

# The need for intelligent change alerting in complex monitoring and control systems.

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## Abstract

As the use of networked information processing tools has grown in battlefield systems, it has had the unintended consequence of increasing and complicating the workloads of leaders and battle staffs. Networking enables continuous plan revision and dissemination in response to new information. New information has to be gathered not only from one's eyes on the external world, but also from digital information systems. In the future this will include information sent from unmanned robotic entities. Current digital systems display information, with the expectation that operators will notice important changes in the display; however, research on human perception and attention suggests that change detection is not reliable in a multi-tasking environment. Operators require assistance in the form of data logging and alerting. With reference to ongoing research in this area, we recommend several properties that an intelligent change alerting system ought to include: (1) a set of default alerts based on expert rules, (2) menu-based alert creation and editing, (3) change database (log of changes) that can be sorted and searched, (4) automatic linkage between related pieces of information (5) selectable alerting mode (e.g., pop-up window vs. auditory alert.), (6) intrusiveness filters, and (7) logging of user reactions to alerts (to provide data for training and further system refinement). In order for an intelligent alerting system to possess these properties, it must be able to tap into the digital data stream flowing on the network. Designers need to ensure that the data required for operator assistance tools is available to be captured, and that such tools are essential integral components of future monitoring and control systems.

## Army Transformation

The US Army is undergoing major transformation. The use of networked information processing tools is proliferating. In the future, semi-autonomous unmanned robotic entities will be controlled by these systems (The Objective Force Task Force, 2002). Networking has already had the unintended consequence of increasing and complicating the observation workloads of leaders and battle staffs, and continued transformation will exacerbate the situation. Visual contact with subordinates will no longer be necessary to remain aware of their positions, forces will spread out, and each unit

will be responsible for controlling a greater area of terrain (Dudley, et al. 2001).

Leaders in this networked environment must monitor a growing variety of data regarding changes in unit plans and other aspects of the tactical situation. The planning process never stops in networked units (Lynch, 2000), because networking enables battle staffs to revise and disseminate plans in response to new information. Commander's Critical Information Requirements (CCIRs) are specified in an initial mission plan. Fulfillment of one or more of these requirements is typically linked to a decision point. As the mission unfolds, however, and new or more detailed information comes to light, both the plan and the CCIRs change. Because everything is much more dynamic, networked units are having trouble keeping track of what the current CCIRs are and when one has been fulfilled. Consequently the full potential of the digital systems to aid in critical and timely decisions is not being realized.

All leaders must keep track of the tactical situation depicted by situational awareness displays. This includes the presence and location of friendly, enemy, and neutral elements and the currency of this information, as coded by icon representations. In the case of unit leaders and vehicle commanders the time available to view displays is limited because, currently, they are expected to keep their heads out the hatch of their vehicles, to observe the situation, and report their observations up the chain of command. As the transformation process continues and robotic systems play roles in observation, unit leaders are likely to be responsible for interpreting sensor data (rather than data collected with their own eyes) and reporting to higher headquarters. It is likely that leaders will also be required to control the movement of the robotic systems.

## Change Blindness

Most current digital systems used for monitoring provide operators with information that must first be perceived, then understood (what is the significance of what I have just perceived?), and then acted upon (now that I understand what is going on, do I need to take any action?). But often, what really needs to be perceived is not explicitly represented. In particular, changes and

relationships are not well represented Operator interfaces display the states of multiple entities; but the job of detecting a change in entity status or a relationship between individual entities requires some mental operation by the operator. As the amount of information displayed increases, however, people become increasingly poor at detecting changes (Durlach, in press).

When monitoring a visual display for a single change, change detection is typically good because the change causes visual transients that automatically draw attention to the location of the change (Rensink, 2002). However, anything that interferes with the perception of those visual transients also interferes with detection of the change (Rensink, 2002). Interference can be caused by an eye blink, a screen flash or a window relocation. Any distraction that competes with attention to the location of the change decreases the probability that the change will be detected. This failure to detect unobvious visual changes is referred to in the psychological research literature as change blindness.

We have documented that change blindness does occur in digital military systems already in use. We conducted a study using the system FCB2 (Force XXI Battle Command, Brigade, and Below), which is a fielded command and control system that can be used in individual vehicles or in tactical operations centers. It includes a situation awareness (SA) map on which icons representing friendly and enemy assets are located. On the right hand, are task buttons allowing the users to conduct system tasks, such as send messages, keep records, or perform terrain analysis. When one of these buttons is pressed, a window or series of windows appears superimposed on the map. The user must supply requested information in these windows in order to perform the desired task.

To assess change detection using this system, we asked people to monitor the screen and report whenever they detected an icon change (for full details, see Durlach and Chen, 2003). No more than 2 icons ever appeared on the map at a time. Under these simple conditions, on average, people detected over 90% of icon changes, such as changes in location. We were more interested, however, in the effect that performing one of the system tasks had on detecting an icon change. To investigate this, we arranged that some of the icon changes occurred at exactly the same time that a systems task was completed. Figure 1 gives a schematic version of what such a change looked like for the observer from one moment to the next (either with a task window open, as on the left, or not, as on the right). On these “distractor” trials, change detection dropped to less than 50%. That is, about half the time, the change was not reported at all. We attribute this change blindness to the visual transients caused by the window closing. These competed for attention with the transients caused by the icon move. In this study, there were only 2 icons on the screen. We expect change blindness to be

even more dramatic in a more tactically realistic situation, with many more icons and sources of distraction.

