Design and Development of Intelligent Military Training Systems and Wargames

D. Vijay Rao

Abstract Today's military teams are required to operate in environments that are increasingly complex. Such settings are characterized by the presence of ill-structured problems, uncertain dynamics, shifting and ill-defined or competing goals, action/feedback loops, time constraints, high stakes, multiple players and roles, and organizational goals and norms. Warfare scenarios are real world systems that typically exhibit such characteristics and are classified as Complex Adaptive Systems. To remain effective in such demanding environments, defence teams must undergo training that targets a range of knowledge, skills and abilities. Thus oftentimes, as the complexity of the transfer domain increases, so, too, should the complexity of the training intervention. The design and development of such complex, large scale training simulator systems demands a formal architecture and development of a military simulation framework that is often based upon the needs, goals of training. In order to design and develop intelligent military training systems of this scale and fidelity to match the real world operations, and be considered as a worthwhile alternative for replacement of field exercises, appropriate Computational Intelligence (CI) paradigms are the only means of development. A common strategy for tackling this goal is incorporating CI techniques into the larger training initiatives and designing intelligent military training systems and wargames. In this chapter, we describe an architectural approach for designing composable, multi-service and joint wargames that can meet the requirements of several military establishments using product-line architectures. This architecture is realized by the design and development of *common* components that are reused across applications and *variable* components that are customizable to different training establishments' training simulators. Some of the important CI techniques that are used to design these wargame components are explained swith suitable examples, followed by their applications to two specific cases of Joint Warfare Simulation System and an Integrated Air Defence Simulation System for air-land battles is explained.

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R. Abielmona et al. (eds.), *Recent Advances in Computational Intelligence in Defense and Security*, Studies in Computational Intelligence 621,
DOI 10.1007/978-3-319-26450-9_21

Keywords Military systems analysis • Modeling and simulation • Constructive simulations • Computational intelligence techniques • Scenario-based exploratory analysis

1 Introduction

Warfare is changing, perhaps more rapidly and fundamentally today, than at any point in history. The emergence of new operational drivers such as asymmetric threats, urban operations, joint and coalition operations and the widespread use of military communications and information technology networks have highlighted the importance of providing warfighters with competencies required to act in a coordinated, adaptable manner, and to make effective decisions in environments characterized by large amounts of sometimes ambiguous information. Warfare systems are characterized by the presence of ill-structured problems, uncertain dynamics, shifting and ill-defined or competing goals, action/feedback loops, time constraints, high stakes, multiple players and roles, and organizational goals and norms. Such systems are typically classified as Complex Adaptive Systems. While the beginnings of understanding warfare as a complex adaptive system dates more than 2500 years to the writings of Sun Tzu, recently, a growing body of literature describes the broader aspects of defence systems and operations as a complex systems science. Complexity results from the inter-relationships, inter-actions and inter-connectivity of elements within a system and between a system and its environment. They are dynamic systems that are able to *adapt in* and *evolve with* a changing environment. Sir Smith's thesis [1] that the world entered a new paradigm of conflict at the end of the 20th and beginning of the 21st centuries, which he calls "war amongst the people", and that Western, industrialized armies are ill-suited to the new style of warfare, is noteworthy.

With rapid advances in technology and increasingly complex defense systems in operation, substantial effort and resources are spent on training for their effective usage. To improve the efficiency, effectiveness, usage and safety of training, organizations and user agencies are investing heavily into developing computer-based training simulators. While investment in new technologies can make available new opportunities for action, it is only through effective training that personnel can be made ready to apply their tools in the most decisive and discriminating fashion. The infeasibility of replicating the environment under which such systems are deployed and operated, coupled with resource constraints and environmental hazards are forcing military organizations worldwide to invest heavily on computer based systems for their training needs. A recent empirical study on the impact of computer based training (CBT) on maintenance costs and actions in a sonar system operations found that CBTs use has adversely influenced parts costs, actions, and labor costs associated with operating and maintenance of the AN/SQQ-89(v) sonar system and has negatively impacted sailor performance on ships. It also suggested that explicit costs are traded for an obscured cost in terms of parts, maintenance actions, labor-hours readiness [2]. Such studies along with the lessons learnt during several training sessions of military training simulators and wargames emphasize that Modeling and Simulation (M&S) is one of the critical success factors that should be mainstay in designing and developing training simulators if they are to be effective. In order to design and develop intelligent military training systems of industry strength scale with fidelity to match the real world operations, and to be considered as a worthwhile alternative for replacement of field exercises, appropriate computational intelligence (CI) paradigms are the only means of development. We describe an architectural approach for designing composable multi-services and joint wargames, and explain the applicability of the various CI techniques in every aspect of the architectural design. These are explained with suitable examples along with potential applications for military systems design are discussed throughout the chapter.

2 Modeling, Simulation and Military Systems Analysis

Operations Research (OR) and Systems Analysis (SA) are the two related methods of logically attempting to solve complex problems having a quantitative analytical component [3, 4]. Figure 1 identifies the various ways of studying a real-world system. Warfare has many facets of study and analysis and generally classified as complex, adaptive systems that are nonlinear, dynamic, and show emergence behaviors. Thus in order to obtain closed form solutions for such systems in their entirety is elusive. Modeling and Simulation (M&S) is thus becoming the main approach used by defense organizations to study warfare systems for analysis and training, model complex military operations, design training and analysis systems of existing and proposed defense systems. (*We shall use the term wargames to also mean the military training systems that are specific instances of the generic class of wargames that are implemented for training purposes while the former also encompasses analytical and research wargames*).

One of the major challenges of military systems analysis is to identify the models that are suitable to the problems at every level of the pyramid. The choice primarily depends upon the purpose, resolution, and objectives of the study and can be classified as strategic level, tactical level and operational level games. All the approaches to force-on-force analysis are underpinned by theories of combat. Combat is an exceedingly complex and simultaneous interaction of several factors that are typically classified under complex adaptive systems. Force-on-Force campaign analysis that use combat models are not intended to predict accurately who is likely to win or lose and an engagement, a battle, a campaign, or a war but to predict whether one system, tactic force structure, or course of action is likely to perform *roughly* better or worse than another. As shown in Fig. 1, there is a continuum of techniques and applications from operations research to force-on-force campaigns and net assessment that spans the complete range of defence decision-making problems. Broadly

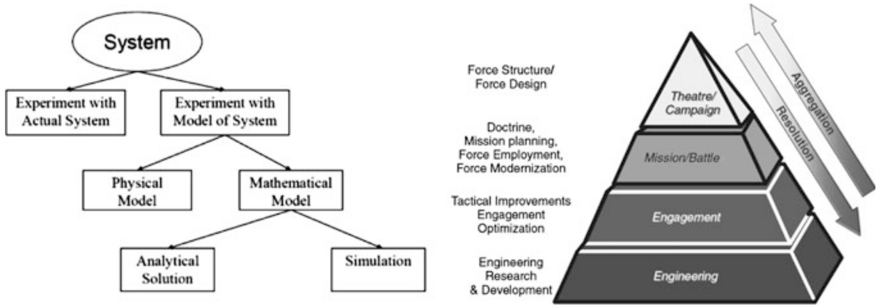


Fig. 1 Ways to study a system [4] and military systems analyses hierarchy [5]

speaking, modeling and simulation may be applied at the tactical, operational or strategic levels to meet the functional requirements of training, operational planning, force structuring to include force development, and, strategy formulation. Simulation is also the only way to test and train for some special environments, such as nuclear events, biological and chemical contamination, and operations that require large-scale mobilization and movement. Analytical simulations are used to study problems like force composition, weapons effectiveness, and logistics issues. Examples to illustrate are:

- What would be the survivability and cost-effectiveness of an unmanned combat system as compared to a manned combat mission?
- Which is the best weapon mix, force mix of aircraft-weapons types and configurations that can achieve the maximal damage to given target with a minimal acceptable loss of own resources?
- Given a set of military resources, what is the optimal deployment of these resources against a given threat scenario.
- In what specific scenarios are joint services operations synergistic? What are the core and critical factors that ensure synergy in jointness?

2.1 Modeling and Simulation Techniques for Training and Analyses

Modern methods of training are being introduced with enhanced use of modeling and simulation [6]. Modeling and simulation refers to the use of models, including emulators, prototypes, simulators, and stimulators, either statically or over time, to develop data as a basis for making managerial or technical decisions and training. The terms "modeling" and "simulation" are often used interchangeably. Simulation is the imitation of the operation of a real-world process or system over time. Simulation not only helps them in learning the given scenarios, but teaching themselves replicate real-life experiences to relive and recreate what they have seen, on their own missions. Basic applications that evolve from the core Modeling and simulation domains of *Engineering*, *Training* and *Analysis* areas into Simulators, Wargames and Performance Evaluation systems are shown in Fig. 2. Depending upon the goals of the study, analytical techniques process simulations, trace driven simulations, or discrete event simulation systems are employed in each of these three areas [7].

Simulation is the imitation of the operation of a real-world process or system over time. A simulation of a system is the operation of a model of the system. The model can be reconfigured and experimented with; usually, this is impossible, too expensive or impractical to do in the system it represents. The operation of the model can be studied, and hence, properties concerning the behavior of the actual system or its subsystem can be inferred. Simulation can be used before an existing system is altered or a new system built, to reduce the chances of failure to meet specifications, to eliminate unforeseen bottlenecks, to prevent under or over-utilization of resources, and to optimize system performance. To simulate is to mimic a real system so that we can explore it, perform experiments on it, and understand it before implementing it in the real world. This becomes extremely important, especially when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist [4].

When we simulate, we are first required to develop a *mathematical model* of the original entity (weapon, equipment or process) wherein, the model so developed represents the key characteristics or behaviors of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the repetitive operation of the processes of the system, over a period of time. This could be to simulate the behavior of a weapon/equipment or a group of entities (platoon/company/combat team) in a particular scenario. Military simulations are seen as a useful way to develop tactical, strategic and doctrinal solutions. The term military simulation can cover a wide spectrum of activities, ranging from full-scale field-exercises, to abstract computerized models that can proceed with little or no human involvement as shown in Fig. 2. The simulations have been universally identified to be of three types—*live*, *virtual* and *constructive* [3].

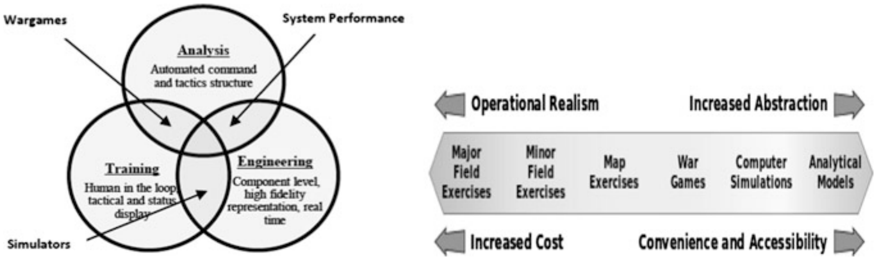


Fig. 2 Application areas of military modeling and simulation: performance evaluations, simulators, and wargames

Live simulation refers to a simulation that involves real people in real systems. For example, two pilots can be trained for dog fighting by using real aircrafts in the air. In this case, the aircrafts and pilots are real, but the interaction between the aircrafts are simulated and simulation decides how effective the pilots and aircrafts are against each other. Similarly, all the weapon systems can be equipped with emitters, and all the equipment and personnel can be equipped with sensors. If the weapons are aimed and fired correctly, the emission by the emitter can be sensed by the sensors, which indicates a hit and a kill.

