Abstract – Understanding the concept of employment (COE) for Information Fusion or other analysis/decision-aiding technology is key to the evaluation of its effectiveness; this paper studies and characterizes the COE for Counterinsurgency applications as drawn from open literature and some interchanges with U.S. Army staff. Managing and executing Counterinsurgency (COIN) situations is complicated business. Collectively, the broad elements of the decision-action space can be broken into “direct” and “indirect” classes of actions, where direct actions are those focused on insurgent force structure in the traditional military sense, and indirect actions those focused on undermining support to the insurgents while simultaneously attacking them militarily. Invoking military doctrine dating from the ideas of a French general in the 1800’s, the US Army has developed a response framework involving various “Lines of Effort” and the notions of Effects-Based Operations to achieve behavioral changes in insurgents as Desired Effects as regards the indirect operations. By and large the situation management framework requires consideration of notions of Complex Adaptive Systems; the paper will make remarks about this SIMA-CAS context. Intelligence support to this Operational Doctrine requires capabilities in Hard and Soft Fusion technology, methods of Influence Networks, Petri Nets, Sequential Decision Making under Extreme Uncertainty, and Model Predictive Control, among other technologies. This paper will provide an overview of the concepts of the operational doctrine itself and the employment of these technologies in this modern-day military operational doctrine for the Counterinsurgency domain.

Keywords: Situation Management, Operational Concept, Effects Based Operations, Decision Making

1 Introduction: Operational Art in Counterinsurgency

The motivation for the study reported on here was actually from an Information Fusion (IF) technology viewpoint. Most would agree that IF is an estimation process intended to provide support to humans conducting analysis or decision-making, such as in Situation Management scenarios. The value of such estimates, at the effectiveness (vs performance) level, will thus be gauged on the basis of how IF-developed estimates aid in the effectiveness of the subsequent analyses or decisions chosen. That is, the effectiveness-based “value argument” for IF technology requires understanding how the IF products are employed in the concept of operations. In our IF research projects for the U.S. Army (see Acknowledgement), our problem domain is Counterinsurgency or “COIN”, and so in planning for test and evaluation of our nominated IF techniques for COIN, we needed to understand how Army decision-makers operate in the COIN environment; this work reports on our initial findings, based on both open-source literature and some discussions with Army scientists and operators.

Insurgency is defined in US Joint Publication 1-02 [1] as “an organized movement aimed at the overthrow of a constituted government through use of subversion and armed conflict”. This definition as a movement sets it apart from both guerilla warfare and terrorism, as they are both methods available to pursue the goals of the political movement; insurgencies do however typically employ violent means toward their ends but those means could, by explicit choice, exclude terrorism. The ultimate goal of an insurgency is to challenge the existing government for control of all or a portion of its territory, or force political concessions in sharing political power. There are many flavors of insurgencies and all have several organizational components, varying dynamics, and various strategies (see [2]). The action space for COIN involves all political, economic, military, paramilitary, psychological, and civic actions that can be taken by a government to defeat an insurgency [1]. It can be seen immediately from this definition that both the understanding of a current situation and its various elements, and the space of possible decisions and actions both have a much larger dimensionality than traditional military decision-making in force-on-force operations.
Collectively, the broad elements of this action space can be broken into “direct” and “indirect” classes of actions, where direct actions are those focused on insurgent force structure in the traditional military sense, and indirect actions those focused on undermining support to the insurgents while simultaneously attacking them militarily. Another way to look at these distinctions is from the viewpoint of theories of war and action, and in particular the notion of “lines of operation”, a principle of war put forward by the famous war theorist Antoine-Henri Jomini, who was a French and later Russian general [3]. Jomini asserted that there were natural lines of operation—in his day these were largely topographically based, such as rivers and mountains but he also allowed for man-made entities such as fortifications and military bases. Alternately, other lines of operation were those concerned exclusively with strategic choice about where to fight, to what purpose, and with what proportional force, etc. These principles seem present in the modern U.S. Army Field Manual literature, for example in [2] where there is a discussion about “Lines of Effort (LOE)”. Quoting from [2] regarding LOE:

