15th International Command and Control Research and Technology Symposium
The Evolution of C2: Where Have We Been? Where Are We Going?

"Observational Studies of a Joint Fire Support Coordination Cell"

Topic 5: Experimentation and Analysis
Topic 8: C2 Assessment Metrics and Tools

Dr Dave Allen
DRDC Centre for Operational Research
Dave.Allen@drdc-rddc.gc.ca

Dr Frederick Lichacz
DRDC Ottawa
Frederick.Lichacz@drdc-rddc.gc.ca

Dr Kendall Wheaton
DRDC Corporate Office
Kendall.Wheaton@drdc-rddc.gc.ca

Canadian Forces Experimentation Centre
Shirley's Bay Campus
3701 Carling Avenue
Ottawa, Ontario, Canada

Abstract

In 2006, Defence Research and Development Canada jointly with the Canadian Forces Experimentation Centre initiated a Joint Fire Support (JFS) Technology Demonstration Project (TDP). The objectives of this TDP are to:

1. Recommend a JFS concept of operations (CONOPS) and architecture.
2. Assess the JFS CONOPS, gaps in capability, and the potential improvements resulting from changes in the people, process and material aspects of the JFS CONOPS.
3. Stimulate the JFS development of requirements, specifications, structure, doctrine and training as well as foster in-house R&D expertise to support an effective application of a fire-support capability.

In support of these goals, a campaign of experiments has been initiated. In February 2009, the JFS Human Factor 1 (HF1) experiment was performed. For this experiment, the typical working environment for a Brigade-level JFS Coordination Cell (JFSCC) was replicated to analyse and assess the performance of the JFSCC operators. The replication of a realistic working environment led to a limited number of experimental controls. Therefore, the JFS HF1 event was closer to an observational study than a well-controlled experiment.

Notwithstanding the lack of experimental controls, useful results on the effectiveness of JFS Command and Control (C2) systems were obtained. More precisely, the JFS HF1 experiment compared the performance of two different Command and Control systems: the JFS prototype, which included a Common Operating Picture and a coordination tool; and a system based upon the current architecture which uses the in-service, un-integrated Canadian Forces(CF) C2 systems. This paper describes the JFS HF1 experiment and summarizes the conclusions obtained from the following analysis.

Introduction

Within the past half century, there have been major changes to military operating environment. Current operations require more interactions between the various services (Army, Air Forces and Navy) and are conducted in an environment that includes various intervening external agencies rather than just two opposing forces. These changes require the development of new concepts of operation and tools to ensure the limitation of collateral damage and fratricide while providing a responsive and effective target engagement process. To address these issues Defence Research and Development Canada (DRDC) jointly with the Canadian Forces Experimentation Centre (CFEC) initiated a Joint Fire Support (JFS) Technology Demonstration Project (TDP) which is directly focusing on optimizing target engagement and developing an effective Canadian Forces Joint Fire Support model for joint and coalition operations.

The JFS TDP is a five-year effort that started in April 2006. The goals of the JFS TDP are to [1]:

1. Recommend a JFS concept of operations (CONOPS) and architecture based on modelling and simulation and war-game results.
2. Assess the JFS CONOPS, gaps in capability, and the potential improvements resulting from changes in the people, process and material aspects of the CONOPS as part of a joint land strike doctrine.

3. Stimulate the JFS development of requirements, specifications, structure, doctrine and training as well as foster in-house R&D expertise to support an effective joint application of a fire-support capability.
4. Provide operators with tools to evaluate future concepts within a system-of-systems JFS architecture.

In support of these goals, a series of experiments have been undertaken to stand-up and evaluate a test-bed consisting of both constructive simulation tools and advanced command and control software. The first series of experiments [2], which did not involve human subjects, addressed the interfacing and integration of the hardware and software. The aim of these experiments was to determine if the test-bed could allow realistic simulation of complex joint operations and a Joint Fire Support Coordination Cell (JFSCC).

A new series of human-in-the-loop experiments have been planned that focuses on the interaction of operators with the software tools and the efficacy of new approaches to enhancing Joint Fires coordination. The first experiment from this new series, the Human-Factor 1 (HF1) experiment, was conducted from 16 to 27 February 2009. The aim of this experiment was to compare the performance of operators in a brigade-level JFSCC using two different Command and Control systems: the JFS prototype, which included a Common Operating Picture and a coordination tool (JADOCS); and, a system based upon the current architecture which uses the in-service, un-integrated Canadian Forces C2 systems. In this manner, it was possible to determine if the JFS prototype represents an improvement over current operational capability and to quantify this improvement.

The HF1 experiment focused only on investigating the improvements provided by the JFS prototype to joint operations, leaving the investigation of solutions to cross-coalition and inter-agency issues for future experiments.

Aim

The aim of this paper is to document the results from the comparison of the two C2 systems used in the JFS HF1 experiment. This comparison, of the performance of the C2 systems, was based on:

- The ability of a JFSCC staff to perform their tasks using the provided systems, the quality of the task outputs, the time required to accomplish the tasks and the risk of making errors;
- The trust of the JFSCC operators in the adequacy and reliability of the system; and
- The JFSCC operators' situation awareness (SA) of the battlefield and their confidence in their SA.

Discussion on the meaning and importance of the results is provided. We conclude the paper with an overview of work performed since JFS HF1 and upcoming studies within the JFS TDP.

Experiment Design

HF1 was conducted in February 2009 at CFEC over a two-week period; each day comprised 6.0 hours of experiment (from 8:30 to 15:30 with a one-hour break for lunch). In the first week, the focus was on a JFS team operating a reduced JFSCC using the JFS prototype as depicted in ***Figure 1***. This prototype included JADOCS (Joint Automated Deep Operations Coordination System) which gave the system a coordination tool and a Common Operating Picture and was interfaced with current CF C2 systems that are described later. During the first week, subjects were briefed on the objectives of the experiment, the background of the scenario used for the experiment and the schedule for the two weeks of experiment. After this half-day of brief, the subjects were trained on the C2 tools (1.5 days). This training was followed by two days of rehearsal to ensure that the participants were familiarized with the operating procedures. During the rehearsal, the participants set-up initial coordinating measures (Airspace Control Orders, Restricted Firing Areas, etc.) and then they participated in the actual conduct of the planned JFSCC experiment (two days) using the JFS prototype.

