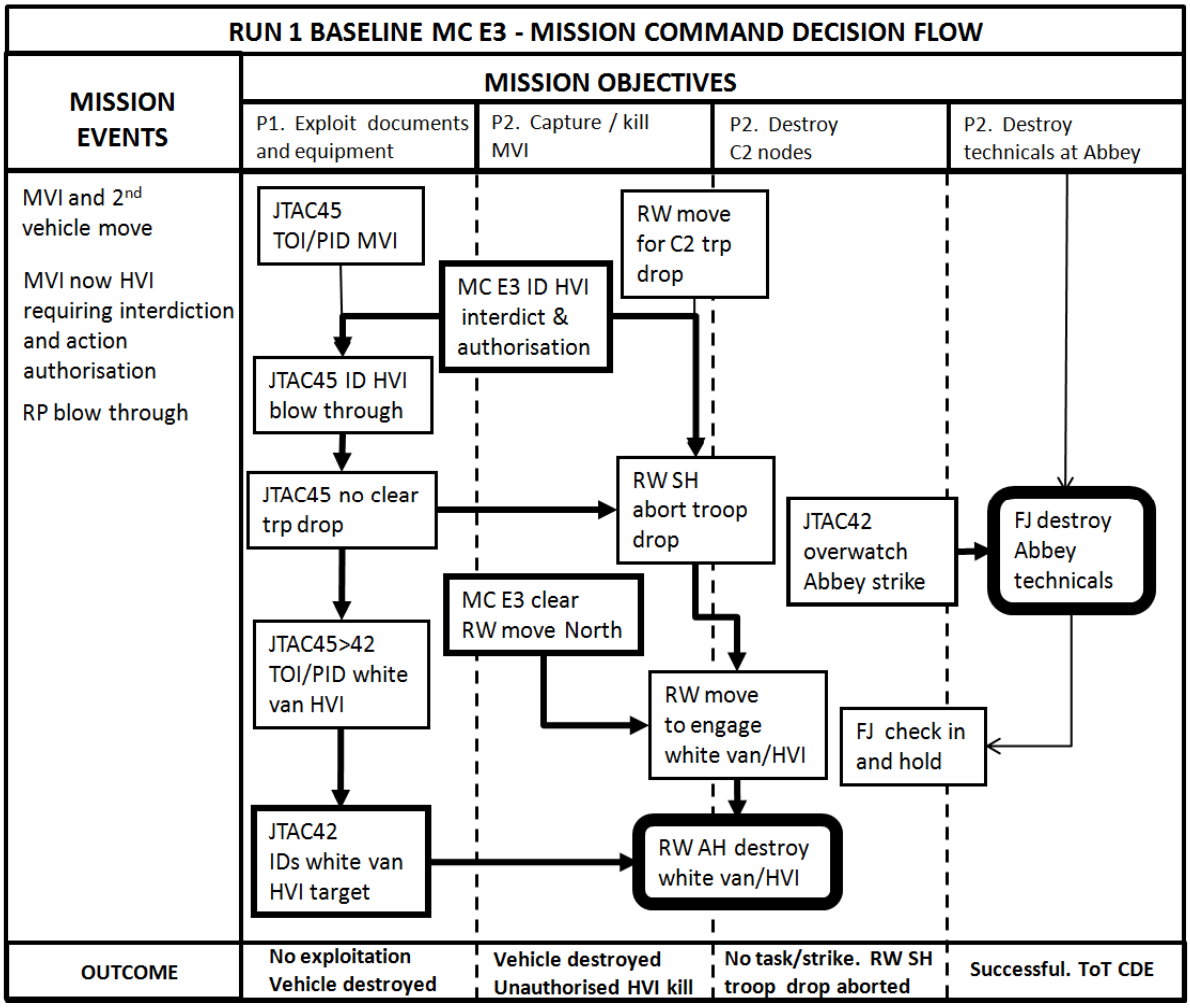

Figure A-6: DAMM Mission Command Decision Flow.

