# SMOKE AND OBSCURANT MODELING IN SUPPORT OF SIMULATION BASED ACQUISITION AND TRAINING

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## ABSTRACT

The U.S. Army Edgewood Chemical Biological Center (ECBC) and its parent command are committed to the implementation of simulation-based acquisition and training techniques. Their value has been demonstrated repeatedly by many organizations and in countless situations representing all aspects of the product life cycle, including combat development, material development, manufacturing, training, and employment. Models and simulations have become practical tools that routinely replace laboratory experiments, field activities, and training exercises while reducing cost and improving safety. They could be particularly effective for smoke and obscurant scenarios, which carry significant environmental clearance costs and additional safety considerations. Numerous models have been developed to simulate smoke and obscurant systems, but most of these have focused on detailed scientific and engineering issues, such as cloud physics and electro-optical performance. Although several attempts have been made to integrate these models into constructive and distributed interactive simulations, no smoke and obscurant model has emerged that supports opertational level activities. This is a significant shortcoming that hampers both training and acquisition. This paper reviews the state of smoke and obscurant models and illustrates how existing simulations have been used to support acquisition and training. It also identifies requirements for operational-level tools and establish a framework for their development.

## 1. MODELING AND SIMULATION TRENDS

Modeling and simulation (M&S) has become an essential technology that is influencing a growing number of mission-critical activities. Organizations within DoD are increasingly using it for operational planning; research, development, and acquisition; test and evaluation; training and mission rehearsal; and, doctrine development. This growth is being fueled by budgetary constraints, environmental concerns, and technological advances, which reduce the cost of complex computer systems while increasing their capabilities.

Historically, most M&S activities have been conducted in vertical stovepipes within application domains (figure 1) and there has been little horizontal integration. The constructive wargames and virtual simulations used for training have seldom been linked, for example, to engineering-level simulations or the physical models they use.

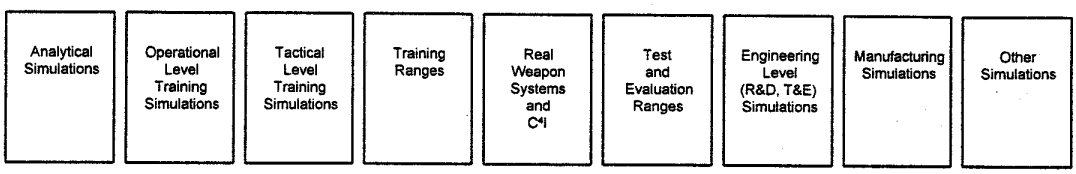


Figure 1. DoD modeling and simulation domains.

The computational burden imposed by high fidelity models has often limited their utility beyond the application domain for which they were developed. This is certainly true for smoke and obscurant models, which have little presence in the preeminent simulation environments. Until recently, horizontal integration was infeasible due to limitations imposed by hardware, software, and design methodologies. This situation is changing, however, as technological developments increase computer system performance, simplify connectivity, reduce cost, improve usability, enhance the development process, and promote software reuse. These factors are reshaping the nature of DoD models and driving a paradigm shift toward a more flexible and efficient simulation environment (figure 2).

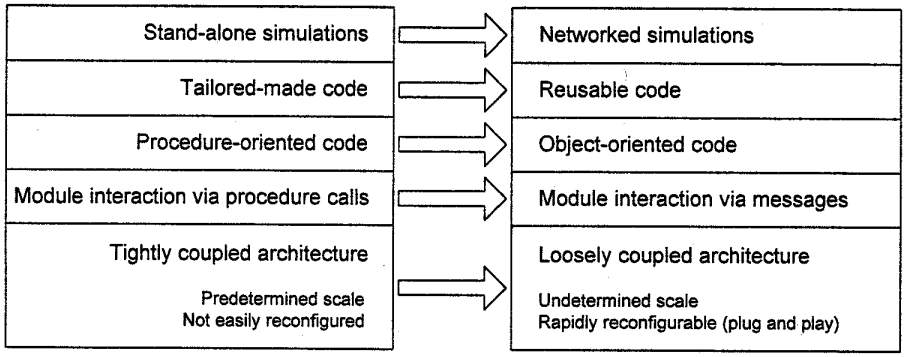


Figure 2. Modeling and simulation trends.