During the second week, the JFS team operated a reduced JFSCC using current CF C2 systems; which included the Land Command Support System (LCSS), the Global Command and Control System – Maritime (GCCS-M), Theatre Battle Management Core System (TBMCS), and the Air Defence Systems Integrator (ADSI). As in the first week, subjects were trained on the applicable systems and tools (one day) and then rehearsed the experimental scenarios (one day) to for familiarization with the operating procedures. Coordination measures were developed using LCSS, GCCS-M or TBMCS (some measures had to be reproduced in more than one C2 system implying some duplication of effort). They then participated in the actual conduct of the planned JFSCC experiment (two days) using this C2 configuration, also shown in *Figure 1*.

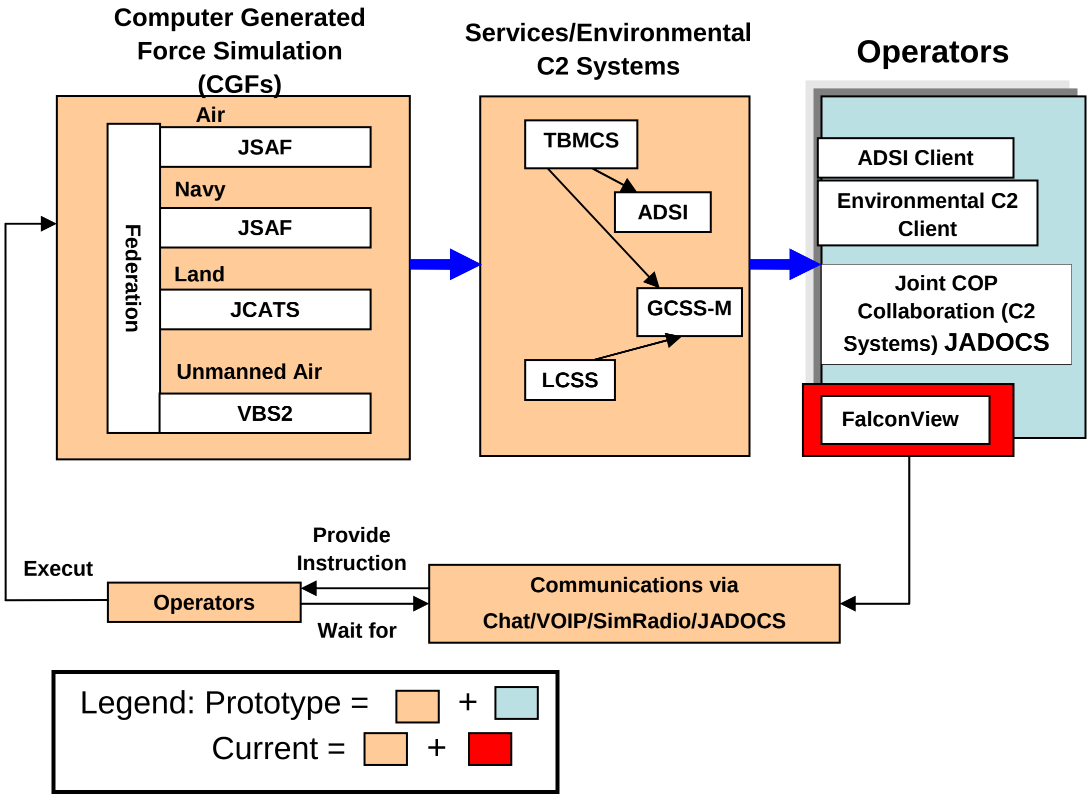


Figure 1. Schematic of both C2 Systems Used During JFS HF1 Experiment

A single group of six operators participated as target audience for the experiment. The experiment setting was designed to represent the work environment of a reduced JFSCC. As depicted in *Figure 1*, the operational and tactical picture supplied to the JFSCC operators was generated in real time by JSAF (Joint Semi-Automated Forces) and JCATS (Joint Conflict and Tactical Simulation) simulation software applications that fed a representation of a real-world situation into separate naval, land, and air command and control systems; GCSS-M, LCSS, TBMCS and ADSI. No field units were used during the experiment; all activity was generated by computer.

During the first week, the "tracks" (information on the movement of the military entities) were passed from LCSS and TBMCS through an integration software package to GCCS-M that re-formatted the data and forwarded it to JADOCS which was running on the operator workstations. JADOCS provided a set of specialized tools for the development of the Air Tasking Order (ATO), the air defence plan, the master air attack plan, the target nomination list, and the joint integrated prioritized target list, as well as map displays, databases of military units, databases of civilian structures, and databases of weapons system capabilities. The combined tool set was used for collective decision making as to the suitability of the target, granting of authority to engage the target, and assigning effects to the target using air, land, and naval capabilities.

During the second week, no Joint Common Operating Picture was provided to the operators. The tracks from JSAF and JCATS were passed to the in-service command and control systems (GCCS-M, LCSS, TBMCS, and ADSI) which were used by the operators for situation awareness. The JFSCC operators did not have access to a single integrated view of the virtual battlefield: the air, land and naval pictures were provided only within their respective C2 systems. Furthermore, due to limitations in the version of LCSS on the test-bed, the operators used FalconView to handle targeting information during the second week. This system was installed on various workstations and facilitated the sharing of target information. It was not integrated with any other C2 systems, or with the CGF software applications.

The target audience for the experiment replicated a JFSCC within a brigade-level headquarters. The task of this cell was to support the deployed units by ensuring, and monitoring, the engagement of pre-planned targets as well as planning and coordinating the engagement of emerging and time-sensitive targets. The target audience played the following JFSCC operator roles for the experiment and were located at operator stations as depicted in *Figure 2* (lower left corner of the main room).