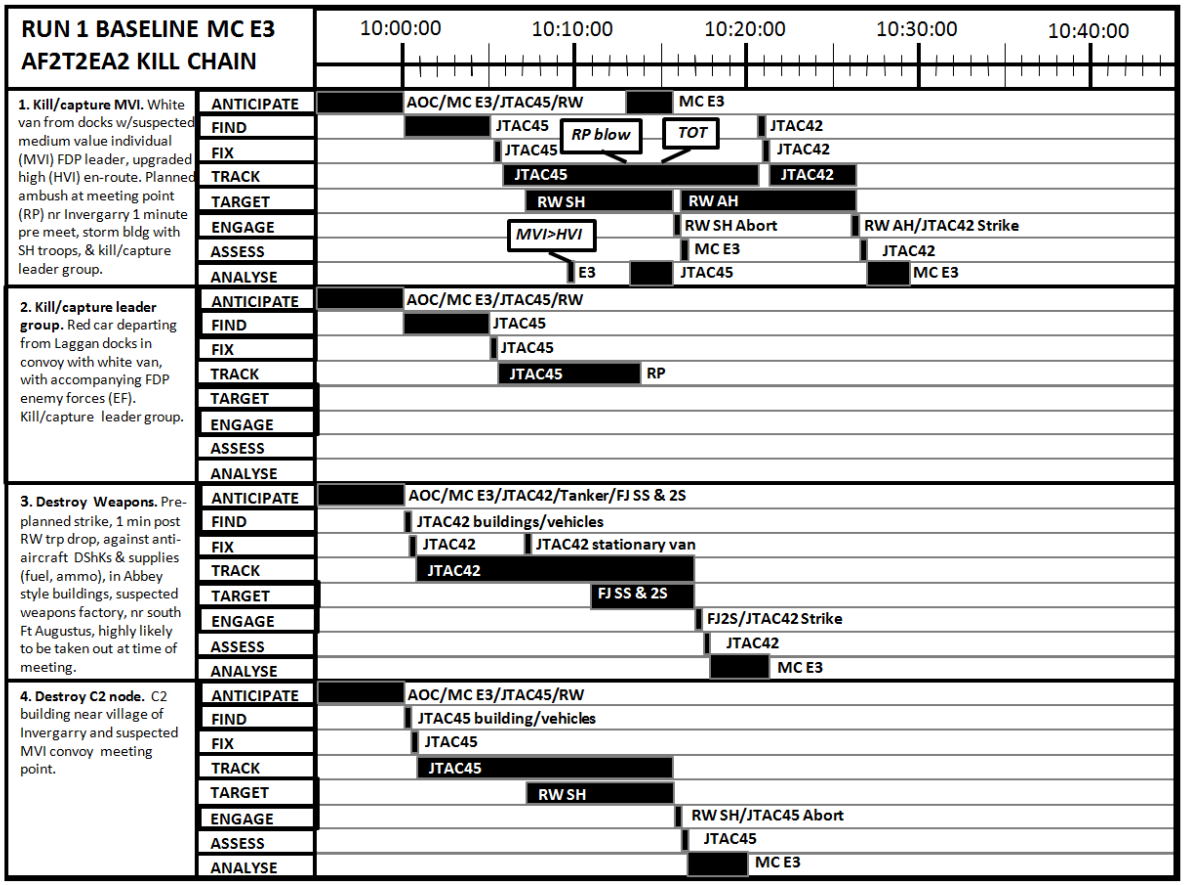

Figure A-7: DAMM AF2T2EA Kill Chain.