“Commanders use LOEs to visualize, describe, and direct operations when positional reference to enemy forces has little relevance, such as an insurgency. FM 3-0 [4] defines a line of effort as a line that links multiple tasks and missions using the logic of purpose—cause and effect—to focus efforts toward establishing operational and strategic conditions. A plan based on LOEs unifies the efforts of all actors participating in a counterinsurgency toward a common purpose. Each LOE represents a conceptual category along which the COIN force commander intends to attack the insurgent strategy and tactics. LOEs are closely related and are not sequential in nature. Successful achievement of the end state requires careful coordination of actions undertaken along all LOEs. Figure 1 below shows example COIN LOEs [4]. The figure also shows how the LOEs try to gain the support of the population to reach the end state.”

Many of the purposeful thrusts in LOE’s in COIN operations can also be related to the notions of “Soft Power”, this phrase coined by Joseph Nye of Harvard University in [5] and in [6]. Soft power relates to the notion of the power of attraction, where influential effects are created by an actor/organization by behaviors that attract insurgents to exhibit desired behaviors. The overall process begins with a Commander specifying his Desired Effects within his specific Line or Lines of Effort. The Desired Effects are a specified end-state to be strived for via the best Course of Action possible. However, the starting point is often to be determined and revolves about Priority Information Requirements or PIR’s. PIRs are nominated by the Intelligence Cell Team and approved by the Commander, and then integrated into an ISR Synchronization Plan (e.g. Tasking and Collection as discussed above). There are also PIR Running Estimates that track the progress in completion of the process of satisfying PIR requirements. In a Brigade Combat Team (BCT) there are “n” Line of Effort Chiefs that are trying to synchronize and integrate the various intel and operations efforts toward achieving progress on each LOE. Effective ISR collection will provide the necessary information to satisfy PIRs and form the basis for Situational Awareness and Sensemaking of the current situation that together with the specified Desired Effects frame the starting and end points of the decision-making, action-taking Situational Management process.

1.1 Effects-based Operations (EBO)

It can also be argued that the End States of any LOE are “Effects” created by the sequence of actions (the “Course of Action”, discussed later) “along” the LOE. Our research on Effects Based Operations (EBO), not a new term but interestingly actively revisited for the COIN problem (e.g. [7]), shows that many references suggest that EBO is a viable concept for COIN, in part because effects are soft-type results, and subsume behavioral end-states, reflecting a human focus. One simple taxonomy of Effects is shown in Figure 2 below (from [8]), a main distinction being “Physical” vs “Behavioral”, which could be equated to “Kinetic” vs “Non-kinetic”.

Figure 1 Lines of Effort for COIN Operations (Stability Operations); from [4]

Figure 2 Sample Taxonomy of Effects (from [8])
Achieving effects is also inevitably about orchestration, about developing synergies that result in effects greater than those that are additive, and thus they are a natural partner to the notion of LOE’s, which require considerable orchestration. Synchronization is key to the notion of EBO; the basic description of effects-based operations is in fact as “coordinated sets of actions directed at shaping the behavior of friend, foe and neutral in peace, crisis, and war” [8]. EBO concepts do not suggest that individual actions create deterministic effects in a straightforward, if-then-then- that, cause-and- effect relationship, but through the use of multiple interdependent actions. Further, EBO does not look to a single effect as the outcome but rather to the actions shaping a behavioral end-state, very similar thinking to the above discussion on LOE end-states. This is to say that it sees both a process and an end-state that are neither precise nor solely the products of the actions we ourselves take. The main causes of the uncertainties in this complex system are the presence of a large number of interdependent variables, each of which will affect the other variables in the system via complex interdependency relationships, many of which can be non-linear.