1. Naval Gun Fires (NGF) Officer
2. Joint Fire Support Coordinator (JFS Coord)
3. Fire Support Coordination Centre (FSCC) Officer
4. Air Support Coordination Centre (ASCC) Officer
5. Tactical Air Control Party (TACP) Officer
6. Joint Fire Support Communicator (JFS Comm)

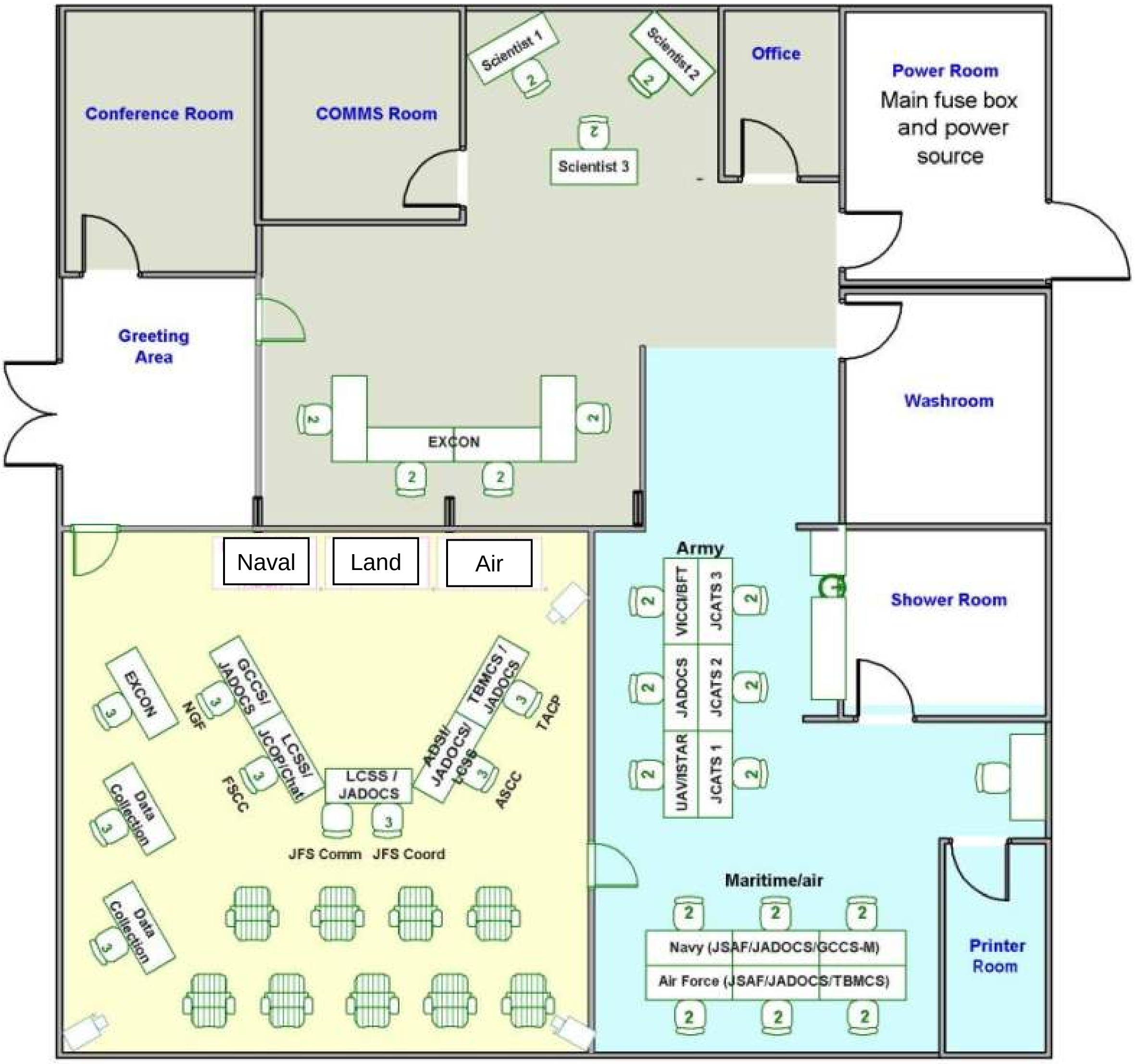


Figure 2. Experimental Layout of the BattleLab During the JFS HF1 Experiment

Figure 2 also depicts the C2 systems that were accessible to the six operators. Note that JADOCS was available only during the first week. Three large screens were set facing the horseshoe layout of the JFSCC. These screens displayed the naval, land and air pictures respectively. Therefore, although the three pictures were not integrated during the second week, each operator still had accessed to the naval, land and air pictures.

During both weeks, the JFSCC operators could communicate amongst themselves verbally or by using the following communication tools: a simulated radio (SimSpeak), a chatting software application (mIRC) and a soft phone (VOIP). They also communicated to higher and lower echelon operators using these same communication tools. The higher and lower echelon operators were part of the experiment white cell and were located in a room adjacent to the JFSCC operators (lower right area of *Figure 2*).

All operators also had access to Microsoft Office products (Internet Explorer, Excel, Power Point, and Word). As well, a Sharepoint portal was made available to the operators to provide background information on the mission. More precisely, this portal provided access to three types of documents: Operational Guidance; Targeting Information; and, Intelligence Reports.

1. Operational Guidance

- **Campaign Plan**: The campaign plan provides the overarching objectives of the mission and the Commander's intent.
- **Operational Plan** (OPLAN): The Operational Plan provides broad guidelines for prioritizing targets, making clear which sets are most important to the operation. The Operational Plan also provides guidance on the sequencing of targeting actions.
- **Order of Battle** (ORBAT): The Order of Battle provides the details of the deployed military capability.
- **Rules of Engagements** (ROE): ROE are directives to military forces (including individuals) that define the circumstances, conditions, degree, and manner in which force, or actions which might be construed as provocative and may or may not be applied. ROE are not used to assign tasks or give tactical instructions.

2. Targeting Information

- **High-Payoff Target List** (HPTL): List of targets whose loss to the enemy will significantly contribute to the success of the friendly Course of Action (COA).
- **Target Selection Standard** (TSS): The TSS specifies the accuracy requirements and other specific criteria that must be met before targets can be attacked.
- **Attack Guidance Matrix** (AGM): The AGM specifies which targets will be attacked, how, when and the desired effects.
- **Target Synchronization Matrix** (TSM): The TSM lists high-priority targets by category and the agencies responsible for detection, attack, and assessment. It combines data from the HPTL, intelligence collection plan, and AGM.
- **No Strike List** (NSL): Items on a NSL are those objects or entities characterized as protected from the effects of military operations under the Laws of Armed Conflict (LOAC), international law, or ROE.
- **Restricted Target List** (RTL): The RTL is a list of targets derived from the Joint Target List that cannot be attacked without prior coordination.

3. Intelligence Reports

- **Patterns of Life**: Information on typical activities occurring in the area of operation.
- **Threat Assessment**: Report providing an estimate of the potential threat within the operating environment.