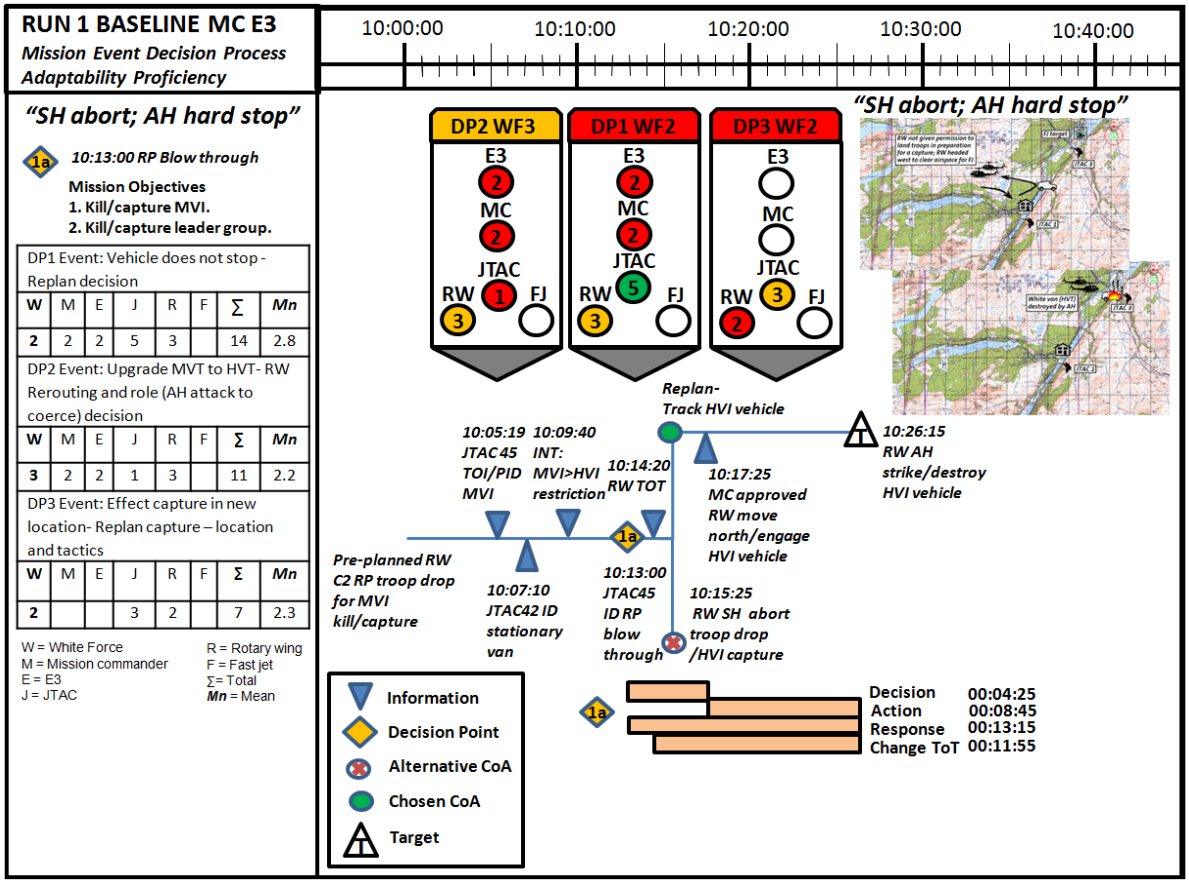

Figure A-8: DAMM Adaptability Proficiency Decision Mapping.

A.7 TOOL USAGE

The creation of scenarios and missions that properly and fully exercised the envisaged use of the DAMM tools proved problematic. This arose because of difficulties in effectively mandating DAMM tool use during the test trials. Variability in tool usage is partly a training issue. However, although the DAMM tools are regarded as enabling technologies, fundamentally they are designed to provide operator aiding and decision support. Tool use is optional. Simple mission management tasks can be completed "manually" without the aid of DAMM tools (c.f. Baseline architecture), relying only on the operator's airmanship and tactical knowledge and skills. Whether or not the DAMM tools actually get used in a realistic trials environment is dependent on the operator's training and perceptions of utility, benefit, and ease of use, as judged in the mission context. Mitigation of the risk of non-usage of tools can be achieved by identification of strong tools use cases, and by integration of validated use cases into the trials scenario missions.

A.8 LEVELS OF PROOF

The DAMM programme of work involved progressive development and test with increasing levels of proof and evidence of integration de-risking and system performance. The work progressed from laboratory bench

testing, through Synthetic Environment (SE) trials, to Live, Virtual and Constructive (LVC) environments and flight test. The levels of proof and weight of evidence required for technology demonstration and test are associated with the Technology Readiness Level (TRL) of the systems under test, and the needs for risk reduction and cost/benefit assurance. For progressing development of concept prototypes at relatively low TRLs 1 – 4, laboratory bench testing and SE evaluations of mission enabling technologies can be appropriate, using only core sub-systems, semi-realistic missions and part-task simulations, comparing only essential equipment, messages and links, and varying critical characteristics of the operating environment, missions, stresses and tasks. Here, relatively low levels of evidence of performance and effectiveness can provide necessary and sufficient for proof of progress and assurance of concept validity, e.g., nominal/ordinal qualitative data level metrics, aircrew subjective ratings, operator usability questionnaires. At high TRLs (5+), demonstrating de-risking and readiness for exploitation in real systems, LVC and flight test of mission enabling technology are needed, using real environments and stresses, current equipment and systems, with objective measurement of performance and effectiveness on realistic operational missions and tasks, and demonstrations of real effects.