Virtual simulation involve humans and/or equipment where actual players use simulation systems in a computer generated synthetic or virtual environment. The running time can be real or in discrete steps, allowing users to concentrate on the key training objective. These represent a specific category of devices that utilize simulation equipment (which exactly replicates the controls of the original equipment) to create a simulated world for the user. In this manner, the system can accept input from the user (e.g., body tracking, voice/sound recognition, physical controllers) and produce output to the user (e.g., visual display, aural display).

Constructive Simulation, also known as *wargaming*, derives its name from the fact that the pieces operating on the battlefield are not individual tanks and aircraft but a construction of many different types of equipment into a single aggregated unit like an armor company, artillery battery.

Wargames are physical or electronic simulation of military operations designed to explore the effects of warfare or testing strategies or an operational concept without actual combat. Wargame is the employment of military resources in training for military operations, either exploring the effects of warfare or testing strategies without actual combat. It is the most cost-effective methodology for training as it creates a realistic environment to generate near-real responses to various contingences as well as handling of complex weapon systems. The main advantage of using wargames is to enable the users to take another look at specific events from a stress free environment and enhance their performance for the given event.

The first two types of simulations are used to train individuals operating equipment, this equipment is in turn controlled by leaders in command posts who see the battle in a more abstract form. Constructive simulations allow these commanders to face situations and make decisions under the stress of time and limited resources just as they will during actual combat. Constructive simulations immerse these commanders in a situation where the enemy is highly trained, experienced, and just as determined to win the war. Here soldiers discover whether the tactics they have been taught really work, here they develop confidence in their ability to operate as a team and win wars. These simulations have emerged as one of the powerful tools of system analysis in military applications. They have been used extensively for training, planning, analysis and decision support purposes. A wide range of wargames has been developed at various resolution levels to support different objectives. Training wargames allows analyzing various aspects of tactics at lower levels. Higher level wargames can be used for evaluation of various employment/deployment plans, different course of action and also evaluation of weapon systems [7, 8].

The new reality of military operations is characterized by complex interactions, adaptivity and nonlinearity, with an increase of uncertainty and risk, explicitly or implicitly, in all dimensions of warfare [9–13]. Uncertainty is the inability to determine a variable value or system state (or nature) or to predict its future evolution. Uncertainty is a fact (that is certain): real-world data will be uncertain, incomplete, ambiguous, contradictory, and vague, and this uncertainty can never be reduced completely; but can only be managed. While uncertainty can only be managed, the real objective of studies is reducing risk in taking informed decisions. Computational Intelligence (CI) paradigms encompass a collection of heuristic techniques to imitate or represent aspects of cognitive and biological processes in nature, which have been successfully used to model and manage these inherent uncertainties in the design and development of wargames.

We propose a number of CI techniques to design intelligent military training simulators and wargames. In contrast to the organisation-specific, training-specific monolithic system development, we propose a product-line, layered approach to design large-scale intelligent wargames that can be easily customized to specific requirements of organisations. Such an architectural framework based approach has its basis in software reuse and component based system development. The various components common to a family of wargame solutions and the variable components that are customised to meet a specific end product is described. All these CI techniques have been integrated in a Discrete Events Simulation Specification (DEVS) framework to design specific end-products to meet the training requirements of military schools [14–18]. These predominant CI techniques that have been successfully used to develop intelligent military training simulators are described in the sections that follow.

3 An Architectural Approach to Design and Development of Wargames

The design and development of large scale simulators, software testbeds and wargames, demands a formal architecture and development of a military simulation framework that is often based upon the needs, goals of training and resolution of the wargames. The Joint Warfare Simulation System (JWSS) is a constructive simulation based software testbed that is designed to cater for *Analysis*, *Training* and preliminary studies of *Engineering* design. The JWSS is designed based on the operational foundations of the military domain; conceptual foundation required for the modeling and theoretical foundations of implementing and composing simulation system. JWSS system design is highly influenced by (i) *scope, resolution of the* *entities involved*, (ii) *level of wargame, trainee audience and objectives* (iii) *number and types of entities being addressed/modeled* (iv) *resolution of the battlefield entities and fidelity of the combat entity models* (v) *number and types of players and their hierarchy configurations* (vi) *area of operations* (vii) *terrain and environmental features* (viii) *time advancement and resolution.* Conventional approaches to designing and developing Wargames are based on a monolithic homogeneous design and development as any software development system. This approach imposes difficulties in developing and maintaining these systems as they must keep evolving to be useful. In JWSS an Inner-Sourcing, hybrid approach to designing common components and an agent-oriented approach to designing wargame components is proposed. Organizations leveraging open-source development practices for their in-house software development is called Inner Source [19].

An Agent Based Modeling Approach to Wargame Development

Agent-oriented system development aims to simplify the construction of complex systems by introducing a natural abstraction layer on top of the object-oriented paradigm composed of autonomous interacting actors [20–22]. It has emerged as a powerful modeling technique that is more realistic for today's dynamic warfare scenarios than the traditional models which were deterministic, stochastic or based on differential equations. These approaches provide a very simple and intuitive framework for modeling warfare and are very limited when it comes to representing the complex interactions of real-world combat because of their high degree of aggregation, multi-resolution modeling and varying attrition rate factors. The effects of random individual agent behavior and of the resulting interactions of agents are phenomenon that traditional equation-based models simply cannot capture. Figure 3a, b shows the agent based architecture of a virtual warfare training simulator [22]. In agent-based modeling (ABM), a system is modeled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents may execute various behaviors appropriate for the system they represent—for example, producing, consuming, or selling. Repetitive competitive interactions between agents are a feature of agent-based modeling, which relies on the power of computers to explore dynamics out of the reach of pure mathematical methods. At the simplest level, an agent-based model consists of a system of agents and the relationships between them. Even a simple agent-based model can exhibit complex behavior patterns and provide valuable information about the dynamics of the real-world system that it emulates. In addition, agents may be capable of evolving, allowing unanticipated behaviors to emerge. Sophisticated ABM sometimes incorporates neural networks, evolutionary algorithms, or other learning techniques to allow realistic learning and adaptation. The benefits of ABM over other modeling techniques can be captured in three statements: (*i*) ABM captures emergent phenomena; (*ii*) ABM provides a natural description of a system; and (*iii*) ABM is flexible. It is clear, however, that the ability of ABM to deal with emergent

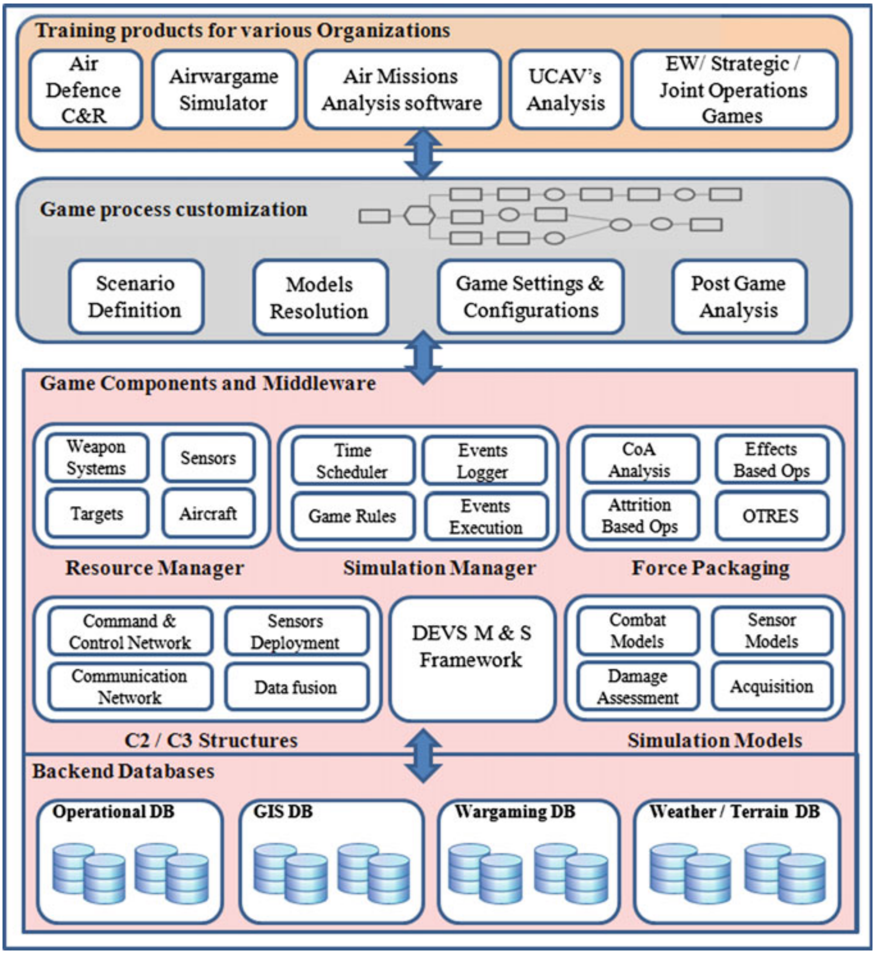


Fig. 3 Joint warfare simulation system architectural framework

phenomena is what drives the other benefits. ABM appear to represent complex, adaptive systems where, non-linearity, interactions and emergence are an inherent nature of systems, such as warfare systems. One may want to use ABM [23] when there is potential for studying emergent phenomena, i.e., when:

- Individual behavior is nonlinear and can be characterized by thresholds, if-then rules, or nonlinear coupling. Describing discontinuity in individual behavior is difficult with differential equations.
- Individual behavior exhibits memory, path-dependence, and hysteresis, non-Markovian behavior, or temporal correlations, including learning and adaptation.

- Agent interactions are heterogeneous and can generate network effects. Aggregate flow equations usually assume global homogeneous mixing, but the topology of the interaction network can lead to significant deviations from predicted aggregate behavior.
- Averages will not work. Aggregate differential equations tend to smooth out fluctuations, not ABM, which is important because under certain conditions, fluctuations can be amplified: the system is linearly stable but unstable to larger perturbations.

Differential equations are a fundamental modeling technique, which finds place in warfare modeling. Land wargames typically use Lanchester laws that are mathematical formulae for calculating the relative strengths of a predator/prey pair. The Lanchester equations are differential equations describing the time dependence of two armies' strengths A and B as a function of time, with the function depending only on A and B. During World War I, Frederick Lanchester devised a series of differential equations to demonstrate the power relationships between opposing forces. Among these are what is known as *Lanchester's Linear Law* (for ancient combat) and *Lanchester's Square Law* (for modern combat with long-range weapons such as firearms). Pursuit-Evasion games, Differential games, air to air combat models such as Adaptive Maneuvering Logic (AML) all have their basis as DE, and have been an active area of research in Warfare modeling [24, 25].