All this background information was developed before the beginning of the experiment, sent to the participants as read-in package and briefed to them on the first morning of the experiment.

Experimental Hypothesis

The hypothesis tested within HF1 was:

> The JFS operators better perform JFS Coordination tasks and have better situation awareness when provided with a Joint Common Operating Picture and an integrated coordination tool compared to when they are limited to the decoupled in-service environmental C2 Systems.

The premise supporting the hypothesis is that the lack of an integrated environmental picture and the focus of each operator on different pictures strongly limit the capability of the JFSCC operators to coordinate their tasks. Note that JFSCC operators have to frequently coordinate their tasks when responding to calls for fire support and this coordination is done under time pressure.

Various related studies have been performed which investigated team task performance based on the team's interaction. In particular, a series of experiments was run collaboratively by the University of Pittsburgh and the Mitre Corporation between June 2000 and April 2002 to investigate factors hindering the collaboration of a distributed team interacting using information technology [3].[1] Using clustering methods, these previous experiments indicated four types of interactions that could lead to inefficient team collaboration. These four types of interaction correspond essentially to Webb's factors for ineffective collaboration [4]:

1. Not requesting collaboration;
2. Lack of timely and relevant support for collaboration;
3. Lack of clarity of provided information; and,
4. Lack of follow-up, i.e., not implementing or using the provided information.

These factors have been considered in the analysis of the JFS HF1 data to provide possible explanation for the difference observed between the two tested C2 systems. This allowed the identification of the main issues that a Joint Common Operating Picture and collaboration tools help solve.

The main assumption for the experiment is that the knowledge, skills and abilities of the JFSCC operators did not change between the four days of experimentation. The only difference was the tools provided and the way the information was displayed. This assumption was likely not entirely valid since as the experiment progressed, it is likely that the operators more easily recalled all the background information constraining the engagement (e.g., Rules of Engagement, OPLAN, Restricted Target List, etc.). This is the reason why the prototype system was tested

[1] Although the team was co-located during the JFS HF1 experiment, the ability of each operator to observe each other due to the obstruction created by the computer screens on each desk (all operators had three monitor screens on their desk) was limited. So, even though some verbal communication was performed among the participants, they also communicated through radio (SimSpeak) and using the chat tool. Therefore, the conclusions from reference [3] are relevant to the current study.

first: if the operators performed better with the prototype C2 system even though the learning process favoured the second system in the experiment (the current CF C2 systems) then it can be concluded that the prototype C2 system definitely provides better support to the JFSCC operators.

Data Collection

To test the experiment hypothesis, it was necessary to capture data on the task performance and the situation awareness of the operators as they used both C2 systems. More precisely, the focus was on capturing the following data:

1. The quality of the task outputs;
2. The time required to accomplish the required tasks;
3. The rate of errors made by the operators;
4. The trust of the JFSCC operators in the adequacy and reliability of the C2 systems; and
5. The JFSCC operators' situation awareness (SA) of the battlefield and their confidence in their SA.

In addition, the following data was also captured:

6. Background information on the experiment participants;
7. Work environment adequacy; and
8. Workload.

Item 1 was measured through a simple comparison of the amount of detail included in the task output and the outputs for the decisions that were made. Items 2 and 3 were collected by monitoring all the workstations and by observing the JFSCC operators.

The data for items 4, 5, 6, 7 and 8 was obtained through the use of surveys. The operator background information was obtained once at the beginning of the experiment while the degree of trust in the tools was measured once at the end of each week. The operators' degree of satisfaction in the layout and work environment was collected once at the end of the experiment. Finally, the operators' situation awareness, confidence in their situation awareness and workload was collected twice daily: before lunch and at the end of each experiment day. The SAGAT methodology ([5], [6]), which is based on Endsley's three level of situation awareness, was used for capturing the situation awareness and its related confidence level while the NASA task load index (TLX) was used for the workload.

The data was analyzed by comparing the task performance, SA, and SA confidence under the two experimental conditions. The overall process was also evaluated for the two experimental conditions based upon the overall time required and the number of mistakes (risk of errors).

The comparison for the task performance was based on the quality of the task outputs. The comparison was made by comparing the outputs produced from each task in response to each target. The overall difference in quality of output for a specific task was computed using a consensus ranking method (the same weight was assigned to all targets). The experiment hypothesis was evaluated by determining the difference in the number of tasks for which the protoype system provided better support compared to the current C2 systems system. A positive result for this difference was deemed to support the experiment hypothesis.

In addition, the way the tasks were performed was analyzed to identify reasons for any performance improvement. The overall time required to process a target and the risk for human error with both systems were also compared but not considered within the hypothesis.

In addition to the SA and SA confidence, the SA score of each individual at a given confidence level was also analyzed. This analysis was done using a Calibration Analysis, which provides a gauge of an operator's meta-SA [8]. That is, Calibration Analysis and meta-SA can be considered an accuracy measure insofar as it evaluates the fit between probability judgments and the corresponding events to which they refer [9]. In essence, calibration represents a characteristic of the operator [9] and can therefore be a useful concept in explaining human performance [8]. The concept of calibration therefore provides a broader measure of a person's understanding of the situation they are in, rather than simply examining SA measures or confidence ratings in isolation from each other.