It will be seen that achieving the “Desired Effects” or the ultimate effects-based goal of a commander, is the result of a sequence of actions and that when taking a particular action that there may be levels of effects (first-order, second-order, etc.). Also, it is clear that there is a notion of degree of any effect created, so the commander should also specify some type of measure or metric by which accomplishment of the effect can be gauged. In turn, it is likely that the computation of any such measures or metrics will depend on observables from the field, in a process not unlike Battle Damage Assessment, and requiring synchronized ISR to obtain the needed observables to measure EBO progress (all this part of the Situation management process). As pointed out by [9], some of these observables will fall into the conventional observable domain such as derived from imagery, whereas the achievement of behavioral and other soft, subtle effects will need to come from indirect and intelligence type observables, that is, what has come to be called Soft Data (a focal point of our Army research).

1.2 Course of Action Development in EBO

The development of an interlinked Course of Action (COA) to create these behavioral, non-kinetic Effects as end-states is very difficult and involves a web of interdependencies that make EBO a process involving notions of Complex Adaptive Systems (CAS). Smith [10] elaborates on this in various ways, and this CAS notion is also discussed in [11] that emphasizes the non-deterministic aspect of any Course of Action producing an intended Effect. Smith [10] has an extended development of the Effects-Based approach for asymmetric operations, and in consideration of what Smith calls an action-reaction cycle model (sensibly equivalent to Situation Management) puts forward the process depicted in Figure 3 that specifically shows the influences of understanding the Social Domain as part of the “Sensemaking” process that ultimately drives the COA development.

Smith argues that what is important are the variables that might influence how particular socio-culturally-based observers or groups of observers will perceive, understand, and make sense of a situation, and view their options for response. He argues that this distinction is critical for effects-based operations because the key to deciding which actions might shape behavior in a specific way is understanding how particular groups and particular cultures might react differently to a given stimulus. A very important notion (see [12]) is that the COA development process starts with a projected “Plausible Future” state so that actions are taken not necessarily on the basis of the current situation but one that is expected to exist at the time actions are taken on it, ie so that the state and actions are as synchronous as possible.

Upon developing and ranking Anticipated or Plausible Futures, a Decision-Maker (DM) would develop some alternative Options for a Course of Action (COA), which we treat as synonymous to a Line of Effort. That is, the COA/LOE are both, importantly, a sequence of actions toward achieving the desired end-state or Desired Effect, DE. Darr et al [13] provide an ontological definition of a COA in which a COA has activities within phases, with
those activities oriented toward specific outcomes, and where the activities should have some MOPs by which they can be measured, and the outcomes some MOE’s which allow their measurement in turn. Figure 4 shows the idea.

Not explicit in Fig 4 but crucial to the definition of a COA are the specifics of activity or action timing. Note too that good COA’s will also be bounded by various constraints such as minimal collateral damage or exclusion zones, etc.

2 Technologies in LOE/EBO/COA Operations

2.1 Influence Networks

As noted here, the COA is (or can be) a rather complex network of interdependent actions and their consequences or effects. In thinking about these ideas it is clearly desirable that some efficient tools exist that allow a COA-planner/decision-maker to at least represent these interactions. One of the tools that has come to be used quite extensively in this application is the Influence Network (see [14]). As best as can be determined, Inference Nets have a history back to what were known as Path Diagrams [15] in the 1920’s; the earliest more modern reference seems to be that of Howard and Matheson [16] who put the first coordinated thoughts together on the Influence Network idea. Pearl [17] has an interesting historical and personal perspective on the evolution of Influence Diagrams. Influence Networks have a particular appeal to the modeling of the softer notion of “effects” in the COIN and socio-cultural application setting.