In many cases, such as wargames, ABM is most natural for describing and simulating a system composed of *behavioral* entities [26–28]. Each agent is implemented using different CI techniques depending upon its purpose. For example, in modeling air warfare tactics in JWSS, the pilot agent can be modeled using a simple behavioral model, a cognitive model, a rule-based model, control-theoretic model, or a neuro-fuzzy model [29–34]. Computer-generated forces and semi-automated forces have an important role to play in modeling counter insurgency operations, terrorist attacks, and operations other than war [35–37]. These are very efficiently modeled using ABMs. In order to design and develop training simulators for such operations, the opponents are modeled using agents governed by simple rules, and emergent phenomenon. Simulators are built for operations, tactics and strategies training using CGF and SAF. Epistemic states are often used to represent an actual or a possible cognitive state that drives the human-like behavior of an agent. Commonly used models are propositional, probabilistic and possibilistic world models, where methods of knowledge representation, reasoning and inferencing about the various mental constructs of the agent, including beliefs, desires, goals, intentions, and knowledge are used to simulate its human-like cognitive states. Validation of CGFs and SAFs is an area of concern; and drawing lessons from these simulations is difficult and caution needs to be exercised.

Main components of Joint Warfare Simulation System (JWSS) Architectural Framework are as follows:

Backend Databases

All the JWSS data is classified into static data (such as resources, weapons, their characteristics) and dynamic (run-time results that are generated by gaming the mission plans) data, stored in the data servers that form the backend for the entire game. The database is designed using MySql and SQLServers that are ADODB and ODBC compliant databases. Backend Databases are partitioned into four functional clusters to improve the performance and maintenance of the servers: *Operational Database, GIS Database, Wargaming Database and Weather/Terrain Database*. *Operational Database* contains data that changes frequently during the game and is dependent on the scenario being simulated. Data about missions, resources deployed, event logs generated during simulation, and results are stored in this database.*GIS Database* contains geographical data such as raster and vector maps of different themes, DTED and DEM data of maps of the Theatre and Area of Operation (AOP) during game customization and game initialization phase. An open source GIS has been customized for the military (Mil-GIS) to depict the various theatres of warfare in JWSS. *Wargaming Database* contains the data which is read only and can be changed only by the controller during the initialization phase. Performance parameters of an aircraft and their configurations, resource specifications, sensor details, target information, force structure, network and game settings all forms part of this database. *Weather/Terrain Database* contains data such as weather and terrain information in an enclosed region specified by the users. Location-based intelligent services (LBIS) are developed on these databases to generate the military intelligence, information, and data that is utilized by the players to decide the course of actions during the wargame exercises. These LBIS along with fuzzy linguistic variables to represent the uncertainty of information obtained from various intelligence sources are generated, collated and inferred to generate the Fog of War during the training exercises. For example, *Suitability of terrain conditions to troops and logistics movement along the selected route to meet the objective is low*.

Resource Manager

Resources of the game include the various types of entities involved in the game such as weapon systems, sensors, platforms such as aircraft, naval ships, air defence artillery, infantry, armour brigades, and the hierarchy of organization and their compositions, platform-weapon configurations, types of targets, expected damages to targets, weapon-target matching and their primary and secondary effects of damages. Weapon systems include all kinds of air-launched and surface-launched weapons like Bombs, Guns, Rockets and Missiles. All types of Aircraft such as *Fighters, Air-to-Air Re-fuellers, Transport, Unmanned combat systems, Unmanned aerial vehicles,* their operational performances, effective radii of action, and effectiveness against targets are stored in the resource databases. Air Defense (AD) units such as Radars, air defense Guns, Mobile Observation Posts, and Aerostats form a part of the Resource Folder. The *Target Folder* contains relevant information of all the static targets and RCS of various aircraft, EW emitter signatures obtained from ESM missions in the game. Targets include Bridges, Airfields, Refineries, Oil Depots and other such vulnerable areas and vulnerable points (VA/VP's). The information in the resource folder is updated as and when new resources are inducted into the services and may not change frequently during the wargame simulation. *Target folder* is updated whenever any new intelligence inputs about targets are made available. Creation and administration of the Resource Folder and Target Folder as per the game scenario is the primary task of the resource manager. *Searching*, *Matching* and *Retrieval* of "similar" images from the target folder to the acquired target from an unmanned system uses fuzzy image retrieval and fuzzy inferencing techniques [38].

Force Packaging

Before planning, study of the anticipated air and ground threats is essentially required to get the near real time information of the battlefield in time and space domain. Anticipated threats determine ingress/egress tactics and techniques to minimize risk, aircraft selection, weapon configuration, weapon delivery mode and other operational factors. Data from many sources such as HUMINT, COMINT and SIGINT enables the most effective use of available resources to destroy or neutralize adversary's assets.

Many critical decisions are taken in the force planning phase. How large a force package should be and which types of aircraft with what weapons configuration is best suited for the mission objective? Should there be a need for escorts in the force package? What likely threats can be encountered and how does one mitigate these risks? Which routes would optimize use of terrain masking? At what time target should be shot down? While planning planner must consider assets availability, range to target, C2/C3 connectivity, and tactics. For tactical routing, planner must focus on suppressing threats using SEAD/AD/ECM/Stand-off escorts and identifying/acquiring the target. In the target area, terrain masking and high speed are used to minimize the threat exposure to adversary's low level air defense. Optimal Deployment of resources against a perceived threat is obtained using Genetic algorithms, and Weapon Target matching used for force packaging the campaigns is done using Genetic algorithms.

C2/C3 Structures

A Command, Control and Communication (C3) structure is an information system employed within a military organization. Command is the functional exercise of authority, based upon knowledge, to attain an objective or goal. Control is the process of verifying and correcting activity such that the objective of command is accomplished. Communication is the ability and function of providing the necessary liaison to exercise effective command between tactical and strategic units of command. Thus the C3 structure can be succinctly defined as a knowledgeable exercise of authority in accomplishing military objectives and goals.

The C3 structure is implemented in JWSS with the Air Defense Direction Centre (ADDC) being responsible for providing air defense to assigned VA/VP using air defense systems against air threats. ADDC is also responsible for communicating the change in status of Control order and status of target. It passes these messages to the Base Air Defense Centre (in case of airbases) or to the Air Defense Command Post (in case of other VA/VP's). The ADDC could control one or more BADC. BADC on receipt of the message from the ADDC activates its own radar and transmits the message on the basis of its track information to engage the threat.

Simulation Manager

The Simulation Manager coordinates and controls the whole entire wargame. It starts the game by starting a simulation clock and initializing the game parameters, target folder, resource folder, war date and block. It allocates resources for the block of game, sets up weather conditions and monitors the game. The missions of various teams are processed by the simulation manager using various simulation models and the results are generated in a quantitative manner. The damage caused to the aircraft, airbase, and other VA/VP's is computed using weaponeering techniques based damage assessment models [6]. Mathematical models have been developed for computing weapon trajectories, wind effects, and atmospheric parameters. Statistical distributions are used to generate various events and for damage assessment. All these events and the effects caused are recorded by the Event Logger to be viewed and analyzed later. Extensive set of fuzzy game rules are used to simulate realistic war scenario such *as if takeoff runway is non-operational then abort the mission, otherwise allow aircraft to take-off, if aircraft in a mission is unserviceable then abort the mission*, *unserviceable factor of 3 % before take-off and 2 % after take-off is acceptable*, *if storm is present at takeoff base then abort the Mission, if landing runway is non-operational, then the landing aircraft is made available after the runway available time added to turn around service time (TRS) of the aircraft.*

Simulation Models

The core functionality of the JWSS framework lies in the various simulation models that are being used extensively by the simulation manager during the course of the game. Some of the classes of models are explained below:

Damage Assessment Models

The assessment of damage has its basis in the various mathematical models developed based on the weaponeering principles, force structure planning, weapon planning directive and the weapon-target matching documents. These models help in determining the optimal quantity of a specific type of weapon required to achieve a specific level of damage to ground targets considering weather, terrain, target vulnerability, weapon effects, munitions delivery errors, damage criteria, probability of kill, weapon detonation reliability, weapon release conditions and other operational factors. An Over the Target Requirement Estimation System (OTRES) tool has been developed based on these principles that estimate the damage caused and generates the courses of action for a planner [21]. The planner selects one course of action (mission plan) which is gamed against the threat (*perceived enemy threat* during mission assessment and *actual enemy threat* during gaming the missions) using the JWSS test-bed to assess the mission effectiveness. Target damage assessment using weaponeering principles gave realistic results when used in field training and deployment of the system. Computation of damages for ground-ground, ground-air, air-ground, and air-air engagements uses physics based, logic based, probabilistic and fuzzy logic based models [21, 24, 25, 39].

Sensor Models

Electronic warfare (EW) is the art and science of denying enemy force, the use of the electromagnetic spectrum while preserving its use for friendly forces. It involves radars, electronic sensors, jammers used in conjunction with traditional weapon systems as part of the warfare. The EW module in JWSS includes firstly modeling of the performance of radars in the presence of different weather and terrain conditions considering the Line of Sight between Radar and the target, secondly electronic countermeasures and electronic, counter- countermeasures and lastly modeling the effect of different types of jammer on the radar performance. The parameters considered in these models are radar characteristics, target characteristics, environment parameters, jammer parameters, threshold detection level.

Combat Models

Combat models are developed for mathematical analysis of attrition process of the forces in combat. Combat is an engagement or a series of engagements between two conflicting forces, which causes attrition. An engagement can be defined as a set of actions within a particular region, over a particular time period, and with a given force structure. In the context of land wargames, it is a complex system involving men, machines, materials, money, environment, terrain and their complicated interactions. Involvement of quantitative and qualitative factors gives rise to different degrees of complexities to the system. Training, battle fatigue, fear, morale, leadership are some qualitative factors which govern human behavior during the battle. Many of these attributes are intangible and we may not be able to give a specific number. Neuro-Fuzzy linguistic variables are used to model these qualitative factors that play an important role in wargames. In the case of naval platforms, trajectories of the weapons launched and the incidence of impact, the warhead tonnage of explosive, and physics based impact dynamics decide the extent of damage caused to the platforms. In air combat scenarios, a weighting factor that is derived from the static combat potential of the packages of both sides is used to assess the aircraft attrition, Adaptive Maneuvering Logic (AML) for one-one, pursuit evasion modes [24] is modeled or a more detailed model that considers the aerodynamics, aircraft weapon load, EW, RWR, MWR, frequencies of operation, on board missiles, and their ranges to compute the dynamic combat potential for gaming and computing the attritions. These entire processes can be simplified by deriving probabilistic game rules that can also be used for quick statistical analysis of the air campaign. The inherent complexity of the combat process leads to great complexity in the operational models of *combat attrition*, and *combat effects*.

Target Acquisition Models

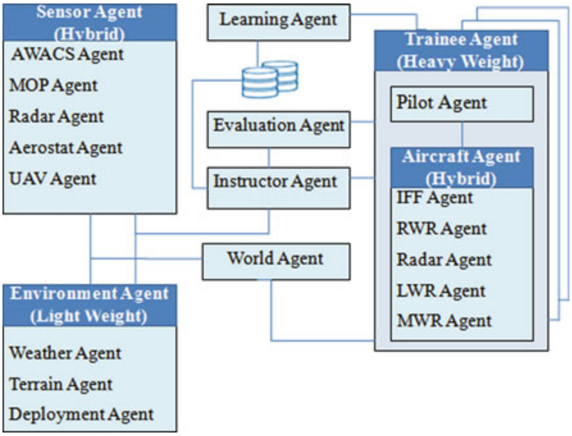
In cases of bad weather, terrain and other environmental conditions, and height of the air attacks, the target may not be acquired by the on-board sensors, and weapons are not released. Mission planners need an estimate of the probability the target would be acquired in order to get a better measure of mission success. As for many air to ground missions, rules of engagement require that the pilot makes a direct visual or instrumental acquisition of the target before weapons are employed. This is true for conventional bombs, rockets, guns and some guided missiles. The choice of tactics and weapons and the estimation of the effectiveness of the mission should include the probability of target acquisition for the successful attack. Mathematical models have been developed to predict the probability that targets can be detected which is applicable not just to the human eye, but to wide variety of on board electro-optical sensors operating in different parts of the electromagnetic frequency spectrum [38, 40]. These models are executed at run time to determine if the target is acquired and record the decisions made by the pilot for analysis.