In an advanced simulated environment, features and components can be varied up to high levels of fidelity and representativeness, within constraints of time and cost. In a programme with progressive test and evaluation, not all the system features need necessarily simulated at a uniformly equivalent level of fidelity, e.g., co-ordinated aircraft behaviours, outside world visual resolution, sensors and communications performance, C2 procedures, cockpit/crew workstation layout, HMI. For mission systems testing, the design of the SE test environment representativeness should provide the standard of fidelity necessary and sufficient to accomplish the specific test objectives. Higher levels of SE representativeness should be needed for features involved directly in the performance of critical mission functions. For networked critical mission system functions and associated tasks, interactions and procedures, particular consideration needs to be given to the requirements for representativeness of SA and tactical information, and data link communication of tasks, threats, targets, tactics, and positions of other assets, routes and airspace.

The Operator-Mission Interface (OMI) is a critical component of DAMM. Involvement of experienced military operators is essential at all the levels of mission system development, test and evaluation. Experienced aircrew are needed to build credible and realistic test scenarios and missions. They are needed to design representative stressing missions and events to test and stress the mission systems and aircrew under evaluation. Experienced operators are needed to adapt and apply realistic, current or developmental CONOPS, training, Tactics, Plans and Procedures (TPP). Mission system test trials need scenarios and missions to focus on crew information quality, decision making, prioritization, mission command and interoperability issues. Critically, they are needed to provide imagination, creativity and expertise to develop new tests for new concepts and technologies, where for DAMM the focus is on the efficiency and effectiveness of distributed adaptive decision making in a highly dynamic networked environment.

A.9 MEASUREMENT AND METRICS

Assessment approaches should use a combination of objective metrics of mission performance, and operator provided expert judgments captured using subjective rating scales. Experience has shown that subjective ratings of aircrew and system performance, captured using simple, reliable and proven methods, provides valuable quantitative evidence and insight on decision making performance, that aids and reinforces the interpretation of objective data. Metrics of should include ratings of decision quality, specifically survivability, effectiveness and timeliness, in addition to SA and workload.

The DAMM programme sought to develop a sensible and practical set of simple rating scale protocols for data capture, during both real-time on-line assessments by SME Observers, and from crew participants during post-run de-briefings. Several versions of the basic structure were employed across the trails. Item content was varied and refined following feedback from users and statistical evidence of item sensitivity and discriminative power. The evidence indicated the value of Team Work metrics, in addition to measurement of individual Task Work, for measuring operator performance in distributed, collaborative networked operations. The protocols used towards the end of the DAMM programme, and the associated metrics structure, are shown in Figure A-9 to Figure A-12 below.

SELF ASSESSMENT OF PARTICIPANT WORKLOAD AND PERFORMANCE

Date: **Time:** **Trial Run Description:** **Participant Role:**

	RATING SCALE	WORKLOAD Time Pressure-Mental Effort-Stress-Team Workload				REPLAN TASK LOAD Decision-Action		SA Attention Demand-Supply-Understanding			DECISION QUALITY Confidence-Survivability-Effectiveness-Timeliness				PERFORMANCE Task Performance-Tools Utility-Adaptability Proficiency-Probability of Mission Success				RATING SCALE
		TP	ME	ST	TWL	DEC	ACT	DEM	SUPP	UND	CON	SURV	EFF	TIM	TP	TU	AP	PMS	
	HIGH 7																		7 HIGH
	6																		6
	5																		5
	4																		4
	3																		3
	2																		2
	LOW 1																		1 LOW

NOTES:

PARTICIPANT PROTOCOL RATING SCALE INTERPRETATION

LOW ANCHORS	DIMENSION (Low1 / 2 / 3 / 4 / 5 / 6 / 7High)	HIGH ANCHORS
	WORKLOAD	
Slow/Leisurely/No time pressure	**WL Time Pressure**	*Rushed/Rapid/Frantic*
Very little/Extremely easy	**WL Mental Effort**	*Extremely hard/Stretched*
Relaxed/Placid/Tranquil/Calm	**WL Stress**	*Anxious/Worried/Up tight/Harassed*
Light/Quiet/Unpressured	**Team Workload**	*Heavy/Busy/Pressured*
	REPLAN TASK LOAD	
Forgiving/Simple/Easy	**Replan Decision** Recognise–Evaluate-Mitigate	*Difficult/Demanding/Complex/Exacting*
Forgiving/Simple/Easy	**Replan Action** Disseminate–Acknowledge–Execute-Report	*Difficult/Demanding/Complex/Exacting*
	SITUATION AWARENESS	
Stable/Simple/Fixed	**SA Demand on Attentional Resources**	*Unstable/Complex/Variable*
Relaxed/Inattentive/Spare Capacity/Singular	**SA Supply of Attentional Resources**	*Alert/Concentrated/Full capacity/Divided*
Uninformative/Meaningless/Unfamiliar	**SA Understanding**	*Informative/Meaningful/Familiar*
	DECISION QUALITY	
Indecisive/ Doubtful/Guess	**DQ Confidence**	*Decisive /Confident /Obvious*
Dangerous/Vulnerable/Risky	**DQ Survivability**	*Safe/Unthreatening/Secure*
Ineffective/Un-useful/Unproductive	**DQ Effectiveness**	*Effective/Capable/Useful*
Behind/Late/Pressurised	**DQ Timeliness**	*Ahead/On-time/In control*
	PERFORMANCE	
Unsatisfactory/Unacceptable/Failure	**Task Performance**	*Perfect/Successful/Satisfied*
Useless/Complicated/Difficult	**Tools Utility**	*Easy/Intuitive/Effective*
No backup plans/ Insensitive/Unresponsive	**Adaptability Proficiency**	*Sensitive/Responsive/Timely effective backup plans*
Fails to meet any mission objectives/0%	**Probability of Mission Success**	*100%/Successfully achieved all mission objectives*

Figure A-9: DAMM Participant CMDM Assessment Protocol.

SME OBSERVER ASSESSMENT OF PARTICIPANTS PERFORMANCE

Date: Time: Trial Run Description: Observed Participant Role(s):

	RATING SCALE	DECISION QUALITY Survivability-Effectiveness-Timeliness			TEAMWORK Communication-Shared SA-Leadership-Support-Team Workload					PERFORMANCE Task Performance-Collaboration-Influence Power-Adaptability Proficiency-Probability Mission Success					RATING SCALE
		SUR	EFF	TIM	COM	SSA	LDR	SUP	TWL	TP	COLL	IP	AP	PMS	
	HIGH 7														7 HIGH
	6														6
	5														5
	4														4
	3														3
	2														2
	LOW 1														1 LOW

Notes:

OBSERVER PROTOCOL RATING SCALE INTERPRETATION

LOW ANCHORS	DIMENSION							HIGH ANCHORS
	Low1	2	3	4	5	6	7High	
				DECISION QUALITY				
Dangerous/Vulnerable/Risky				**DQ Survivability**				*Safe/Unthreatening/Secure*
Ineffective/Useless/Unproductive				**DQ Effectiveness**				*Effective/Capable/Useful*
Behind/Late/Pressurised				**DQ Timeliness**				*Ahead/On-time/In control*
				TEAMWORK				
Silent/Unclear/Confused/Slow/Uninformative				**Communication**				*Clear/Timely/Coherent/Concise/Rapid/Informative*
Uninformative/Meaningless/Unfamiliar				**Shared SA**				*Informative/Meaningful/Familiar*
Indecisive/Unassertive/Confused/Uncommunicative				**Leadership**				*Commanding/Directing/Guiding/Initiating*
Ignoring/Hindering/Blocking/Criticising/Conflicting				**Support**				*Monitoring/Advising/Correcting/Assisting*
Light/Quiet/Unpressured				**Team Workload**				*Heavy/Busy/Pressured*
				PERFORMANCE				
Unsatisfactory/Unacceptable/Failure				**Task Performance**				*Perfect/Successful/Satisfied*
Separate/Independent/Divided/Conflicting				**Collaboration**				*Joint/Shared/Coordinated/Cooperating*
Powerless/Weak/Irrelevant/Not Involved				**Influence Power**				*Influential/Powerful/Forceful/Decisive/Critical*
No backup plans/ Insensitive/Unresponsive				**Adaptability Proficiency**				*Sensitive/Responsive/Timely effective backup plans*
Fails to achieve any mission objective/0%				**Probability of Mission Success**				*100%/ All mission objectives successfully achieved*