The Defense Modeling and Simulation Office (DMSO) has capitalized on these trends to produce a High Level Architecture (HLA)[1] that unifies all M&S domains under a single technical framework. Future DoD M&S systems will be required to comply with the HLA, which specifies a design philosophy, imposes documentation requirements, and provides a common cross-platform run time infrastructure (RTI). The HLA will facilitate linkages between models and promote software reuse across all M&S domains. We are entering a period where software, that was developed for one specific purpose, can be used without modification in many different applications. This will enable engineering-level, constructive wargames, and virtual simulations to use physical models to increase their fidelity with real world phenomena.

## 2. SMOKE AND OBSCURANT MODELS

Several physical models have been developed to simulate the production, transport, and diffusion of battlefield obscurants and assess their effect on tactical sensors. The U.S. Army Research Laboratory (ARL) has been a major contributor and it maintains two smoke and obscurant models in its Electro-Optical Systems Atmospheric Effects Library[2,3]. GRNADE[4] simulates multiple-round salvos of tube-launched grenades (L8A1 and M76) and is used for

self-screening analysis. The Combined Obscuration Model for Battlefield-Induced Contaminants (COMBIC)[5,6] is more comprehensive and can simulate: high explosive and vehicular dust; phosphorus and hexachloroethane munitions; diesel fuel, oil, and rubber fires; generator-disseminated oils; other screening aerosols, and user-defined sources.

COMBIC has been used in numerous, diverse applications and is arguably the dominant model in this field. It operates on level terrain and only considers a horizontally homogeneous wind (figure 3). These limitations led ARL to develop a derivative model, the Simulation of Aerosol Behavior in Realistic Environments (SABRE)[7], that can use a terrain-dependent wind field. SABRE was an EOSAEL module for some time, but is no longer supported by ARL and has been withdrawn from the library, leaving it without a smoke and obscurant model that handles non-uniform wind and terrain.

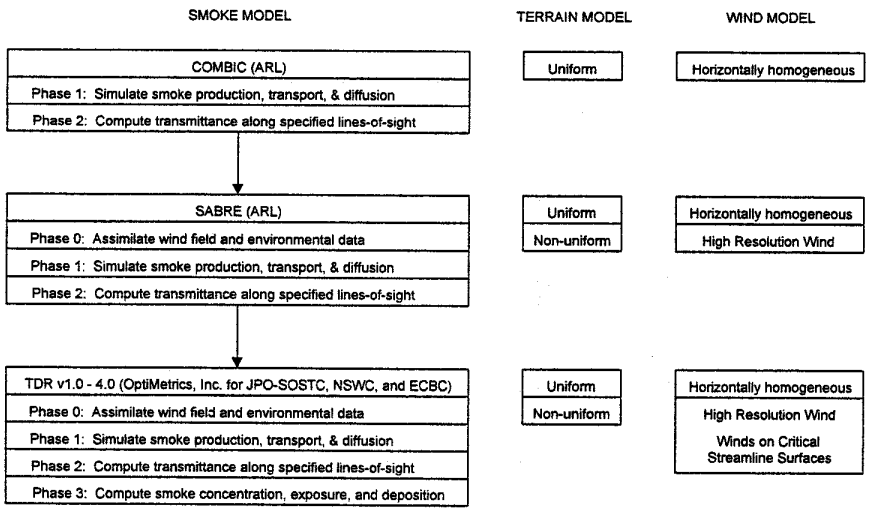


Figure 3. Lineage and primary characteristics of COMBIC and its derivatives.

The Joint Project Office for Smoke, Obscurants, and Special Technologies Counter-measures (JPO-SOSTC), Naval Surface Warfare Center (NSWC), ECBC, and OptiMetrics, Inc. (OMI) have enhanced SABRE to create the Transport, Diffusion, and Radiance (TDR) model[8]. It has been integrated into several applications and can operate in a stand-alone mode on numerous computing platforms.