In an Influence Net (basically a graph, with directed nodes and arcs), the nodes of the graphical network represent hypotheses or propositions and the arcs represent direct dependency relationships between the hypotheses. Conditional probabilities, often subjectively asserted by Subject Matter experts (SME’s) are associated with the nodes of the net that encode the strengths of the dependencies. Algorithms and tools have been developed that efficiently compute new values of all the variables whenever any variable value is specified. Influence Nets and Bayesian Nets have many similarities and also some differences. Influence Nets are Directed Acyclic Graphs (DAGs) where nodes in the graph represent random variables, while the edges between pairs of variables represent causal relationships. Researchers at George Mason University (where extensive funded research on IN’s has occurred for military applications), have avoided the typical BN problems of scalability and knowledge elicitation in the application of Influence Nets by using a technique called Causal Strength or CAST (see [18, 19]). CAST builds upon the so-called “Noisy-OR” concept in BN development which assumes that all causes of an effect are independent of each other, that each cause is capable, by itself, of causing the effect, and that this capability is not affected by the presence or absence of other active causes. This limitation means that it is not possible to capture such causal notions as synergy among causes, interference, necessity, and the like, but such thinking often mirrors the way humans think of dependencies.

As has been remarked previously, timing of actions is very important, and Timed Influence nets (TIN’s) have been developed to model the temporal aspects of COA’s/LOE’s. COA selection is thus the result of a tradeoff/analysis process where different action and action-timing strategies are explored and evaluated. This may include the use of various tools that aid in the nomination process such as described in [20] but in general leads to a process as shown in Fig 5 (from [21]):

Figure 5 . COA Nomination and Tradeoff Process (from [21])

Note that tools such as TINs can also be used to monitor the real-time evolution of a COA, by having the actions inserted into the model as they really occur, and examining the effects of variations in actual vs planned action times, delays, effect persistence, etc. A further extension of the TIN concept is to incorporate stochastic temporal effects such as delays, leading to the Stochastic TIN idea as discussed in [22]. Still further extensions of the TIN idea are in [23] that addresses the important aspect of socio-cultural influences on a COA prototype.

Naturally, the TINs can become quite complex as these additional factors are considered; the example of [23] is shown in Fig 6.

Figure 6 . TIN with Socio-cultural Influences Accounted (from [23])

DARPA has also studied these exact type problems on a program initially called Integrated Battle Command and then named as Conflict Modeling, Planning and Outcomes
Experimentation Program (COMPOEX) (see[24]). Figure 7 below shows the LOE-based construct this program addresses, emphasizing the interdependencies among LOE-specific Actions and Effects.

![Figure 7: Notion of a Campaign Plan Employing Multiple LOEs showing Interdependencies (from [25])](image)

As pointed out in [24], no known tools support the type of complex modeling that is required to fully support Campaign Plan operations in irregular and COIN type environments; what is needed is a family of models.

2.2 Sequential Decision Making Under Uncertainty

As has been described, the TINs and chosen COAs represent sequences of timed actions as projected by the best modeling that can be done. Of course in the military domain the world is non-cooperative and involves intelligent adversaries, and of course there will be errors in models and various unknowable effects that ultimately create a COA evolution that is not as predicted. This means that the TIN modeling process will be recursive and iterative, with the models and COA action choices being done as time progresses, in effect imputing a sequential decision-making requirement onto the COA/LOE process. Sequential decision making, a.k.a dynamic decision making, is characterized by three common features: A series of actions must be taken over time to achieve some overall goal; the actions are interdependent so that later decisions depend on earlier actions; and the environment changes both spontaneously and as a consequence of earlier actions [26].

There are many subtleties involved in dynamic/sequential decision making (DDM/SDM). Russel and Norvig [27] have a good list of factors that influence the nature of a DDM/SDM problem, summarized here in Table 1:

<table>
<thead>
<tr>
<th>Factor</th>
<th>COIN/irregular Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finite vs Continuous Situational States</td>
<td>Generally continuous, unbounded states; possible to discretize but still an added complexity</td>
</tr>
<tr>
<td>Finite vs Continuous Action States</td>
<td>Closer to continuous than finite, although resource-limited</td>
</tr>
</tbody>
</table>

2.2.1 Some Remarks on Markov Decision Processes

It is beyond the scope of this paper to discuss the technical details of Markov Decision Processes (MDP) but it is felt that some remarks should be made about them since they seem to dominate much of the literature on DDM/SDM in the sense of modeling, analysis, and implementation. Markov Decision Processes are also known by other names including sequential stochastic optimization, discrete-time stochastic control, and stochastic dynamic programming.