Figure A-10: DAMM Observer Assessment Protocol.

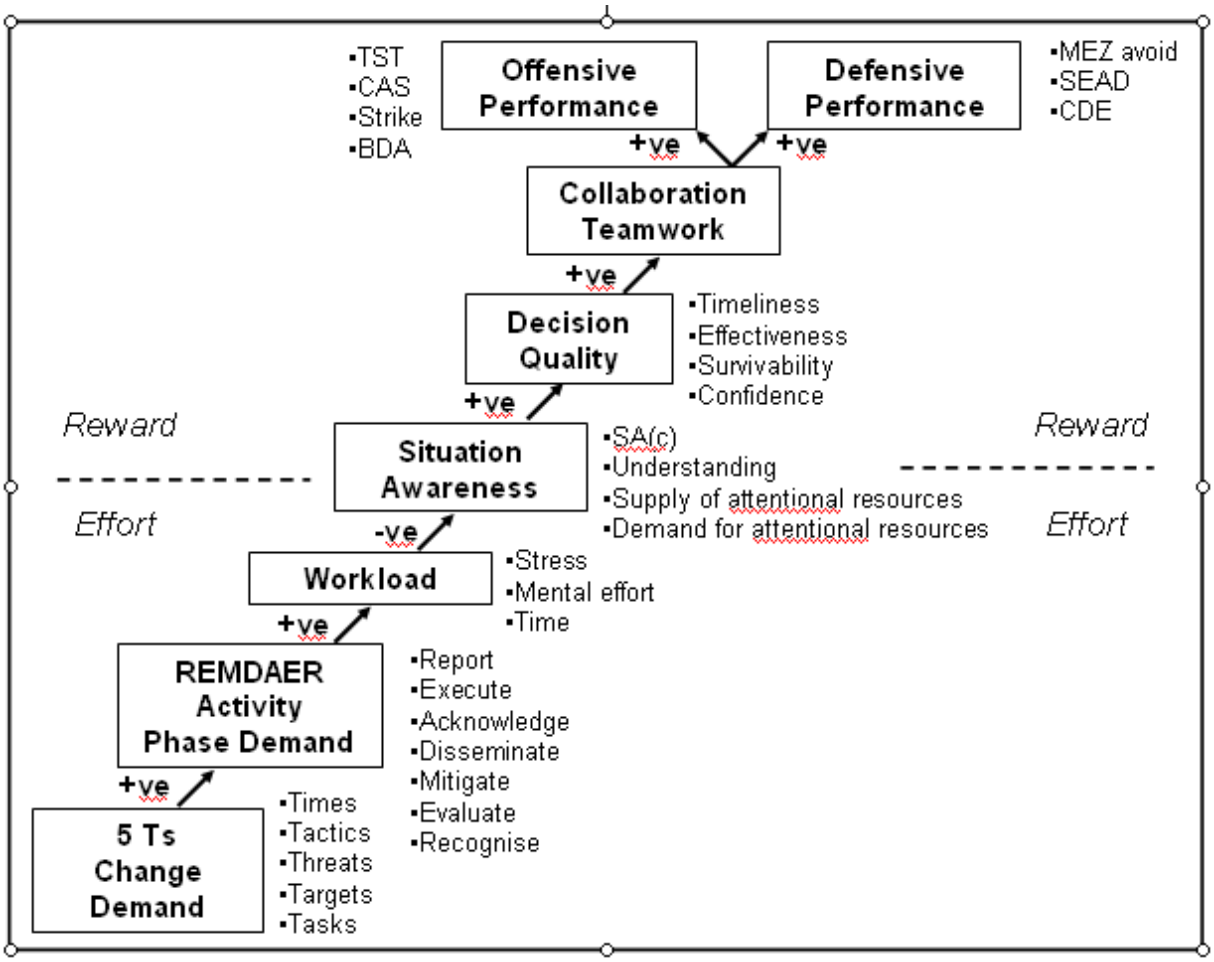

Figure A-11: Reward/Effort Metrics Structure.