COMBIC and TDR were originally developed in the mid 1980s to the early 1990s using prevailing techniques. They are large, monolithic programs that are written in FORTRAN using extremely unstructured code. Their software components make extensive use of global variables and are, therefore, highly interdependent. In short, they are not well suited for use in a simulation environment that is increasingly distributed and object-oriented.

Both models describe clouds as a collection of one to five subclouds, which can be either Gaussian puffs or plumes. When a source is activated, subcloud states are computed at discrete downwind distances and the results are saved in a history file. All predictions are made using the atmospheric conditions that existed at the time of source activation. Although this approach is computationally efficient, it is not responsive to changes in atmospheric conditions that might occur during the cloud's lifetime. It also requires a large amount of data to be maintained (and possibly transferred) for subsequent calculations.

Because they were developed several years ago, COMBIC and TDR only simulate sources and obscurants that were available (primarily to U.S. forces) at that time. The models have not been updated significantly to include equipment, munitions, or materials that have been fielded in recent years or are currently under development by the U.S., our allies, and potential adversaries. Both models enable the user to specify source and obscurant characteristics through data inputs, but this requires an intimate knowledge of the material and model properties.

Neither of these programs model vehicles or vehicular components. They have no awareness of specific vehicle types nor the location and orientation of smoke generation equipment on those vehicles. Consequently, COMBIC and TDR could not be used by themselves to examine operational usage where component placement is an issue. This limitation is aggravated by their inability to accept unscripted inputs. The models cannot be used without augmentation to respond to ad hoc smoke events that might be generated randomly, by a constructive wargame under player control, or by networked simulators in a virtual exercise. In addition some deficiencies have been noted in their predictive algorithms. Most notably, COMBIC does not accurately model evaporative losses from disseminated oils as a function of temperature[9]. This affects the predicted quantity of suspended liquid that is actually available for producing screening effects, a critical factor in some applications where oil smokes are employed.

## 3. SMOKE SYSTEM PERFORMANCE MODEL

The Smoke System Performance Model (SSPM)[10] was developed by ECBC and OMI to eliminate many of the limitations noted above. It is a collection of C++ classes that model the essential elements of smoke and obscurant systems. The classes can be integrated with engineering-level models, constructive wargames, and virtual simulations to enhance their ability to simulate battlefield obscuration.

SSPM models relevant items, such as vehicles, components, clouds, obscurant materials, and vehicular grenades. Each class encapsulates the essential technical characteristics of the item it represents, as they relate to smoke and obscurant production, and provides default functionality. The default behaviors vary in sophistication and can be overridden if enhanced functionality is required. The notional default behavior of SSPM clouds can be enhanced by using a smoke and obscurant model, such as COMBIC or TDR, to simulate cloud production, transport, and diffusion. When this is done, SSPM acts as a preprocessor by simulating operations at a higher level and directing the smoke and obscurant models to place clouds with specified characteristics at designated times and places.

SSPM is limited only by the scope of the systems it currently models. The latest version can simulate thirteen vehicles, seven vehicle-launched grenades, vehicle engine exhaust smoke systems, and two smoke generators. It does not yet model smoke pots or artillery, mortar, rocket, and aircraft-delivered obscurants. Only one of the vehicles and one of the grenades are foreign systems.

## 4. ENGINEERING LEVEL MODELS

SSPM has been linked to COMBIC in the Cloud Density Visualization Utility (CDVis)[10], an engineering-level model that presents a graphical representation of simulated clouds (figure 4). CDVis uses SSPM to execute complex obscuration scenarios, COMBIC Phase I to predict cloud histories, and COMBIC Phase II to compute concentration path lengths along specified lines-of-sight. The concentration path lengths or their corresponding transmittance values are then presented as false color images, enabling the user to perceive the clouds in three dimensions as a function of time.