DEVS Framework

Discrete Event System Specification (DEVS) is a universal formalism for discrete event dynamical systems [16, 17]. DEVS offers an expressive framework for modelling, design, analysis and simulation of autonomous and hybrid systems. Because of its system theoretic basis, DEVS is a universal formalism for discrete event dynamical systems. The DEVS framework enables a large system to be specified by hierarchically decomposing the system into modules called *Atomic* or *Component Models*, each having the internal structure and the state transition [15, 16]. The specification of the coupling between the component models and the hierarchy structure of the atomic models corresponds to the *Network* or *Coupled model* of the DEVS formalism [14–18]. DEVS environments are implemented over middleware systems such as HLA, RMI, and CORBA. DEVS exhibits concepts of systems theory and modeling and supports capturing the system behavior from the physical and behavioral perspectives that are implemented using CI techniques (Fig. 4).

A mission objective (goal) set by the instructor is designed within a contextual setting and also describing the scenario and settings within which the training is imparted and the trainees are assessed. The lesson plans are designed using all the four types of learning depending upon the nature of lessons and training to be imparted [41, 42]. The lesson plans are designed based on the domain knowledge that is explicitly represented by ontology of the warfare resources, aircraft, weapons, performance characteristics, constraints, weather, and terrain information. The lesson plans are dynamically adapted by asking relevant questions on the concepts of learning from the ontology and reasoning based on the answers to change the lesson plans accordingly. The goals are decomposed as tasks, and sub-tasks in a

Fig. 4 Agent architecture for JWSS



hierarchical manner, indicating the roles of the armed services, support organizations and people who would be collaborating to collectively achieve the objective. Case based Planning and Reasoning can be used to retrieve the past cases and adapted to the future mission plans [43–49]. The sequence and timing diagrams of the tasks are generated and these are associated with the resource constraints and resolution of conflicts. The assessment of the trainees is done by evaluating the plans made by the trainees to meet the goals. The Learning Management sub-system (LMS) in this simulator architecture (JWSS) is responsible for planning the lessons for the trainees, storing and updating the contents, evaluate the trainees and also learn from the behavior of the trainees for further lesson planning. The LMS consists of three prominent agents: Instructor agent, Learning agent and Evaluation agent. The Instructor agent is composed of a Lesson Planner that identifies a goal for the trainees, composes the lesson plan from the learning objects and given to all the trainees. The trainees decompose the task into a number of independent tasks that are to be achieved by each of the teams, in order to achieve the objectives of the goal. The Instructor agent updates the state of a lesson plan and creates a scenario that is based upon the information received from weather, terrain and deployment agent and provides an information service to the world agent after its own process of reasoning. This information is then used by other agents such as Manual Observation Post (MOP), Pilot, Unmanned Air Vehicle (UAV), Identification Friend/Foe (IFF), Radar Warning Receiver (RWR), Missile Warning Receiver (MWR), Laser Warning Receiver (LWR), Mission Planning, Sensor Performance, Target Acquisition and Damage Assessment and Computation (Fig. 3a, b).

4 Computational Intelligence Techniques in Designing JWSS

JWSS has been designed in the military domain for training, analysis, to generate strategic scenarios for forecasting, creating what-if scenarios and evaluating effectiveness of military operations and procedures.

4.1 Design of a Joint Services Military Ontology

Ontologies are specifications of the conceptualisation and corresponding vocabulary used to describe a domain [18, 50]. It is an explicit description of a domain and defines a common vocabulary as a shared understanding. It defines the basic concepts and their relationships in a domain as machine understandable definitions. We design a military ontology consisting of a formal and declarative representation which includes the vocabulary (or names) for referring to the terms of army, navy and airforce and the logical statements that describe what the terms are, how they are related to each other, and how they can or cannot be related to each other (Figs. 5, 6). Ontology therefore provides a vocabulary for representing and communicating knowledge about some aspect of military training and a set of relationships that hold among the terms in that vocabulary. The main purpose of ontology is, however, not to specify the vocabulary relating to an area of interest but to capture the underlying conceptualisations [51–56]. Noy and McGuinness [41] have identified five reasons for the development of ontology:

- to share common understanding of the structure of information amongst people or software agents;
- to enable reuse of domain knowledge;
- to make domain assumptions explicit;
- to separate domain knowledge from the operational knowledge;
- to analyse domain knowledge.

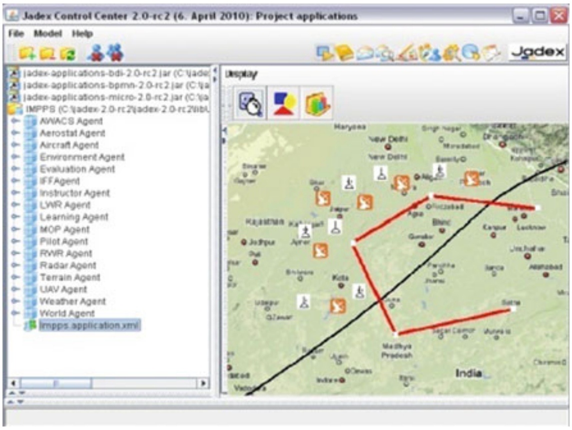


Fig. 5 Mission planning simulator in agent-oriented architectures

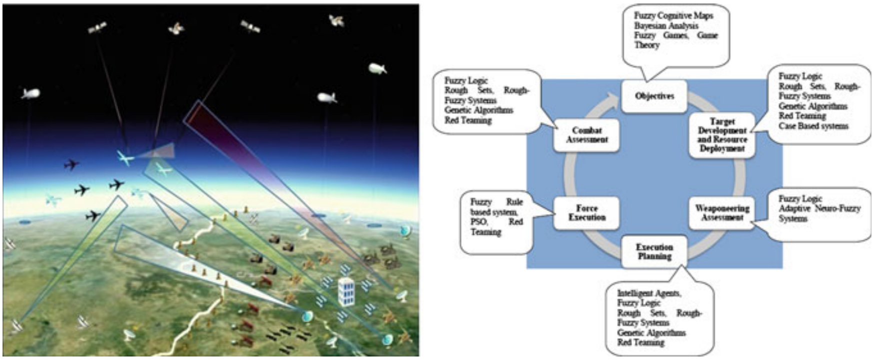


Fig. 6 Steps in conducting a military wargame and the application of CI techniques

Three main challenges in designing reusable learning objects are (i) intelligence; (ii) sharable; and (iii) dynamic. This is overcome by developing semantic metadata for providing intelligence to learning objects; developing content packaging for enhancing the sharability of learning objects and developing learning object repository with ontologies and Semantic Web technologies for making learning objects more dynamic [57–60]. To meet these challenges the following methodological steps are followed to design and develop the online environment of learning object repository.

- *Stage 1*: To develop a metadata framework which integrates the most suitable metadata as well as proposed pedagogical and military metadata elements that can be applied to a variety of learning objects.
- *Stage 2*: To apply a content packaging standard that packages learning objects together so they can be exported to and retrieved from various learning management systems.
- *Stage 3*: To identify the ontology (i.e. a common vocabulary of terms and concepts) for construction education and to develop a Semantic Web environment that will increase sharability of objects within construction domains.

In the design of the JWSS, military domain knowledge is represented and stored as ontology in Protégé (Fig. 7a, b). Protégé is a freely available, open-source platform that provides a suite of tools to construct domain models and knowledge-based applications that use ontologies [61–63]. At its core, Protégé implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats (including the Web Ontology Language, OWL and Resource Description Framework (RDF)). Protégé can be customized to provide domain-friendly support for creating knowledge models and entering data. Further, Protégé can be extended by way of a plug-in architecture and a Java-based Application Programming Interface (API) for building knowledge-based tools and applications (Fig. 8).

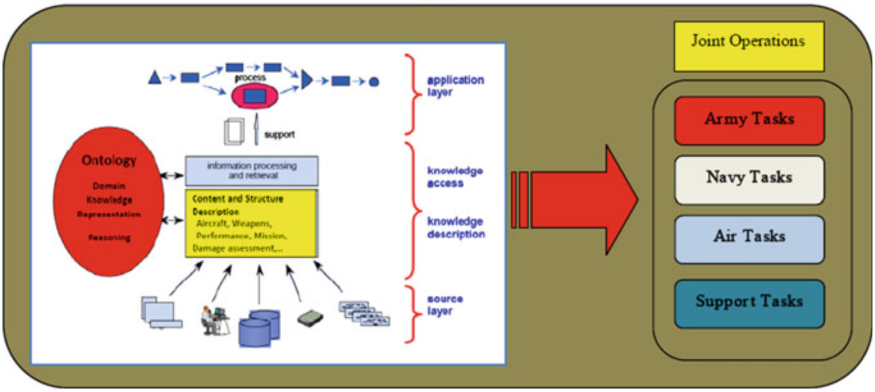


Fig. 7 Architecture of the LMS for dynamically composing joint operations lesson plans

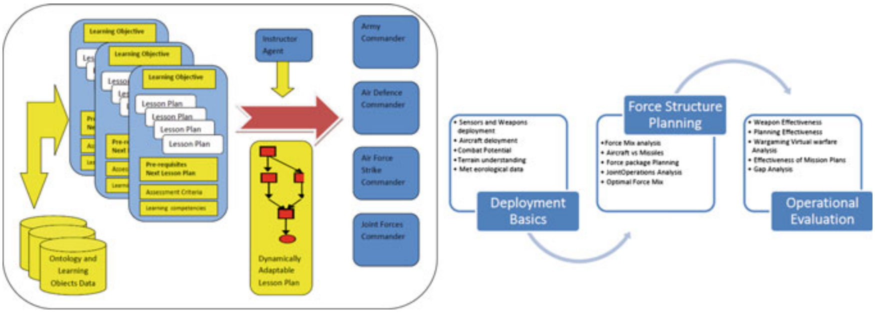


Fig. 8 Ontology based Instructor agent to dynamically plan adaptable lessons based on competency gaps

Protégé can load OWL/RDF ontologies, edit and visualise classes and properties; execute reasoners such as description logic classifiers and edit OWL individuals for SemanticWeb. Protégé is widely used for modelling of simple applications to high-tech, high-powered applications. It also offers support to ontology libraries and OWL language. Military ontology for joint operations is designed and developed for the JWSS using Protégé. While metadata of learning objects describe the artifacts of learning objects that are shared by diverse domains, an ontology represents a knowledge domain that shares the relationships of learning objects within a specific context.

Reasoning the Ontology
One of the main reasons for building an ontology-based application is to use a reasoner to derive additional truths about the concepts. A reasoner is a piece of software able to infer logical consequences from a set of asserted facts or axioms. The notion of a semantic reasoner generalises that of an inference engine, by providing a richer set of mechanisms to work with. The inference rules are commonly specified by means of an ontology language, and often a description language. Many reasoners use first-order predicate logic to perform reasoning; inference commonly proceeds by forward chaining and backward chaining. In the JWSS, reasoning helps in formulating questions for testing the understanding of related concepts. This is used to evaluate the competency of trainees, lessons planned and perform a gap analysis so that new lessons can be generated to fill the gaps [64–67].