As usual, we assume the Markov Property: the effects of an action taken in a state depend only on that state and not on the prior history. It can be seen that this process model is quite similar to the notion of an Influence Net and that the sequence of actions that would be chosen correspond to a Course of Action in the overall EBO model. While some actions may produce deterministic effects, we usually deal with the stochastic case where there is a transition probability that describes the likelihood of any outcome from an action. At any moment, there is the current state of the world S (the current “situation”), and if we have an approach to define our preferred actions, given the state, this is called a “policy”. The goal of MDP analysis then is to determine an optimal policy as regards rewards. Importantly, in this basic case we assume the state S is observable, ie we can observe and know the effects of any action (or other factors that influence the state). There is also the choice of a planning horizon (time) over which to consider the development of the policy. For some finite horizon, there is also the notion of the discounting of the rewards, with strategies typically...
defining a preference for immediate rewards so that future rewards are discounted. In the stochastic case, the notion of an expected total reward over the horizon can be formed, this expectation usually being called a “value function”. The relation between the value function at the present stage and the one at the following stage is expressed by the “functional equation”. Optimal decisions depending on stage and state are determined backwards step by step as those maximizing the right hand side of the functional equation in a dynamic programming procedure.

Realistically, it can be argued, the transitions from one state to the other as a result of the actions taken do not occur instantaneously as assumed in the traditional MDP model. In “Semi-MDPs”, there is a “holding time” for states to change or effects to take hold, which is an integer-valued stochastic variable described by a transition probability. Further, in various cases the current situation or state may not be directly observable, in which case the model is adjusted to the “Partially Observable MDP or POMDP”. The possible additional complexities of course can go on to include yet other process conditions necessitating further adjustments in the process model.

2.2.2 Second-order Uncertainty and Extreme Uncertainty in Decision-Making

We argue for this topic to be included in our discussion since other research we have conducted shows that in the COIN environment that:

- There are no reliable deductive models of COIN agents and their relational dynamics
- The adversaries are extraordinarily deceptive and agile in their tactics techniques and procedures
- The observational data are very imprecise and for linguistic reports sensibly unable to be calibrated

resulting in higher-than-typical levels of uncertainty in evidential data as well as in the underlying phenomena.

The notion of “Second-Order Uncertainty (SOU)” relates to uncertainty in uncertainty, and is largely if not exclusively related to epistemic or knowledge-based uncertainty (as opposed to “aleatory” uncertainty which deals with the inherent uncertainty in systems and processes). That is, it arises as a result of fragility or weakness in the knowledge being applied to some problem, and is also associated to the process or function of knowledge elicitation from human Subject Matter Experts (SME’s), since it is via such processes that the nature and levels of SOU are determined or discovered. In decision-making (DM), the presence of SOU is known to have an effect on the way DM is carried out and on the nature of the results [28]. From the point of view of probabilistic frameworks, second-order uncertainty is dominated by two representational forms: imprecise probabilities (IP) and second-order probabilities. Almost all the research on SOU/IP is Bayesian-framed and the computational challenge for a decision-aiding capability is to estimate posteriori probabilities for states of interest, which brings up the challenge of propagation techniques for both second-order probabilities and probability intervals, another way to express the second-order uncertainty. This is a field still in development and still facing computational and implementation challenges. A flavor for the field can be obtained by reviewing the “SIPTA” (Society for Imprecise Probability; Theory and Application) conference proceedings.

Regarding extreme uncertainty, our literature search shows some interesting results:

- There is no clear taxonomy nor formalization of such terms as—severe, deep, complete, and other adjectives descriptive of “high” states of uncertainty, necessary for establishing clear understanding and bounds of these possibly different domains
- Most of the literature is from the economics domain; interestingly we could not find any literature related to military applications.