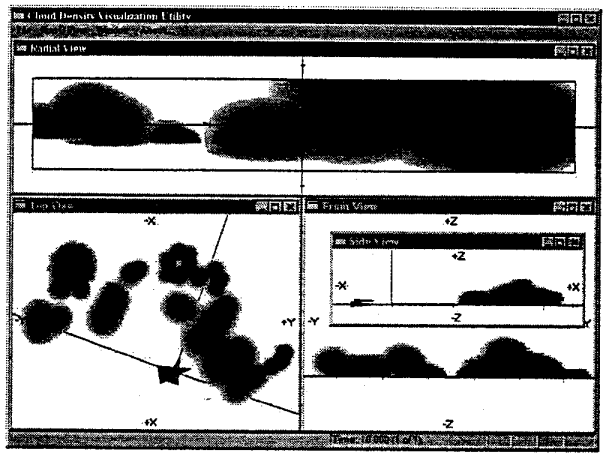

Figure 4. CDVis displaying cloud density images for the front, side, top, and radial views of a simulated obscuration event.

SSPM has also been linked to COMBIC in a battle management system (BMS) for chemical staff officers that will be used to evaluate smoke and obscurant plans (figure 5). The BMS is similar to CDVis in its use of SSPM and COMBIC, but it superimposes a birds eye view of the simulated clouds on a tactical land map. The BMS also predicts sensor effectiveness on a horizontal plane from a given location at a designated time and distance above ground level. Effectiveness is presented as a radar plot that uses green, amber, and red to depict regions of increasing cloud density in accordance with specified transmission thresholds.

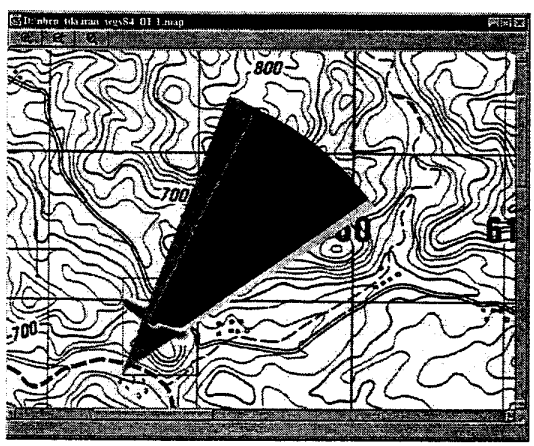


Figure 5. Chemical Staff Officer's BMS displaying a sensor effectiveness plot superimposed on a cloud density image of a simulated obscuration event.

This program demonstrates the power of object-oriented methodologies, which foster software reuse by encapsulating functionality and enabling components to be assembled into new and different applications. Most of the smoke-related code in BMS is identical to that used in CDVis. The only difference is some minor additions that were applied to support its unique display requirements. Also, the BMS graphical user interface is written in Java while SSPM and its CDVis extensions are written in C++ and the extended cloud class places an object wrapper around COMBIC's FORTRAN code. The object-oriented technology enables these disparate components to be drawn together with relative ease to create a new and useful application.

## 5. CONSTRUCTIVE WARGAMES

JPO-SOSTC, NSWC, the USMC Systems Command, and OMI have integrated TDR into a many-on-many Sensor/Obscurant Engagement Simulation (SOES). It has been used by combat and material developers to assess tactical concepts for smoke employment in littoral operations (figure 6). SOES uses physical models to simulate sensor performance and TDR Phase I to produce terrain-sensitive smoke clouds. Intervisibility issues are addressed using digital terrain elevation data and TDR Phase II.

SOES uses TDR as an independent executable program without augmentation, so it is limited to the smoke sources that TDR inherently supports. These sources are positioned and activated in accordance with an scripted scenario.