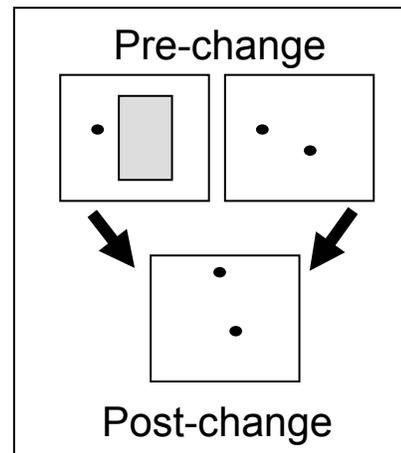


Figure 1. Schematic illustration of an icon position change with a distractor before the change (left) or without a distractor. Probability of observers detecting the position change was only about .5 when there was a distractor present, compared to about .9 when there was no distractor.

## Change Logs and Alert Systems

What could we do to assist the operator in detecting changes? Instead of requiring the operator to notice changes, changes could be explicitly represented. But then the question becomes, what is the best way to represent them to aid the user? One approach would be to log all changes, and provide the ability of the user to inspect the log for change information. This was the approach taken in the initial design of a prototype Future Force Command and Control station in a project managed by DARPA (Defense Advanced Research Projects Agency; see Lickteig, Sanders, Durlach, Lussier, Carnahan, and Sauer, 2003). Four operators employed the prototype system to conduct a simulated deliberate attack mission. Their robotic assets included 13 simulated unmanned air and ground moveable platforms, plus a collection of immobile ground sensors. Any status changes to semi-autonomous entities were logged in a table called the Battlefield Assistant. (BA). During the course of experimenting with the system it became clear from operator feedback that this logging system was inadequate. Users were overwhelmed by the amount of information in the log. It required too much searching to find the information being sought. At a minimum, operators wanted some way to organize the BA information that would facilitate their information search. They also wanted the information ranked somehow, according to importance. For particular critical changes, they wanted explicit alerts. However, the 4 different duty positions did not necessarily want the same events alerted.

The designers evolved a system in which changes were still logged in the BA; however, several advanced features were added. Entries in the BA were organized into categories. There were 5 predefined categories, which appeared under different tabs: geospatial, effects, search, system, time. But users could also define their own tabs. Acknowledged alerts were sent to an acknowledged tab, to reduce the number of entries to be searched under each of the other tabs.

Each operator was able to design their own alerts, using a menu-based alert editing system. Moreover, for each customized alert, the method of notification could be selected. Options were pop-up window, computer-generated voice alert, or BA entry only. Alerts could be customized either pre-mission during planning, or during the actual mission itself. Alerts could be rather general: Any FRIEND enters Named Area of Interest-Alpha. Or they could be quite specific: DARYA-1 or DARYA-2 or DARYA-3 in sensor range of UAV-1.

The alerting system that emerged from this project was an improvement on simply logging all status changes. However, there is room for further refinement. On average, operators had over 2000 entries in their BAs after a 90 minute simulation run. Despite the organization of information into tabs, users still could not cope with this many entries. A better way of finding the critical piece of information is needed. The difficulty with accomplishing this is knowing ahead of time what the critical information will be, so that an alerting system can make that information stand out. The person setting the alerts needs to have a good appreciation of what they are going to want to know; but in a dynamic situation, this is not always possible ahead of time. The operators in these experiments were quite experienced leaders, sophisticated in command and control, and yet they still had some difficulty in anticipating the information that warranted alerts. Less experienced operators would likely have even more difficulty.

There are some situations that will always be of importance (e.g., a friendly force has entered your kill zone); these could be alerted by default. The U.S. Army has developed alerts within a variety of digital Command, Control, and Communications (C3) systems. For example, FBCB2 will alert a vehicle commander when his/her vehicle comes within 500 meters of a minefield. However, each digital C3 system has its own unique features in terms of the capability it gives users to control alerts. A Phase II Small Business Innovation Research (SBIR) project funded by the Office of the Secretary of Defense, and performed by FSCX, Inc., applies an approach that will enable a common alerting interface across different C3 systems. The product called System to Help Identify and Empower Leader Decisions (SHIELD) evolved from the domain of automated after action review (AAR) systems. These systems use rule sets to continually analyze the data stream from collective

training exercises and periodically create AAR aids illustrating significant aspects of unit performance for immediate use at the end of exercises (Morrison and Meliza, 1999).