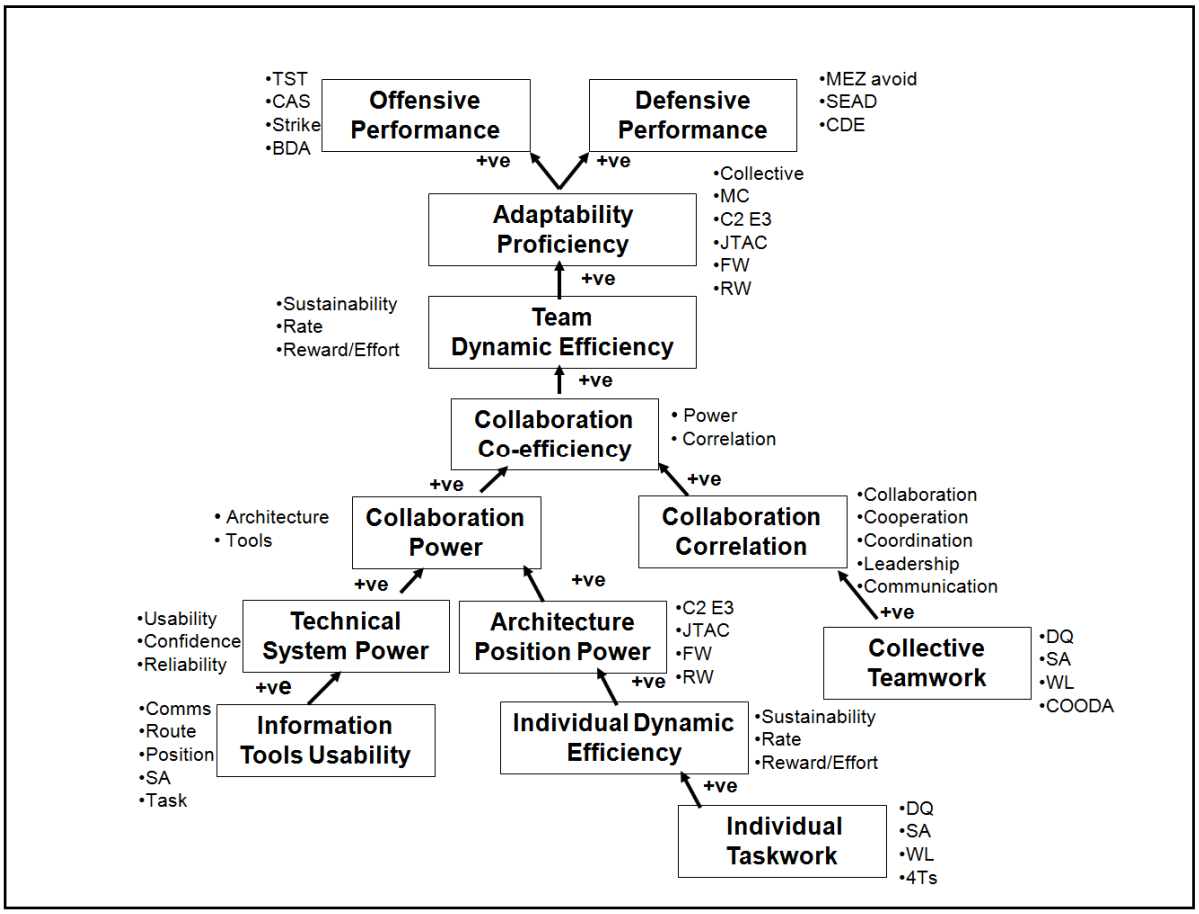

Figure A-12: Collaboration Metrics Structure.