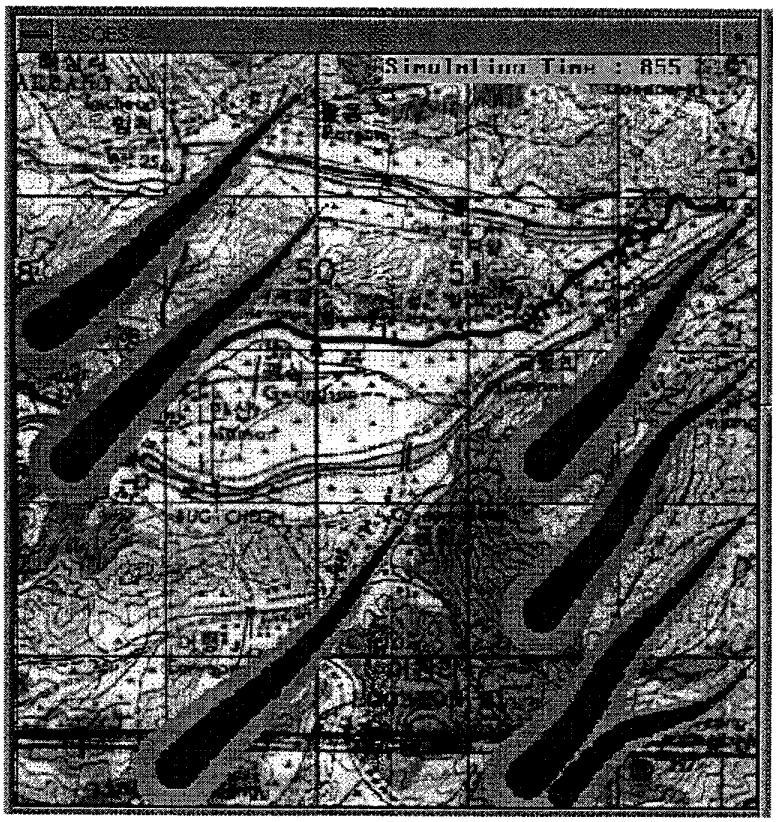

Figure 6. A SOES display depicting terrain sensitive TDR-generated clouds.

The US Army Training and Doctrine Command has integrated COMBIC into CASTFOREM, a stochastic force-on-force model that is used to assess combat system performance[11]. It is the Army's primary tool for conducting formal Analysis of Alternatives (AoA). CASTFOREM uses COMBIC to predict transmissivity through obscurant clouds, which have been produced by simulated combat events. When activated, COMBIC is employed throughout the gaming exercise, but the smoke effectiveness assessments are limited to discrete engagement segments and only affect certain operations, such as laser range finding and missile flyout. During laser operations, CASTFOREM does consider the affect of obscurants on a laser beam and will attenuate the returning signal appropriately. During guided missile flyouts, CASTFOREM periodically uses COMBIC to determine if obscurants have cause the missile to break lock.

Obscurant usage places a large computational burden on CASTFOREM and can significantly increase run times. Because COMBIC is used in its native form, CASTFOREM can only use standard sources. And, because there is no direct linkage to operational entities, such as vehicles, artillery units, and aircraft, smoke events must be manually inserted by exercise controllers.

## 6. VIRTUAL SIMULATIONS

In recent years, DoD has invested heavily in distributed interactive simulation (DIS) technologies that enable manned and unmanned simulators to interact on a common virtual battlefield. DIS simulations have been used extensively for small unit training and are increasingly used in other applications, including simulation based acquisition. Interactions are facilitated through the exchange of messages using well defined protocols. The DIS standard provides for the transmission of some smoke information, enabling one battlefield entity to produce a smoke event and report its state to all other networked simulations.

The Modular Semi-Automated Forces (ModSAF) program is used extensively in DIS applications to populate the virtual world with battlefield entities, such as aircraft and armored vehicles. These entities behave in an intelligent manner and are indistinguishable from their manned counterparts.

The use of smoke and obscurants by ModSAF entities is notional. Certain vehicle types have a limited ability to launch salvos of self-protective grenades and artillery/mortar projectiles. No other smoke sources are supported. ModSAF uses pre-computed COMBIC history files to instantiate obscurant clouds, but these clouds are limited to one subcloud each, which severely restricts their fidelity. ModSAF does consider obscurant effects on entity engagements, but few other DIS applications do. The scene generators on most manned DIS simulators cannot render smoke clouds (with the exception of some trailing effects attached to some entities) and they do not affect crew vision whatsoever.