SHIELD prepares aids in mid exercise analyzing the digital data stream among vehicular and tactical operations center-based digital systems. FSCX, Inc. has succeeded in demonstrating SHIELD working as a stand alone system and as an application running on FCBC2 hardware at the same time as FBCB2 is running. For example, SHIELD provides an alert when a unit violates a boundary, entering the area of operations of another friendly unit, creating the potential for fratricides. The alert can be provided to the battle staff, to the commander of the unit violating the boundary, and/or to the commander of the unit whose sector has been violated, using the same software.

The concept is to provide a collection of expert rule sets, which a leader can select as deemed appropriate to the mission (e.g., rules for fratricide prevention). But all alerts produce pop-up windows, so there is a danger that the alerts could become too intrusive. To prevent this, an intrusiveness filter has been provided, allowing the operator to filter out alerts under various conditions (e.g., don't alert me if I already have 3 alerts on the screen). SHIELD also supports and records a variety of user reactions to alerts (i.e., have an alert disappear for a few minutes, have an alert disappear for the remainder of the mission, call up recommended courses of action, and/or address the situation causing the alert). The SHIELD system is still under development; and so we don't have user feedback data to report. The system does have the potential to be a valuable alerting, training, and decision aid system. Because of its data capture capabilities -- it logs all alerts plus operator reaction to alerts -- it can be used as a research environment to produce the data required for its own further refinement.

## **Dealing with Changing Information Requirements**

To recap the discussion: people monitoring multiple processes or streams of information need help detecting changes. For some situations, alerts could be set by default. These could be supplemented by the use of an alert editing tool. Editing should be possible during mission planning or on the fly, as the mission unfolds. The appropriateness of customized alerts will be as good as the operator's ability to anticipate the critical conditions that warrant alerting. The problem is that operators can not always anticipate the information they are going to want. As a dynamic situation unfolds, the type of information required often becomes more specific than that which could be anticipated ahead of time. New information requirements arise, and old ones become

irrelevant. This is why preset alerts alone are not sufficient. We saw in discussion of the DARPA experiment that change logging added to alerting; but was not sufficient. There was too much information to sort through in the log. To be of benefit, the log has to take the form of a searchable database, in which information can be retrieved in flexible ways.

The advantage of logging changes as a searchable database was demonstrated in a study conducted in the context of naval airspace monitoring. Divita and Nugent (2000) had demonstrated change blindness in this context, and subsequently, Smallman and St. John (2003) developed and evaluated a change detection tool (CHEX, for Change History Explicit), to assist operators. Observers watched a SA map displaying airspace activity, and were to detect and identify aircraft that became critical (posed a potential threat) during a dynamic air warfare scenario. When CHEX was in use, all airspace changes were logged in a (continuously viewable) table. The table could be flexibly sorted (by change significance, change type, change recency, or aircraft ID). If the operator highlighted a table entry, this automatically highlighted the relevant aircraft icon on the SA map. Conversely, selecting an icon on the map automatically highlighted table entries relevant to that aircraft. The study showed that detecting important aircraft changes was both more accurate and more timely when CHEX was available, than when it was not. Moreover, CHEX assisted in recovering SA after an interruption. Observers equipped with CHEX also did better than observers given only a static chronological log of all changes. Smallman and St. John (2003) attribute the benefits of CHEX to (1) the ability to sort the table according to different criteria, so as to match the strategy of the operator and (2) the automatic linking and highlighting between the table of changes and the SA map, when aircraft in either were selected.

Combining both of these attributes with a change logger, plus an alert editing tool could greatly improve an operator's ability to cope with the control of multiple semi-autonomous systems. Allowing operators to sort information according to situation-relevant criteria (instead of predetermined criteria) helps them deal with unanticipated situations. A "Find" ability might also be of benefit. The automatic linking of table and map information would also be beneficial, allowing the immediate geographical location of relevant platforms and their relationship to other entities.

## Recommendations

The elements we suggest an intelligent change detection tool should have include: (1) a set of default alerts based on expert rules, (2) menu-based alert editing both during mission planning and execution, (3) change database (log of changes) that can be sorted and searched,

(4) automatic linkage between different pieces of information for the same entity, e.g., when an item in the change log is selected, the relevant icon on the SA map is highlighted at the same time, and conversely, (5) selectable alerting mode for each alert (e.g., pop-up window vs. voice alert, etc.), (6) intrusiveness filters, and (7) logging of user reactions to alerts (to provide data for AAR and further system refinement).

In order for an intelligent change detection system to function as we suggest, it must be able to tap into the digital data stream containing the information pertaining to satisfying alert conditions. It cannot function if the data necessary to support the system cannot be captured. Moreover, the way the data are packaged influence how readily it can be utilized. If data are published across the network in a format unfriendly to the change detection system, an additional step of data reconstruction and deduction will be required. All too often, tools to assist or train the human-in-the-loop are design afterthoughts. Their construction and operation is hampered by lack of forethought regarding the data such aids will require (Meliza and Brown, 1997). We have reached a point where we know we will need training aids, change detection aids, and decision aids in systems intended to control multiple semi-autonomous systems. Therefore, these aids need to stop being engineering afterthoughts. They need to be integral system components whose design and data requirements are taken into consideration upfront.

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