4.2 *Strategic Planning Wargames Using Fuzzy Cognitive Maps*

Strategic Planning is a multi-dimensional assessment of a situation where several geo-political, economic and military dimensions are evaluated before arriving at course of actions. Existing relationships between countries can be described from a variety of perspectives, such as historical, respectful, friendly, neighboring, cultural, traditions, ideological, religious, trade, political, and economic aspects. One way to build these relationships is to strengthen the economic relationships, wherein the decision maker takes into consideration many factors and variables that influence the promotion of these relationships, prominent among them being economic relationship. This information and these factors are diversified and may involve different dimensions and the challenges in Strategic Planning lie in recognizing, finding and extracting the underlying relations and strengths of influence of these different variables. A conscientious decision maker who takes responsibility for promoting and strengthening bilateral economic relationships needs access to information that is fuzzy and qualitative. Military options are usually the method of last resort, and a brute-force approach that is often the result of a trigger that evolves over states and time domain when the geo-political options fail. This basic *concept* of the information is represented as a linguistic variable whose values are words rather than numbers across different domains including the political and investment domains. Due to nature of the problem, data from different domains that is imprecise, ill-structured, uncertain and ambiguous needs to be modeled. A fuzzy ontology that represents the geo-political, historical, respectful, friendly, neighboring, cultural, traditions, ideological, religious, trade, and political, military and economic ties is constructed using Protégé software. This Ontology is useful for acquiring and sharing knowledge, building a common consensus and constructing knowledge-based systems that can be used to build sub-schemas to represent the perspectives of the stakeholders, and reason the ontology for hidden and underlying relationships and their strengths of influence. Fuzzy Cognitive Maps (FCM) are fuzzy graph structures for representing causal reasoning with a fuzzy relation to a causal concept [68]. Fuzzy cognitive maps are especially applicable in the soft knowledge domains such as political science, military science, history, international relations, and Strategic Planning Wargames. Fuzzy logic generated from fuzzy theory and FCM is a collaboration between fuzzy logic and concept mapping. FCM is used to demonstrate knowledge of the causality of concepts to define a system in a domain starting with fuzzy weights quantified by numbers or words [69]. As a soft-system modeling and mapping approach, FCM combines aspects of qualitative methods with the advantages of quantitative (causal algebra) methods. In a FCM, the positive (+) and the negative (−) signs above each arrowed line provide a causal relationship whereby each fuzzy concept is linked with another one. In this sense, the FCM is a cognitive map of relations between the elements (e.g., concepts, events, resources) that enables the computation of the impact of these elements on each other, where the theory behind that computation is fuzzy logic. Since FCMs are signed fuzzy non-hierarchic digraphs [69], metrics can be used for further computations, and causal conceptual centrality in cognitive maps can be defined with adjacency-matrix [68] (Fig. 9).

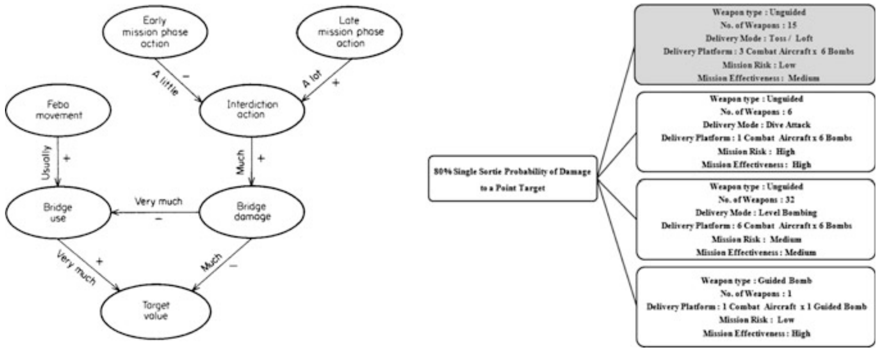


Fig. 9 Assessing the bridge target value in forward edge of battle area (FEBA) operation and course of action analysis

The various steps in constructing an FCM for representing a crisis situation are:

(1) Identification of factors and representing them as concepts
(2) Specification of relationships among concepts
(3) Defining the levels of all factors,
(4) Defining the intensities of causal effects,
(5) Identify changeable factors versus dependent factors,
(6) Simulating the fuzzy cognitive map,
(7) Modifying the fuzzy cognitive map,
(8) Simulating the modified fuzzy cognitive map, and
(9) Deriving the Conclusions from Reasoning.

FCMs for various crisis situations are constructed and used for assessing value of targets, prioritization of targets, and evaluating effects-based operations. In the JWSS, strategic planning considers all the concepts represented in fuzzy ontology, qualitative attributes of selecting the Course of Action (CoA), weaponeering principles of damage computation, reasoning the ontology and generating the course of actions.

4.3 Adaptive Lesson Plans Using Game Trees

The adaptability of the game playing depending on the background and training needs of different users is selected by two main cognitive criteria memory and learning. The competency level required by the lesson plan is compared with the competency level of the trainee. The gap is reduced by reasoning the ontology concepts and choosing the lesson plans that are represented in a *concept-map* and implemented as a *concept-graph*. The trainee is now switched to a new lesson that matches with the competency of the lessons. The lesson plans for the Army, Navy and Air Force and Joint operations which demand inter-disciplinary domain knowledge are organized as a concept graph. The starting node for the trainee is identified based on the competency level and based on the various preliminary questions, the Instructor agent reasons from the ontology *concept-graph* and composes the new lesson plan by traversing it to reduce the competency gap (Fig. 10).

Consider a training exercise for military operations in which the trainees from different branches of specializations with different skills, prior training and field operations are assigned tasks of a campaign (Table 1). These tasks are assigned to the trainees with the intent of teaching concepts, examples, and field cases which are then evaluated in the field training. The prior training is used to compute the trainee competency factor, and the lesson plan initially assigned has the training competency level. The gap which is the difference between the two values is used to decide the switched lesson plan so that the semantic distance is minimised. The military ontology is used to traverse the concept-map that is implemented as a concept graph, and is used to adapt the lesson plans for the trainee with the goal of minimising the semantic gap in the lessons chosen. The quantitative answers for the different tasks given to the trainees are calculated by wargaming the tasks and

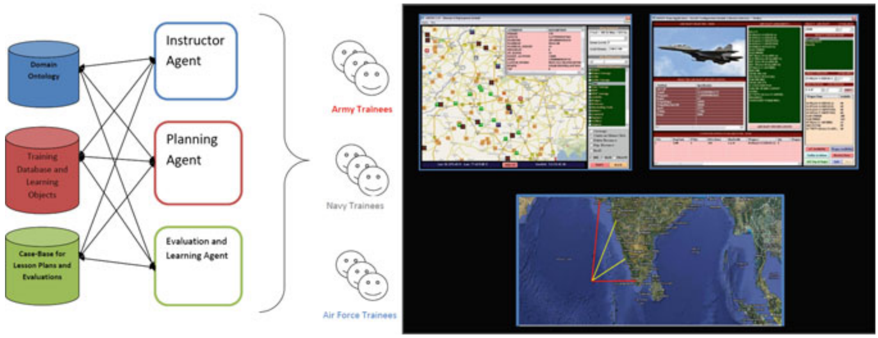


Fig. 10 Architecture of agents in JWSS and screens depicting the army, air and naval tasks for trainees

Table 1 Classification of live, virtual and constructive simulations

People	Systems	Operation	*Simulation*
Real	Real	Simulated	*Live*
Real	Simulated	Simulated	*Virtual*
Simulated	Simulated	Simulated	*Constructive*

generating the mission success factors for the two lessons: one that is conventionally computed using databases, and the other that uses ontology [41]. Consider the cases of two trainees (named Trainee 1 and Trainee 3) with different game scenarios and lesson plans from the same training system.

Trainee 1: To understand and evolve different strategies to gather Location based Intelligence necessary as pre-curser to destroy the target (Fig. 11).

Trainee 3: To understand the concepts in Mission Planning and Air Tasking operations (Fig. 12).

The mission success factor for Trainee 1 increased from 7.2 to 9.3 and from 5.3 to 9.8 on running the JWSS wargame by using the military ontology. The ontology requirements found an importance in military simulators mainly because of the Joint Warfare operations that are introduced in the course of training. These values may or may not have increased as much with the individual service wargames. This gives an intuitive indication of synergy in joint wargames that demand a much greater understanding of the warfare concepts and applying them in joint missions that surpass the boundaries of individual wargames (Table 2).

Fig. 11 T-001 Game scenario lesson plans generated for Trainee 1

Fig. 12 T-003 Game scenario lesson plans generated for Trainee 3

Table 2 Fuzzy antecedents (factors) to generate training lesson plans

Mission_ID	Trainee	Service	Training and field operations skills	Lesson plan (Task)	Trainee competency factor	Training competency factor	Competency gap	Mission success factor (1–10) conventional	Mission success factor (1–10) ontology and adaptive lessons
#001	T-001	Intelligence	Low	ESM and location based intelligence gathering	7	8	1	7.2	9.3
#002	T-002	Navy	High	Anti-submarine warfare	2	5	3	4.6	6.4
#003	T-003	AirForce	High	Strike and air-air combat	7	8	1	5.3	9.8
#004	T-004	Logistics	Low	Mobilization of logistics and road move plan	5	8	3	6.8	7.4
#005	T-005	Army	Very high	Air defence guns deployment	6	8	2	7.2	9.3

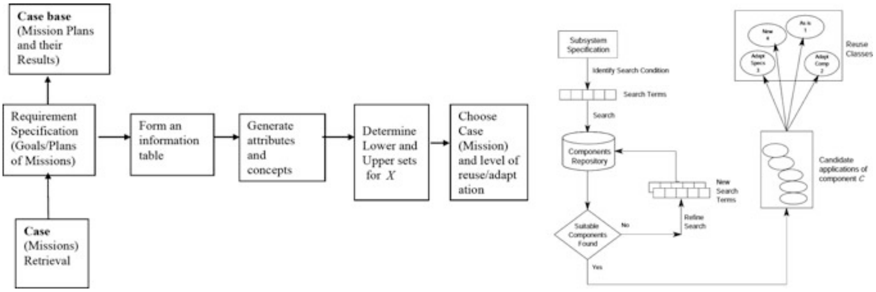


Fig. 13 Case base of missions plans and retrieval of relevant missions using rough-fuzzy techniques

4.4 Case Based Planning and Adaptation of Missions

In case-based planning (CBP), previously generated plans are stored as cases in memory and can be reused to solve similar planning problems in the future. CBP can save considerable time over planning from scratch (generative planning), thus offering a potential (heuristic) mechanism for handling intractable problems. One drawback of CBP systems has been the need for a highly structured memory that requires significant domain engineering and complex memory indexing schemes to enable efficient case retrieval. Computational intelligence techniques based on Rough-Fuzzy hybridization techniques are used to retrieve past mission plans that meet the military goals and/or effects to meet the present military objectives and software components that are stored as a case-base. These are implemented in the JWSS system for effective planning (Fig. 13).