The Close Combat Tactical Trainer (CCTT) is a family of networked simulations that is used to train armor, cavalry, and mechanized infantry platoons in the performance of collective tasks. CCTT includes manned simulators for numerous combat vehicles and a semi-automated forces program (similar to ModSAF) that can control a wide variety of friendly or opposing units. CCTT uses a variant of the DIS standard protocols to establish and maintain the synthetic environment.

CCTT has an extremely limited capability for simulating smoke events and only supports three obscurant types: hydrochloric acid, red phosphorus, and white phosphorus. Manned CCTT simulators do render smoke clouds using an animation technique that can vary transmittance in accordance with obscurant characteristics. This does affect crew visibility which can influence combat operations. Other obscurant effects are not supported.

## 7. FUTURE REQUIREMENTS

Smoke and obscurants do affect battlefield sensors and those effects can influence combat operations. It is important for obscurant systems to be reasonably represented in models and simulations so that their influence can be properly assessed. The capabilities and limitations of U.S., allied, and opposing forces must all be considered. Smoke and obscurant modeling should not be done for its own sake, but it must be done to insure that soldiers are properly trained and equipped to operate on the dirty battlefield. It is incumbent upon the smoke and obscurant community to make sure that occurs.

The survey presented above describes the current state of smoke and obscurant modeling. It is by no means comprehensive, but does highlight strengths and weaknesses in several application domains. The survey illustrates that smoke and obscurant modelers have done extremely good work where it was feasible to do so. They have developed excellent physical models that reasonably simulate the growth, transport, and diffusion of obscurant clouds while striking a balance between fidelity requirements and computational constraints. And, the physical models have been used in numerous applications to perform useful training and analytical functions. The survey also illustrates, however, that smoke and obscurant modelers have failed to accomplish what heretofore was infeasible to do. Despite all good intentions and a lot of intense effort, they have not managed to insert a significant amount of smoke and obscurant play into the tactical simulations that are routinely used for training and simulation-based acquisition. Given technological limitations, it was just too difficult to achieve. That situation is changing.

Recent advancements in hardware and software technologies are enabling simulations to model physical phenomena with increasing fidelity. The emergence of new design methodologies are facilitating the development of true software components that can readily be used in diverse computing environments. This is an excellent time to begin the development of smoke and obscurant components for the simulation community at large.

These components must be comprehensive, flexible, authoritative, efficient, self-contained, and HLA compliant, as described below:

**Comprehensive**. Collectively, the simulation components should model all smoke and obscurant systems that U.S. forces are likely to use or encounter on any future battlefield.

**Flexible**. For maximum applicability across all M&S domains, each component (or variation thereof) must be able to operate at several resolutions. High fidelity simulations will need high fidelity smoke representations while low fidelity simulations will need the opposite. Also, cloud behavior must be 4-dimensional (i.e., sensitive to spatial and temporal variations in atmospheric conditions, if they exist).

**Authoritative**. Each component must simulate the item it represents with sufficient fidelity to satisfy the smoke and obscurant community at all possible resolutions.

**Efficient**. Smoke and obscurant modeling is computationally intensive and that burden has limited its utility in many applications. The simulation components must employ more efficient algorithms than those used today, particularly for modeling cloud behavior and obscurant effects. The use of neural nets and related technologies should be investigated to determine if they can enhance performance without degrading fidelity. Also, data exchange requirements among networked simulators must be minimized

**Self-contained**. Developers will not use the components if it is difficult to integrate them into applications. Consequently, they must be designed using accepted object-oriented

techniques which require they encapsulate all characteristics and behaviors and expose a well-defined interface.

**HLA compliant**. The simulation components must be developed in accordance with the HLA specification. They must be fully documented with federation object models (FOM) and/or simulation object models (SOM), as appropriate. The components must employ the simulation support services provided by the RTI.

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