Experimental Observations

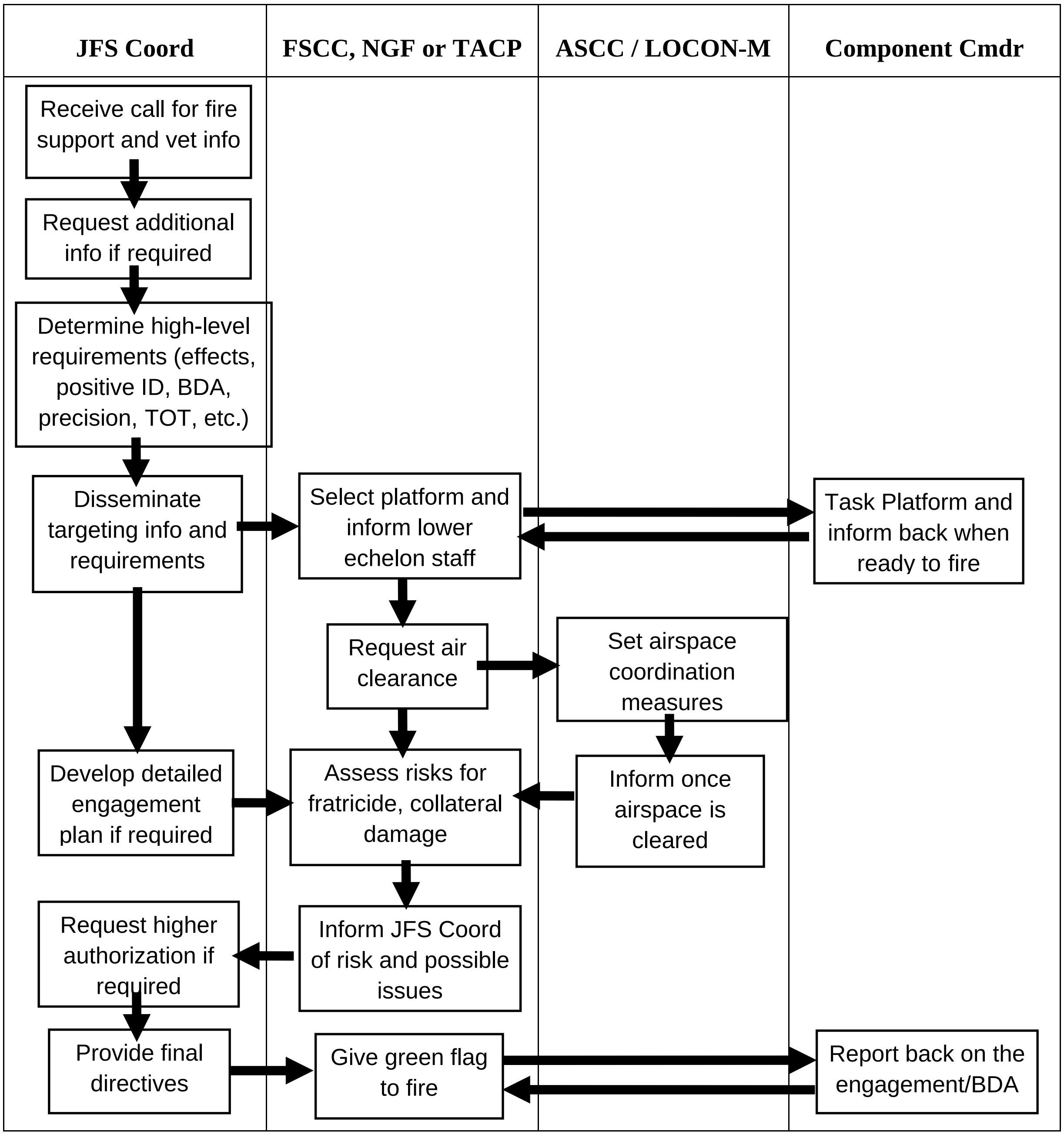
Table 1 shows the typical process observed during the first week of the experiment. The call for fire support was sent to the JFSCC by radio or mIRC. The JFS Coordinator acknowledged the call for fire support and vetted the information. He also requested more information or more accurate information when the provided information was assessed to be insufficient. Based upon the information received, the JFS Coordinator determined the targeting requirements: the desired effects; need for positive identification, "eyes" on target, communication lines, battle damage assessment; required time on target; target priority; and, required targeting precision. The Attack Guidance Matrix and High Priority Target List were used for determining these requirements.

Once the high-level requirements were determined, the JFS Coordinator disseminated the target information and targeting requirements using JADOCS. Based upon the location of platforms relative to the target, the location of the targets and the need for precision targeting, options for the targeting platform were discussed among the JFSCC operators. The JFS Coordinator then requested FSCC, TACP or NGF officer to further process the call for fire support. The choice of officer depended on the preferred type of platform selected for the fire support: FSCC for artillery, TACP for air assets (fighter, attack helicopter) and NGF for naval ships or maritime helicopters.

Using the high-level requirements, the assigned firing officer would ensure the availability of the platform and required ammunition. He also passed the targeting information to lower echelon staff and monitored their readiness for firing. He then requested airspace clearance. The ASCC made the request for airspace coordination measures (ACM) and ensured the ACMs were sent to higher echelon for approval. The firing officer was informed once the coordination measures were in place.

After requesting airspace clearance, the firing officer then assessed the risk for fratricide and collateral damage. The location of blue-force units and the no-strike list were used for these assessments. He then informed the JFS Coordinator with regards to the readiness of the firing units and the risk for fratricide and collateral damage. The JFS Coordinator requested authorization from higher echelon if required.

Table 1. Observed Process in Response to Calls for Fire Support



Lower echelon staff reported on the engagement and Battle Damage Assessment (BDA) once the firing was completed. The JFS Communicator kept a report of all engagements.

The set of tasks observed during the second week were similar to the ones from the first week with the exception that all collateral damage estimation (CDE) was either performed by the FSCC or the JFS Coordinator. Due to limited access to mensuration tools and limited geographical views of the no-strike list (only entered into FalconView), only these two operators could adequately perform this task during the second week. One should also note that the dissemination of targeting information was more laborious during the second week since the same data had to be entered into more than one system (into a shared Excel spreadsheet, FalconView and GCCS-M).

An Excel spreadsheet was used during the second week to coordinate the targeting tasks performed by the various operators. This Excel spreadsheet provided some of the functionality of JADOCS to coordinate the team's effort in responding to call for fire support. For each target, the spreadsheet displayed: the target number; target description; target location (using Army grid reference); the effects required; target priority; the actions required from JFC, FSCC, TACP, NFS, ASCC, and for BDA; the mission status; relevant remarks; and, the fire plan data. Although the utilization of such tool had not been planned for the second week, it was allowed since it reflects current modus operandi in theatre where operators are developing their own tools to help perform their work.

Experimental Results

Task Comparison

The outputs and outcomes produced by each C2 system were compared. This comparison was not performed by subject matter experts but through a simple direct comparison of the decisions made and outputs produced when processing the same target in each experimental condition.

From the list of activities observed (see ***Table 1***), the following outputs or outcomes were expected:

- A list of requirements for the engagement;
- The dissemination of the targeting information;
- The selection of a firing platform;
- A request for airspace clearance;
- The development of Airspace Coordination Measures;
- The assessment of CDE; and
- The development of an engagement plan.