4.5 Optimal Deployment of Resources and Weapon-Target Optimisation Using Genetic Algorithms

In deriving an optimal deployment strategy of resources against a perceived threat scenario, a intelligent strategy that mitigates the risk of the threat while minimizing the damage to own resources is developed using genetic algorithms. Another sub-system that uses GA for optimization is the platform-weapon-target matching that maximizes the estimated damage to a given target. Genetic algorithms provide an evolutionary approach towards solving the problem at hand by aiming to improve the fitness of each successive generation of possible solutions, mimicking the process of natural selection on a suitably simplistic scale. Unlike other search-based optimization procedures such as Hill Climbing or Random Search, GAs have consistently achieved good performance in terms of balancing between the two conflicting objectives of any search procedure, which are the *exploitation* of the best solution and the *exploration* of the search space. An initial population of individuals (positions of deployment, considering the constraints of performance, detection probability of sensors, terrain and weather conditions; Platform-Weapon-Target damage effectiveness based on the physical hard-points and effectiveness of the weapons against a given target) is required as a starting point for the optimization process. To this effect, we seed a uniformly distributed population within the desired bounds of the solution space. A fitness function (maximizing the effective target detection) is then defined, which assigns a score to every member of the current generation based on the evaluation of relevant characteristics, which in this case are the total volume enclosed by the network of sensors, with given detection and communication capabilities. The fittest individuals from this pool are identified for creating the next generation via the chosen implementations of selection and crossover functions, which dictate the process of reproduction and survival of individuals. A mutation factor is also specified for the genome to reduce the chances of the solution converging towards a local maximum. For every individual, a convex hull is stretched over the point cloud formed by the nodes in three dimensional space to form a polyhedron. The volume of this polyhedron not only serves as the initial score for the individual prior to constraint checking, but its visualization can also be used to identify shadow zones as well as highlight nodes surplus to requirements in achieving the given objective. For the duration of the optimization phase, we assume that the transmission and detection ranges for all nodes are omni-directional and isotropic by default. Node and medium characteristics are then used to compute the distortions to the coverage spheres of each node. As Delaunay triangulation is used to form the convex hull for each individual, every node has three neighbors, without accounting for any redundancy requirements. Once the optimization is complete and a solution is obtained, the direction vectors of antennas on each node can be specified, taking into consideration its neighbors and face coverage specifications.

Since shadow zones in such a scenario are essentially holes in the coverage shell, penalties are required on the raw scores to discourage such arrangements from participating in the evolution of the genome. In every successive generation, the score of the best-fit individual is expected to improve due to selective breeding. As the score stagnates with respect to average change in fitness, generation, or time, the algorithm terminates with an optimal solution as its output.

4.6 Red Teaming Using Intelligent Agents and Computer Generated Forces

Red teaming is the practice of viewing a problem from an adversary or competitor's perspective. The goal of most red teams is to enhance decision making, either by specifying the adversary's preferences and strategies or by simply acting as a devil's advocate. Red teaming may be more or less structured, and a wide range of approaches exists. These techniques help analysts and policy-makers stretch their thinking through structured techniques that challenge underlying assumptions and broaden the range of possible outcomes considered. Alternative analysis includes techniques to challenge analytic assumptions (e.g. ‘devil’s advocacy’), and those to expand the range of possible outcomes considered (e.g. ‘what-if analysis,’ and ‘alternative scenarios’). Collective behavior is the result of evolutionary processes that shape behavior to modify and respond to environmental conditions (Gordon 2014). Investigating how these algorithms evolve can show how diverse forms of collective behavior arise from their function in diverse environments. An assessed deployment of the enemy’s ground defence, air defence, with inputs from ESM missions, ground picture images from unmanned systems, and other human, and electronic intelligence, developing triggers from strategic games, a military-geo-political, economic, trades, and cultural map using fuzzy cognitive maps is developed. Strategic Course of Action (CoA) analysis is developed by considering the plausible CoA of the Red teaming analysis Missions are then planned against targets that are prioritized against the back-drop of the assessed red team. An assessment of the situation is made by using a game theoretic framework is built which is then given to the commanders as a specific scenario for analysis. The CI techniques used in modeling the Red teaming are behavioral game theory, cognitive process modeling, multi-agent systems, Markov decision process and social networks modeling. These factors are used in conjunction with the FCMs to predict the plausible next CoAs the adversary would take in order to react to the developing scenario. Bayesian Belief networks, Dempster-Shafer theory, Belief-Desire-Intention model to represent the epistemic states of red teaming agents, Influence diagrams for decision making, modal logics and deduction techniques are used in red teaming’s possible world assessment.

4.7 Automatic Target Recognition by Unmanned Systems

In the JWSS, a list of targets and information obtained from various sensors, ELINT, COMINT and HUMINT is stored in a specialized database called *Target Folder*. Automatic Target Recognition (ATR) refers to the use of computer processing to detect and recognize target signatures in sensor data. The sensor data are usually an image from a forward-looking infrared camera, electro-optic sensor, synthetic-aperture radar, television camera, or laser radar, although ATR techniques can be applied to non-imaging sensors as well. ATR has become increasingly important in modern defense strategy because it permits precision strikes against certain tactical targets with reduced risk and increased efficiency, while minimizing collateral damage to other objects. If computers can be made to detect and recognize targets automatically, the workload of a pilot can be reduced and the accuracy and efficiency of the pilot’s weapons can be improved. An overview of the CI techniques that are used in ATR is shown in Fig. 14. An image enhancement technique based on Blind De-convolution algorithm to improve the image quality followed by edge enhancement algorithms that adaptively enhance the edges and

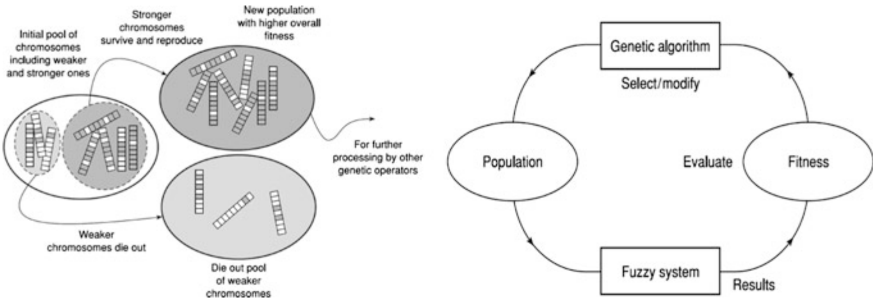


Fig. 14 Process of GA and integrating GA with Fuzzy logic system

wipe off blurriness in the image is implemented in the JWSS. The de-blurring results of the proposed algorithm and retrieval of plausible matching images using Content based image retrieval (CBIR) proved better than the conventional techniques. Using either the color, shape or texture features separately to compare and retrieve images with crisp equal weights was found to be ineffective. Instead, a fuzzy combination of the color, shape and texture features to design a better query retrieval system is implemented, where the feature weights are assigned depending upon the different conditions when the image was taken. This methodology based on Fuzzy techniques was very effective in identifying the target images obtained from UAV missions and has been implemented in the JWSS to model the effectiveness of UAV missions [38] (Fig. 15).

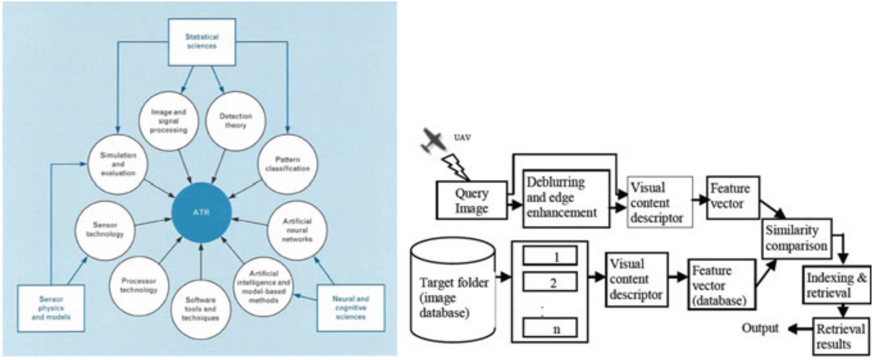


Fig. 15 Computational Intelligence techniques in ATR, and image recognition and detection in UAV/UCAV missions in JWSS

4.8 Design of Game Rules Using Fuzzy Rule Based Systems

Crisp rules use the cookie cutter function to identify the damages caused from the weapons. We design and develop a fuzzy cookie cutter damage function that generates rules that are used to game the missions and assess the damages caused to targets and own resources. Traditional approaches to wargame simulations use classical logic for damage assessment. Classical two-valued logic system, crisp set theory and crisp probability on which the damage assessment is based, are inadequate and insufficient for dealing with real-life war scenario that involves complexity and different sources of uncertainty. Damage assessment for a target done using cookie-cutter function gives the probability of damage of a target. Crisp cookie-cutter function states that a target is damaged inside a circle of specified radius r, and no damage occurs outside it

$$d(x,y) = 1, \quad x^2 + y^2 \le r^2 \\ 0, \ \text{otherwise}$$

where, *d(x, y)* is the damage function of the point target by a weapon whose point of impact is *(x, y)* [3] The target is assumed to be completely damaged within the circle of radius r and no damage occurs outside r. The notion of probability stems from, and depends on, the idea of repeated trials. Under identical and repeatable laboratory conditions conducted on simple models, this probabilistic notion readily applies; but, in real-world systems, experiments are rarely identical and repeatable. Therefore, for the subjective assessment of complex military systems, probability has its limitations. Fuzzy Logic is the logic behind approximate reasoning instead of exact reasoning. As knowledge acquisition in wargames design and development is obtained from pilots and defence analysts, it is usually true that facts and rules are neither totally certain nor totally consistent due to the varied experience sets of the pilots. This leads to the reasoning processes used by experts in certain situations as approximate. The theory of fuzzy sets is used to help assess uncertain information derived from this approximate reasoning process. Structural damage can be considered as a linguistic variable with values such as "severely damaged," or "moderately damaged." These are meaningful classifications but not clearly defined. With the use of fuzzy sets, however, we can quantify such terminology and apply it in a meaningful way to help solve a complex problem. An evident advantage of the fuzzy set approach is the possibility of representing numeric and linguistic variables in a uniform way and of using a formalized calculus to manipulate these variables. For example, consider a large area-target of size of 550 ft to be attacked, where the fuzzy variables *target-ground contrast* 80 %, the *terrain*, rated 8, is fairly smooth, aircraft altitude is 900 ft, aircraft range is 5000 ft is flying at 100 knots speed. The *target identification factor* for this target is seen as "good" with value 7.3295. In this mission, on firing the rules for inference, the offset from the desired point of impact is 29 m, considered "less"(i.e. fairly accurate targeting); *weapon-target match* is 6 (average), "good" *target identification factor*

7.3295, the relative damage caused is 28.9187 which is a “moderate” damage to the target.

In the JWSS, AI based techniques such as a fuzzy rule-based system to design the game rules in a mission planning and evaluation system [70]. The conventional crisp cookie cutter function used to compute the probabilistic damage caused to a target is replaced by a fuzzy cookie-cutter function, which takes into account many physical parameters before assessing the possibilistic damage caused to the target. This methodology of damage assessment computation of targets using fuzzy rule bases gave realistic results, comparable with the experts’ judgements, in field training.