2.3 Model Predictive Control

This type of stepwise or what could be called an evolutionary decision-making model can also be seen in the control theory literature. Model Predictive Control, MPC, is a form of control in which the current control action is obtained by solving on-line, at each sampling instant, a finite horizon open-loop optimal control problem, using the current state of the “plant” or process as the initial state; the optimization yields an optimal control sequence and the first control in this sequence is applied to the plant; see Fig 8. Control action adjustments are made at each time step, adjusting to the current state. This is also described as a receding-horizon or moving horizon approach to optimal control, where there is a “plant” or process model—eg this could be the TIN for a particular COA—that allows the determination of a “tracking error”, namely the difference between the predicted output and the desired reference (TIN model), is minimized over a future horizon, possibly subject to constraints on the manipulated inputs and outputs, here the planned actions.

![Figure 8. Concept of Model Predictive Control](image)

In implementing MPC, at time t only the first input of the optimal command sequence is actually applied to the “plant”; the remaining optimal inputs are discarded, and a
new optimal control problem is solved at time \( t + 1 \). In the COA case, only the best current action to take is taken at time \( t \), and the next cycle of the COA problem or TIN model process is then addressed. Evolutionary methods such as MPC have been studied for EBO COA applications; see [29], [11] for example. There is of course in all this the theoretical and the pragmatic; but what seems to be agreed to is the need for careful orchestration of actions and operations—an example of a real-world application is discussed in [30] regarding real operations in Afghanistan.

### 2.4 Cognitive Aspects of Sequential Decision Making

Although we are interested in employing technology in smart ways to aid sequential decision making, humans are still a main component of the overall man-machine process of optimally executing EBO COAs. Although humans bring important capabilities to the process, they also bring various cognitive deficiencies that system designers need to know about. For example it is well-known that the order in which information is received can affect final judgment, eg [31, 32]. Humans also tend to fuse data in an averaging-type process rather than in a Bayesian way as a result of an anchoring-adjustment way of combining the data, in part influenced by the ordering behavior [33]. Other studies have shown that both primacy and recency effects exist. That is, under certain circumstances what information humans’ process first may have a pronounced effect on their final judgment, and under other circumstances what they process last profoundly affects their final judgment. In a review of order effects in belief updating, Hogarth and Einhorn [31] note that the literature is unclear as to what kind of order effects are most prevalent.

Another effect in human-based decision-making is the so-called “Ellsberg Paradox” that shows that humans are basically ambiguity-averse and prefer definite information to indefinite even though the expected payoff or utility of the alternative decisions are equal [34]. Said another way, humans violate the expected utility framework often modeled for decision-making.

#### 2.4.1 Decision-making in Complex and Novel Environments

Regarding decision-making process models, most literature involving decision-making experiments show that humans are not rational decision-makers, forming and weighing various options; this is usually attributed to most real-world decision-making contexts involving ambiguity, time stress, distractions, etc. Klein has nominated a naturalistic decision-making model where decision makers use past experience to make decisions in field settings, called Recognition-Primed Decision (RPD); see [35]. For those cases where the situations are both complex and entirely novel, Klein recommends novices or decision makers use the systematic rational analytical process. However, as noted above this solution does not apply even with applicable past experience. If rational analytical decision making is too slow for complex situations, it cannot be viable for extremely complex and novel environments or for less experienced personnel. Diaz [36] forms a different model that is a derivative of the RPD that allows for an “exploration” cycle for the novel situation that is not immediately or straightforwardly recognizable; this model is called ExDM, signifying an Exploration of alternative situational interpretations and Exploitation of immediately recognized situations.

### 3 Conclusions

The depiction of Operational Art for COIN shown here is an approximation as it has not been verified with official sources. However, we believe it forms a first model of a concept of employment for “fitting” the Information Fusion process into in order to understand how IF estimates at different levels as well as the formation of plausible future-time estimates interplay with this depiction of COIN decision-making and COA development. It is clear that these processes are complex, incremental, and layered, and requiring temporal adjustments in fusion processes.

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