Table 2 provides the logic on which the task comparison was performed and also the results of the comparison for both weeks. The results indicate that the JFS prototype improved the performance of two of the required tasks.

Table 2. Overall Results from Task Comparison

Task	Comparison Methodology	Prototype	Current C2
Determination of engagement requirements	Number of appropriate engagement requirements (time, precision, resources) identified.	No preference	No preference
Dissemination of target information	Effort required for disseminating the target information.	Preferred	
Selection of firing platforms	Comparison of adequacy of selected platform (selection or not of optimal platform based on time pressure, ammunition load, distance to target, target location and engagement requirements).	Inconclusive due to re-use of scenario and most vignettes	
Request for airspace clearance	Number of airspace clearance performed and JFSCC operators' awareness of airspace clearance request status.	Preferred	
Development of airspace coordination measures	Validity of ACMs and speed of response to airspace clearance.	Inconclusive due to unavailability of ADSI	
Assessment of CDE	Adequacy of target determined CDE level and associated required authority level.	No preference	No preference
Development of engagement plan	SMEs assessment of the developed engagement plan.	No preference	No preference

The two tasks for which the prototype led to an improved performance are: the Dissemination of Target Information; and, the Request for Airspace Clearance. For the Dissemination of Target Information, the average the number of keystrokes was less with the prototype than with the current C2 systems. The comparison showed a ratio of 76.5% between the numbers of keystrokes with the prototype versus the current system.

Although the same ratio of air clearance requests per target were observed both weeks, the alert system within JADOCS for informing the ASCC of the request suggests that the JFS prototype better supported this task. Furthermore, during the first week all participants were capable of keeping track of the status of the Air Clearance Measures since the ACMs were shared across all operators during that week. Every operator also had access to the Air Picture. Furthermore, the lack of a capability to visualize the ACMs was partly responsible for human errors made during the second week. Therefore, this comparison indicates clearly that an improvement was provided by the JFS prototype for this task.

Risk of Errors Comparison

The risk for human errors comparison was performed by counting the number of human errors that occurred both weeks, categorizing the types of errors, and determining which system has a higher risk for each category.

During the first week, two errors when using the C2 prototype were identified:

1. A mistake was made entering the coordinates of a target into JADOCS.
2. The name associated with the location of a target was wrong although the coordinates were correct.

During the second week, four errors were identified:

1. On two occasions, fires were given a “green light” before completion of the airspace clearance.
2. On one occasion, a target was engaged without final authorization to engage.
3. One call for fire support was not acknowledged nor processed by the JFSCC.

The reasons for the errors were identified by analyzing the activity of all operators at the time the mistake was observed. This analysis indicated four different causes: Wrong key struck, reliance on imprecise verbal communication, misreading entries in long narrow rows, and lack of attention on relevant information. A priori all these types of errors are possible for both systems but with a different rate of frequency. ***Table 3*** summarizes the frequency for each type of error and mentions the reasons for which each of the errors are more likely with the current C2 system.

Table 3. Comparison of the Expected Frequency of Errors Between the Two C2 Systems

Type of Error	Observed frequency with Enhanced	Observed frequency with Legacy	Expected Comparison
Wrong Key Struck	2/2 days	0	Higher frequency for current C2 system since it required more typing.
Imprecise verbal interaction	0	2/2 days	Higher frequency for current C2 system since operators relied more on verbal interaction.
Misreading	0	1/2 days	Higher frequency for current C2 system due to lower quality of the information display and the request for “eye-balling” between C2 systems.
Lack of attention on relevant information	0	1/2 days	Higher frequency for current C2 system due to the lack of alert systems.

A comparison of the two systems leads to the following list of reasons to expect a higher error rate with the current C2 system:

- The current C2 system requires more data entry tasks increasing the risk for typographical errors;
- The current C2 system requires more verbal interaction between staff from different environmental services (naval, land, air) that use different terminology.

- Delays in the update of the shared Excel spreadsheet and the losses of updates, due to near-same-time update to the spreadsheet, were a source of errors for the current C2 system;
- The current C2 system required the operator to compare by eye the relative location of targets and each environment service's (naval, land and air) blue force entities since these were provided by different systems;
- In the current C2 system, some operators did not have access to the location of ground forces limiting considerably their understanding of the battlefield. They depended on other operators (through verbal interaction) to support their activities which is not very accurate;
- There was no alert system for potential conflicts when planning an engagement in the current C2 system. In particular, the operators were not informed if a blue force entity was moving to close to a target or if a target was moving too close to an entity on the No Strike List.

Trust in System Comparison

At the end of each two-day testing period, for each C2 technology, all participants using the C2 systems (not just the JFSCC operators) were given a questionnaire that asked them about the degree of trust they had in regard to various aspects of the C2 technologies that they were using.

A t-test (a full factorial ANOVA was not used because there were only 4 participant responders) was used to analyze the Trust data (see ***Table 4***). As shown in ***Table 4***, there was a significant difference in trust ratings between the JFS prototype and the current C2 system. For the prototype, the operators had a mean trust rating of 88.72% and a mean trust rating of 35.54% for the current system.

Table 4. ANOVA Table for the Trust Data

Variable	***Mean***	***Standard Deviation***	***N***	***Difference***	***Standard Deviation Difference***	***t***	***df***	***p-level***
Prototype	88.72	7.94						
Current C2	35.54	34.07	28	53.18	35.7	7.88	27	.000001

This difference in trust can be partially explained by the instability of LCSS that failed frequently during the second week. However, pre-conceived views of the operators on the various C2 systems might have biased this result.

SA and SA Confidence Comparison

The SA data was subjected to separate 2 x 2 (C2 systems: Prototype vs. Current C2 systems) (time of day: midday vs. end of day) repeated measures analysis of variance (ANOVAs) (see ***Table 5***). The analysis revealed null effects for C2 systems (Prototype = 69% vs. Current C2 =

68%), time of day (Midday = 69% vs. End of Day = 68%), and the interaction between the C2 systems and time of day.