4.9 Environment Modeling in JWSS

It receives information from weather, terrain and deployment agent and provides an information service to the world agent after its own process of reasoning. This information is then used by other agents such as Manual Observation Post (MOP), *Pilot*, Unmanned Air Vehicle (UAV), Identification Friend/Foe (IFF), Radar Warning Receiver (RWR), Missile Warning Receiver (MWR), Laser Warning Receiver (LWR), *Mission Planning*, *Sensor Performance*, *Target Acquisition* and *Damage Assessment and Computation*. The weather agent is an important agent that that has functions such as *Get_Visibility()*, *Get_Temperature()* and *Get CloudCover()*. The weather agents’s reasoning has been designed using ANFIS, a neuro-fuzzy hybridization technique that is used to predict the Mission_Success_Factor(), considering the weather conditions along the mission route [50, 71].

Surface aviation weather observations include weather elements and forecasts pertaining to flying. A network of airport stations provides routine up-to-date surface weather information. Upper-air weather data is received from sounding balloons (radiosonde observations) and pilot weather reports that furnish temperature, humidity, pressure, and wind data. Aircraft in flight also report turbulence, icing and height of cloud tops. The weather radar provides detailed information about precipitation, winds, and weather systems. Doppler technology allows the radar to provide measurements of winds through a large vertical depth of the atmosphere. Terminal Doppler weather radars are used to alert and warn airport controllers of approaching wind shear, gust fronts, and heavy precipitation which could cause hazardous conditions for take-off, landing and diversion. Low-level wind shear alert systems provide pilots and controllers with information on hazardous surface wind conditions (on and near airbases) that create unsafe operational conditions. Visible, infrared and other types of images of clouds are taken from weather satellites in orbit. Weather is a continuous, multi-dimensional, spatio-temporally data intensive, dynamic and partly chaotic process. Traditionally, two main approaches for weather forecasting are followed: Numerical Weather Prediction and Analogue forecasting. For the JWSS application, it is needed to consider the past weather conditions at given places of operation and predict the weather for simulation of mission tasks in real-time. In this paper, the ANFIS neuro-fuzzy hybridization technique is used to predict the weather conditions along the mission route and study the effects of weather in the virtual warfare scenario analysis in terms of pilot decisions in mission planning, performance of sensors, and target identification and damage assessment.

A Neuro-Fuzzy Hybridization Approach to Weather Prediction

The weather agent has been designed using ANFIS to give the predicted Mission_Success_factor in weather constraints. In the following section, the neuro-fuzzy hybridization approach will be discussed. Both neural networks and fuzzy systems are dynamic, parallel processing systems that estimate input–output functions [6–8]. They estimate a function without any mathematical model and learn from experience with sample data. It has also been proven that (1) any rule-based fuzzy system may be approximated by a neural net and (2) any neural net (feed-forward, multilayered) may be approximated by a rule-based fuzzy system. Fuzzy systems can be broadly categorized into two families. The first includes linguistic models based on collections of IF–THEN rules, whose antecedents and consequents utilize fuzzy values. The Mamdani model falls in this group where the knowledge is represented as it is shown in the following expression.

$$R^i : If\, X_1\, is\, A_1^i\; and\, X_2\, is\, A_2^i \ldots\ldots..and\, X_n\, is\, A_m^i,\, then\, y^i\, is\, B^i$$

The second category, which is used to model the Weather prediction problem is the Sugeno-type and it uses a rule structure that has fuzzy antecedent and functional consequent parts. This can be viewed as the expansion of piece-wise linear partition represented as shown in the rule below.

$$R^i : If\, X_1\, is\, A_1^i\; and\, X_2\, is\, A_2^i \ldots\ldots..and\, X_n\, is\, A_m^i,\, then\, y^i = a_0^1 + a_1^i X_1 + \;\ldots.. + a_n^i X_n$$

$$\tilde{A} \cap \tilde{B} = \left\{ \left(x, \mu_{\tilde{\mathrm{A}} \cap \tilde{\mathrm{B}}}(x) \right) | \mu_{\tilde{\mathrm{A}} \cap \tilde{\mathrm{B}}}(x) = \mu_{\tilde{\mathrm{A}}}(x) \wedge \mu_{\tilde{\mathrm{B}}}(x) = \min\left(\mu_{\tilde{\mathrm{A}}}(x), \mu_{\tilde{\mathrm{B}}}(x) \right) \right\} \quad (1)$$

The conjunction “and” Operation between fuzzy sets known as *Linguistics*, for the implementation of the Mamdani rules is done by employing special Fuzzy Operators called T-Norms [6]. The ANFIS uses by default the Minimum T-Norm which is the case here and it can be seen in the above equations. The approach approximates a nonlinear system with a combination of several linear systems, by decomposing the whole input space into several partial fuzzy spaces and representing each output space with a linear equation. Such models are capable of representing both qualitative and quantitative information and allow relatively easier application of powerful learning techniques for their identification from data. They are capable of approximating any continuous real-valued function on a compact set to any degree of accuracy. This type of knowledge representation does not allow the output variables to be described in linguistic terms and the parameter optimization is carried out iteratively using a nonlinear optimization method.

Fuzzy systems exhibit both symbolic and numeric features. Neuro-fuzzy computing is a judicious integration of the merits of neural and fuzzy approaches, enables one to build more intelligent decision-making systems. Neuro-fuzzy hybridization is done broadly in two ways: a neural network equipped with the capability of handling fuzzy information [termed fuzzy-neural network] and a fuzzy system augmented by neural networks to enhance some of its characteristics like flexibility, speed, and adaptability [termed neural-fuzzy system]. ANFIS is an adaptive network that is functionally equivalent to a fuzzy inference system and referred to in literature as “adaptive network based fuzzy inference system” or “adaptive neuro-fuzzy inference system” (Fig. 3). In the ANFIS model, crisp input series are converted to fuzzy inputs by developing triangular, trapezoidal and sigmoid membership functions for each input series. These fuzzy inputs are processed through a network of transfer functions at the nodes of different layers of the network to obtain fuzzy outputs with linear membership functions that are combined to obtain a single crisp output the predicted Mission_Success_Factor, as the ANFIS method permits only one output in the model. The following Eqs. 2–4 correspond to triangular, trapezoidal and sigmoid membership functions (Figs. 16, 17).

$$\mu_s(X) = \begin{cases} 0 \text{ if } X < a \\ (X - a)/(c - a) \text{ if } X \in [a, c) \\ (b - X)/(b - c) \text{ if } X \in [c, b] \\ 0 \text{ if } X > b \end{cases} \tag{2}$$

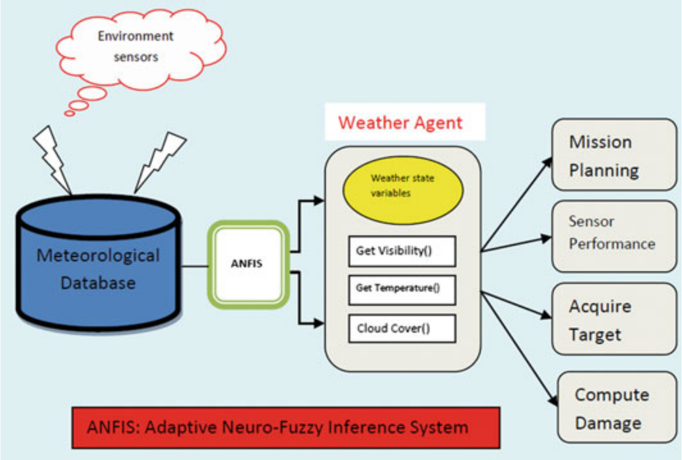
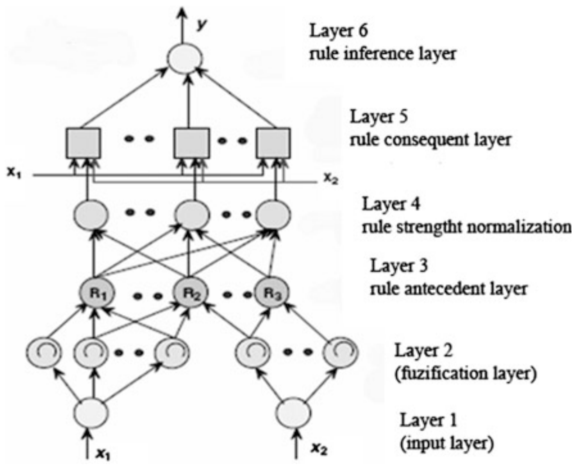


Fig. 16 Weather agent’s architecture and behaviors

Fig. 17 ANFIS architecture to design the weather agent



$$\mu_s(X) = \begin{cases} 0, & \text{if } X \le a \\ (X-a)/(m-a), & \text{if } X \in (a, m) \\ 1, & \text{if } X \in [m, n] \\ (b-X)/(b-n), & \text{if } X \in (n, b) \\ 0, & \text{if } X \ge b \end{cases} \tag{3}$$

$$f(x; a, c) = \frac{1}{1 + e^{-a(x-c)}} \tag{4}$$

Weather conditions of interest to JWSS [19, 21, 22, 71] are classified as Precipitation (Drizzle, Rain, Snow, Snow-grains, Ice crystals, Ice pellets and Hail), Obscuration (Mist, Fog, Dust, Sand, Haze, Spray, Volcanic ash, Smoke) and Others (Dust/Sand whirls, Squalls, Funnel cloud, Tornado or Water spout, Sandstorm, Dust-storm). Temperature, Clouds, Height of cloud base, Wind speed and direction, Icing, Precipitation, Visibility, Fog, Mist, Rain, Thunderstorm, Haze, dust/sand whirls and squall speeds are quantified using linguistic fuzzy variables. Target Identification factor: Rapid and certain target detection and identification are the dominant factors in the success of all air-to-ground attacks. The ability of tactical fighters to penetrate enemy defenses and to acquire and identify ground targets successfully within weather constraints is a keystone of success in a mission. It has been observed that aerial observers respond to targets in a manner indicating that detection/ identification represents a continuum rather than discrete phenomena. At one extreme the response is based on the ability to merely discriminate the existence of a military object among non-military objects (detection) [26–28]. At the other extreme the observer can describe the object in precise detail (identification). Factors considered for computing the Target Identification factor are target size, percent contrast, illumination, terrain, weather conditions, altitude and speed of the aircraft at time of target acquisition. **Target Size:** As target size increases, probability of correct target identification increases. It may vary from small to large tactical targets, including personnel, trucks, and tanks to big targets as bridges, runways and taxi-tracks. **Contrast:** Target/Ground Brightness Contrast is expressed as a percentage. **Illumination:** Detection performance increases as illumination increases. Effects of decreases in illumination occurring after sunset and before sunrise are very important and need to be considered. **Terrain:** Types of terrain have been defined in terms such as number of slope changes per unit area and average slope change. Four different terrain types have been defined-fairly smooth, moderately rough, rough, and very rough. As the roughness of terrain increases, percent terrain view decreases, and decrease in detection performance is observed. **Weather:** Temperature, humidity, and wind effects the performance of sensors (such as Radars) deployed, where as conditions such as Precipitation, icing, wind, visibility, fog, rain, date and time of operation, clouds, and storm effect the pilots' decisions in planning and executing the missions. **Altitude:** The relationship between altitude and target detection/identification is normally one in which there is assumed to be an optimal altitude; above and below this optimum altitude, detection is reduced. As altitude increases, detection performance decreases. As altitude is increased beyond an optimal point, detection probability falls off rapidly.