Table 5. ANOVA Table for SA Data

Effect	***df Effect***	***MS Effect***	***df Error***	***MS Error***	***F-value***	***p-level***
C2 System	1	9.21	9	99.87	.09	.76
Time of Day	1	15.94	9	149.00	.11	.75
Interaction	1	211.23	9	70.87	2.98	.12

Figure 3 provides calibration curves for the operators' overall over/under-confidence for the JFS prototype and the current C2 systems. These curves were obtained by plotting the percentage of correct responses associated with each confidence category (between 50% and 100%). In this way, overconfidence (under-confidence) is denoted by points falling below (above) the solid ideal calibration line [10]. In terms of predicting behaviour, persons who demonstrate ideal calibration (i.e., their confidence and SA response accuracy are perfectly matched) illustrate the greatest understanding of SA and would be expected to make the most appropriate decision(s) within an appropriate amount of time. In contrast, persons who are overconfident believe that they are doing better than they really are and may be prone to enter into decisions and actions where they should exercise greater caution, whereas those persons who are under-confident in their responses tend to be much more cautious and hesitant to engage decisions and actions [11].

Lee was the first to use a calibration methodology to study the relationship between SA and confidence [8]. According to Lee, calibration research provides a gauge of the operator's meta-SA. Like calibration research in general, meta-SA can be conceived as an accuracy measure insofar as it evaluates the fit between probability judgements and the corresponding events to which they refer (see [12]). In essence, calibration, or meta-SA, represents a characteristic of the operator and can therefore be a useful concept in explaining human performance [8]. The concept of meta-SA therefore provides a broader measure of a person's understanding of the situation they are in than simply examining SA measures alone or in isolation from confidence data.

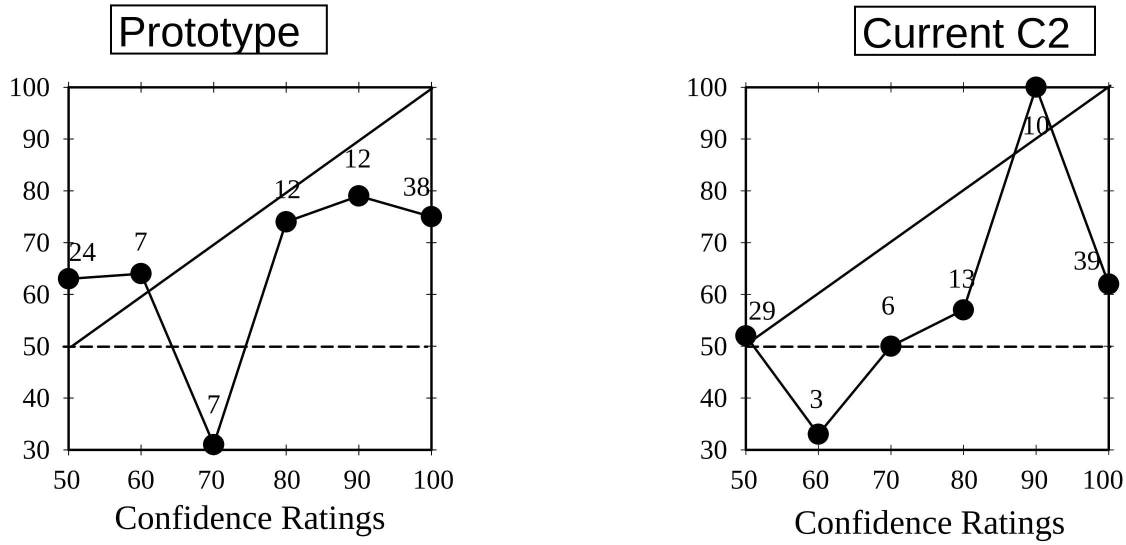


Figure 3. *Calibration curves for overall responses, Prototype and Current C2 data. The values next to each data point denote the percentage of time each confidence level was used.*

As shown in Figure 3, the calibration curve associated with the prototype lies closer to ideal calibration than does the calibration curve for the current system. In essence, this data informs us that, in general, the operators have a better understanding of their SA when using the JFS prototype system than they do when they are using the current C2 system. Accordingly, it would be predicted that the operators should make better decisions when using the prototype system. In fact, when presented with this data, the officer playing the role of the Joint Fires Support Coordinator, indicated that the calibration data associated with the current C2 system was indicative of a potentially higher incidence of fratricide rather than the data associated with the prototype: a finding that he expected would be observed when comparing the two C2 systems.

A caveat should be made at this point. The interpretation of the calibration data should be made cautiously because the calibration curves are based on a small data set and are descriptive in nature. Certainly, continued research in this field of inquiry is required to have a clearer understanding of the relationship between the development of the concept of meta-SA and C2 technologies. However, with this said, the calibration curves obtained in this study support the hypothesis of this study insofar as they illustrate a tendency to show that SA, or rather meta-SA, is better with the JFS prototype than with the current C2 system.

Even if a person demonstrates good SA, there can be a disconnect between the decisions and actions that follow a particular demonstrated level of SA [5]. Pairing confidence data with SA data allows the researcher some insight into a person's degree of understanding of their SA. Since confidence in one's knowledge systems has been shown to be an important predictor of behaviour ([11], [13], [14], [15]), it can be argued that calibration data is a more important predictor of decision-making and behaviour than SA and confidence data alone ([16], [17]). Indeed, researchers have shown that the closer people are to ideal calibration, the more accurate and fast their decisions [18]; this can not be predicted from SA and confidence data alone.

Findings

The experiment was initiated to test the following hypothesis:

> The JFS operators better perform JFS Coordination tasks and have better situation awareness when provided with a Joint Common Operating Picture and an integrated coordination tool compared to when they are limited to the decoupled in-service environmental C2 Systems

The analysis of the experimental data has failed to show a difference between the situation awareness obtained for both conditions. However, this lack of difference in situation awareness might have resulted from the lack of differences between the experimental scenarios used for testing the two C2 systems.

Notwithstanding the lack of difference in situation awareness, the analysis has indicated some important differences with regards to four important aspects:

- A significant improvement in task performance when using the prototype system for two required tasks: Dissemination of Targeting Information and the Request for Airspace Clearance.
- A significant reduction in the number of human errors and the associated risk when using the prototype.
- A significant increase in the operators' trust with the prototype system.
- A significant improvement in the operators' confidence in their own situation awareness.

These results were supported by feedback from the experiment participants. Most of these participants had recent relevant experience within a theatre fire support coordination cell and were very impressed with the capability provided by the JFS prototype; in particular for coordinating the required tasks, clearing fire, avoiding fratricide and integrating constraints such as the No Strike List.

Considering the observations made during the HF1 experiment within Webb's framework for ineffective collaboration [4], two of the factors identified by Webb appear to be relevant to issues observed with the current C2 system:

1. Lack of timely and relevant support for collaboration; and,
2. Lack of clarity of the provided information.

The inclusion of a task coordination tool and of a Joint Common Operating Picture, which leads to a reduce amount of inaccurate verbal interaction, within the JFS appears to largely reduce these two issues.

Finally, although the experiment highlights some of the benefits of providing a Joint Fires Support Coordination Cell with a Joint Common Operating Picture and an integrated coordination tool, the purpose of the experiment was not to make any recommendation for or against providing such systems. The purpose of the experiment was rather to identify and quantify the main benefits provided by such systems. The decision to provide or not such systems should consider the associated cost (the cost of acquisition, maintenance, and related training costs) and perform a detailed options analysis considering all possible systems currently available, or ones which could be developed, and determining which capability gap is most essential to address within the near future.

Conclusion

The JFS HF1 experiment has been the first experiment involving human subjects to test the developed JFS prototype and JFS Concept of Operations. The experiment has been successful in quantifying the benefits provided by the JFS prototype in particular with regards to the reduction of human errors, improvement of operators' confidence (in own situation awareness as well as in the system), and improvement of the information management (clearer information exchange). In addition, feedback from the participants was obtained that indicated avenues to further improve the definition of the JFS project requirements. All these results have been of great value to the JFS management team and indicate promising avenues for better integration of the all resources involved within the JFS process to ensure an agile and effective JFS organization.

Since the completion of the JFS HF1 experiment, other activities have been accomplished. A JFS Human Factor 2 (HF2) experiment was performed in December 2009. The HF2 experiment considered a broader experiment audience than HF1. An intelligence cell; Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) cell; a Judge Advisory Group (JAG) officer, and, a J2 and J3 Ops officer also participated in the experiment. Furthermore, the required tasks were extended beyond the response to calls for fire support and execution of high priority targets and time sensitive targets to include target development. This experiment provided further inputs with regard to the benefits provided by a Joint Common Operating Picture and a Task Coordination tool. At the moment of writing this paper, the analysis of the data from the JFS HF2 experiment was still underway.

Another experiment is scheduled for May 2010 and will scrutinize more closely the requirements for airspace management. Tools and processes supporting a more dynamic airspace clearance and air assets coordination will be assessed.

Even though the JFS experiments have provided useful feedback on tools and processes, the most important benefit from these experiments lie somewhere else: the series of Joint Fire Support experiments has provided a unique opportunity for bringing together military operators, engineers and defence scientists to collaborate on solving current military issues and learning from each other.

References

[1] Joint Fires Support Project Team. *Joint Fires Support TDP Overview*. Draft Version 0.4, January 2008.

[2] D. Allen, N. Abdellaoui, J. Archibald, W. Fraser and K. Wheaton. *Integrated Joint Fires Coordination Experiment – Initial Report*. DRDC CORA TM 2008-045 October 2008.

[3] A. Soller. *Computational Analysis of Knowledge Sharing in Collaborative Distance Learning*. Doctoral Dissertation, University of Pittsburgh, PA, 2002.

[4] N. Webb. *Interaction in Cooperative Groups: The Theoretical Anatomy of Group Learning*. R. Hertz-Lazarowitz and N. Miller (Eds.), p. 105, Cambridge University Press, 1992.

[5] Endsley, M. R. *Situation awareness global assessment technique (SAGAT)*. In Proceedings of the National Aerospace Engineering Conference (NAECON), Vol. 3, pp.789-795. (New York: IEEE) 1988.

[6] Endsley, M. R. *Theoretical underpinnings of situation awareness: A critical review*. In M. R. Endsley & D. J. Garland (Eds.), Situation Awareness Analysis and Measurement, pp. 3-32 (Mahwah, NJ: Erlbaum) 2000.

[7] Lichacz, F. M. J. & Farrell, P. S. E. *Situation awareness and the calibration of confidence within a multi-national operational net assessment*. Military Psychology, 17, pp.247-268, 2005.

[8] Lee, J. D. *Measuring driver adaptation to in-vehicle information systems: Dissociation of subjective and objective situation awareness measures*. In Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting, Houston TX, pp. 992-996 (Santa Monica, CA: The Human Factors and Ergonomics Society), September-October 1999.

[9] Thompson, M. M., Naccarato, M. E., Parker, K. C. H., and Moskowitz, G. B. *The personal need for structure and personal fear of invalidity measures: Historical perspectives, current applications, and future directions*. In G. B. Moskowitz (Ed.), Cognitive Social Psychology: On the tenure and future of social cognition. Erlbaum, pp. 19-39, 2001.

[10] Lichacz, F. M. J. *Augmenting our understanding of the relationship between situation awareness and confidence using calibration analysis*. Ergonomics, 51, pp.1489-1502, 2008.

[11] Griffin, D. and Tversky, A. *The weighing of evidence and the determinants of confidence*. Cognitive Psychology, 24, 411-435, 1992.

[12] Keren, G. *Calibration and probability judgments: Conceptual and methodological issues*. Acta Psychologica, 77, 217-273, 1991

[13] Adams, M. J., Tenney, Y. J., and Pew, R. W. *Situation awareness and the cognitive management of complex systems*. Human Factors, 37, pp.85-104, 1995.

[14] Canon-Bowers, J. A. and Salas, E. *Cognitive psychology and team training: Shared mental models and team training*. Paper presented at the Fifth Annual Meeting of the Society for Industrial and Organizational Psychology, Miami, FL., April 1990.

[15] Artman, H. *Team situation assessment and information distribution*. Ergonomics, 43, 1111-1128, 2000.

[16] Leone, C., Wallace, H. M., & Modglin, K. *The need for closure and the need for structure: Interrelationships, correlates, and outcomes*. The Journal of Psychology, 133, 553-562, 1999.

[17] Neuberg, S. & Newsom, J. Y. *Personal need for structure: Individual differences in the desire for simple structure*. Journal of Personality and Social Psychology, 65, 113-131, 1993.

[18] Baranski, J. V. and Petrusic, W, M. *Probing the locus of confidence judgments: Experiments on the time to determine confidence*. Journal of Experimental Psychology: Human Perception and Performance, 24, 929-945.