Data on all these factors are collected from meteorological department databases, handbooks and experimental field trials and heuristic knowledge from experts and defense analysts (in questionnaire form) are collected and recorded. They are then represented as decision matrices and decision trees which form the basis to design the membership functions and rules. The rules are then executed in the mission processing module and defuzzified to obtain the damage to target. These results are then compared to the expected output and fine-tuned before storing in the rule base. A decision to include the new rule or not is provided to the commander. Missions and results of the missions are stored as a case-base for retrieval and reuse of missions plans in new situations. The fuzzy linguistic variables used in the design of the game rules are as follows:

Mission_Success_Factor (with weather constraints): **[1–10]** {Very Low: [**0.0–3.5**]; Low with Moderate Risk [**2.5–5.5**]; Medium with Controllable Risk [**4.5–7.5**]; High with Moderate Risk [**6.5–8.0**]; Very High with Low Risk [**7.5–10.0**]} **Temperature:** [Very Low, Low, Moderate, High, Very High] **Fog-Haze:** [Shallow, Patches, Low Drifting, Blowing, Showers, Thunderstorm, Freezing, Partial] **Wind-Speed:** [Light, Moderate, Heavy] **Clouds/Cloud Base**: [Shallow, Patches, Low Drifting, Blowing, Showers, Thunderstorm, Partial]; [Height (ft)] **Visibility:** [Low, Medium, Clear] **Turbulence:** [Clear, Low, Medium, Heavy] **Storm/Squalls:** [Clear, Low, Medium, Heavy] **Sky Cover:** [Clear, Few, Scattered, Broken, Overcast, Vertical Visibility] **Terrain:** [**1–100**] {Fairly Smooth [**0–22**]; Moderately Rough [**14–49**]; Rough [**45–81**]; Very Rough [**75–100**]}.

Target Size (in feet): {Very small: [**0–100**]; Small: [**70–190**]; Medium sized: [**160–300**]; Large: [**270–400**]; Fairly Large: [**360–500**]; Extremely Large: [**450–900**]} **Damage:** Offset (in meters): {Very Less:[**0–23**]; Less: [**16–36**]; Medium: [**34–57**]; Large: [**56–80**]; Very Large [**78–100**]} **Weapon Target Match:** [**0–10**] {Poor: [**0–3.6**]; Average: [**3.36–6.669**]; Good: [**6.73–14.2**]}

Target Identification Factor: [**0–10**] {Very poorly identified: [**0–1.19**]; Poorly identified [**0.96–2.43**]; Average identification [**2.34–5.61**]; Good identification [**5.43–7.55**]; Excellent identification [**7.35–10**]} **Relative Damage (Damage relative to intended damage):** [**0–100**] {Mild: [**0–18**]; Moderate: [**16–36**]; Average: [**34–57**]; Severe: [**56–80**]; Fully Damaged: [**78–96**]}.

Data from meteorological database is used to train the network to apply a hybrid method whose membership functions and parameters keep changing until the weather forecast error is minimized (Fig. 5a, b). Then the resulting model is applied to the test data of the mission time and places en-route from take-off base, target and landing base.

5 Results Discussion

The fuzzy variables are used to calculate the Mission success factor based on the prevailing weather conditions generated by the ANFIS model, target identification factor and firing of the rules to compute the relative damage to the target. Offset is calculated using actual altitude, actual vertical flight path angle, actual wind speed and observed altitude, observed altitude, observed vertical flight path angle, observed wind speed by the weapon system trajectory calculation module and the aircraft speed as the input variables (Table 5). Offset is a measure of induced error, wind induced error, and vertical flight path angle induced error.

Case Mission ID # 001: Consider a large area-target of size of 550 ft to be attacked, where the fuzzy variables *target-ground contrast* 80 %, the *terrain*, rated 8, is fairly smooth, aircraft altitude is 900 ft, aircraft range is 5000 ft is flying at 100 knots speed. The *target identification factor* for this target is computed as "good" with value 7.32. (*In the tables below * denotes the Missions planned and executed when considering the Weather conditions.*)

In this mission, on firing the rules for inference, the offset from the desired point of impact is 29 m, considered "less"(i.e. fairly accurate targeting); *weapon-target match* is 6 (average), "good" *target identification factor* 7.32, the relative damage caused is 28.92 which is a "moderate" damage to the target. We consider two scenarios of weather conditions at the given place and time or the mission plan (Fig. 2). Weather conditions are identified based on the place and time of missions. The ANFIS model computes the Mission_Success_Factor as 8.4 when no weather conditions are considered, and reduces to 3.7 when weather conditions are considered in the JWSS (Table 3). These conditions also reduce the Relative Damage from 28.91 to 13.55 (Table 5) and *offset* of the weapon hitting away from the intended target increased from 29.03 to 37.54 (Table 6).

Table 3 Fuzzy rules to determine the mission success factor in weather conditions

MissionID	Temperature	Fog-Haze	Wind speed (m/s)	Clouds/base	Visibility	Turbulence	Storm/squalls	Mission success factor
#001	Moderate	Clear	Low-drifting	Clear	Clear	Low	Clear	8.4
#001*	Very low	Moderate	High	Low	Poor	High	Clear	3.7
#002	Moderate	Clear	Moderate	Scattered	Clear	Low	Clear	9.8
#002*	Very high	Haze	High	Low	Poor	Low	Squall	7.1

**denotes the Missions planned and executed when considering the Weather conditions*

Table 4 Fuzzy rules to determine the target identification factor

MissionID	Target size(ft)	Target-ground contrast %	Illumination (foot candles)	Terrain	Weather_mission success factor	Aircraft altitude (feet)	Aircraft range (feet)	Aircraft speed (knots)	Target identification factor
#001	550	80	40	8	8.4	900	5000	100	7.32
#001*	550	45	20	8	3.7	900	5000	80	5.67
#002	550	80	60	7	9.8	750	4000	80	8.03
#002*	550	45	30	7	7.1	750	4000	60	6.43

**denotes the Missions planned and executed when considering the Weather conditions*

Table 5 Fuzzy rules to compute the *Relative damage to target*

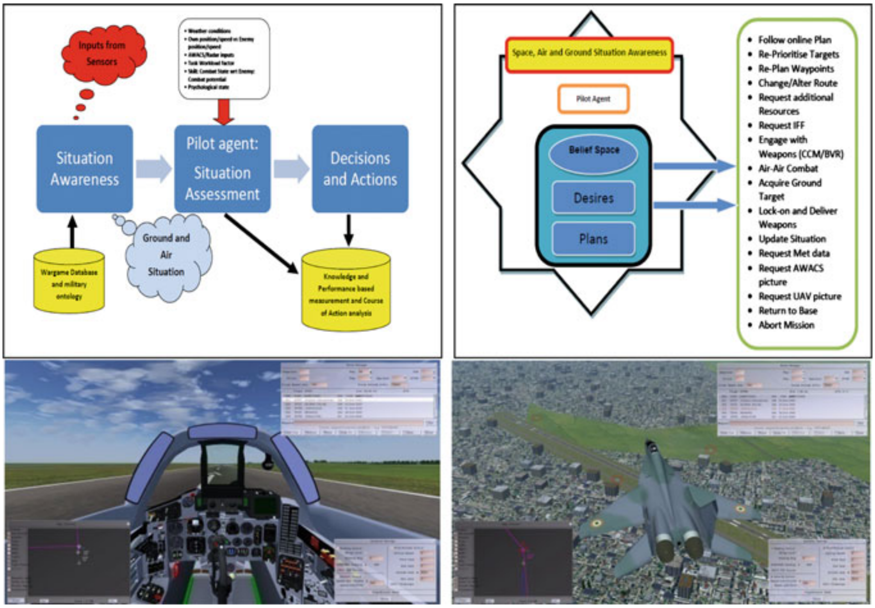
MissionID	Offset (meters)	Target radius (km)	Weapon-target match	Weapon delivery mode	Target identification factor	Relative damage
# 001	29.03	0.09	6	6	7.32	28.91
#001*	37.54	0.09	6	6	5.67	13.55
# 002	6.07	90.0	9	9	8.03	88.74
#002*	12.65	90.0	9	9	6.43	65.92

**denotes the Missions planned and executed when considering the Weather conditions*

Case Mission ID # 002: Another mission planned by the commander where a similar target is chosen with the fuzzy variables as shown in Tables 3 and 4. While the offset has reduced to 6 m, considered "very less" (i.e. very accurate targeting), choosing a different weapon system and delivery improved the weapon-target match to 9 ("good"), and mode of weapon delivery 9, the *target identification factor* also improved to 8.033 (considered "excellent"), and the relative damage caused is 88.74, which is a "substantial" damage to the target (Tables 4 and 5). Weather conditions are again identified based on the place and time of missions. The ANFIS gives the Mission_Success_factor as 9.8 when no weather conditions are considered, and reduces to 7.1 when weather conditions are considered in the JWSS (Tables 3 and 4). These conditions also reduce the Relative Damage from 28.91 to 13.55 (Table 5) and *offset* of the weapon hitting away from the intended target increased from 6.07 to 12.05 (Table 6). These attributes form the antecedents of the fuzzy rule and the consequent is shown in the last column of the tables. For all the missions that the pilots plan in the wargame exercises, these fuzzy game rules are used to infer the expected damage caused to the target. These missions form a part of a case-base which is used as part of the '*learning*' by the system for future instructional use.

5.1 Modeling Pilot Agents in Air Warfare Simulation System

Advances in combat aircraft avionics and onboard automation, information from onboard and ground sensors and satellites, pose a threat in terms of data and cognition overload to the pilot. Under these conditions, decision making becomes a difficult task.



The factors identified in Table 7 are representative of the two pilots P1 and P2, who differ mainly in *Information Processing* and decision making, *Risk taking* and *Reaction to stress* which are typically identified personality traits. Data collected using clinical and psychometric tests for all the pilots are stored in the Pilot's database. These (fuzzy) attribute values from the pilot's database are fuzzified and used to determine the pilot's personality as one of the inputs to the ANFIS tool (Table 8).

5.2 *Data Mining Techniques and Reasoning in Wargame Results Analytics*

Having designed and developed the JWSS as an exploratory, battlefield experimentation, test-bed using an inner-sourcing, product-line architecture that supports multi-resolution models and a wargame process customization script to cater to various military training establishments, this test-bed serves as a platform for mission analysis, and doctrine analysis, using data mining and pattern analysis techniques. Digital Battlefield simulation and experimentation uses data mining techniques such as association, clustering, classification, learning, decision trees and rules that provide insights into the doctrines and their effectiveness [72]. Each of these methods use CI techniques, in turn, to arrive at realistic rules for doctrine assessment and evaluation (Fig. 18).

Table 6 Fuzzy attributes to determine the *offset* of the weapon from the intended target

Mission ID #	Apparent altitude (km)	Apparent angle (degrees)	Apparent wind velocity (km/hr)	Actual altitude (km)	Actual angle (degrees)	Actual wind velocity (km/hr)	Aircraft speed (km/hr)	Offset (m)
001	1.65	−26.9	−25.24	1.67	−26.9	−25.24	829.8	29.03
002*	1.65	−26.9	−23.9	1.67	−26.9	−25.24	820.1	37.54
002	1.65	−25.2	−28	1.65	−25.2	−30.4	830.2	6.07
002*	1.65	−25.2	−22	1.65	−25.2	−30.4	824.7	12.65

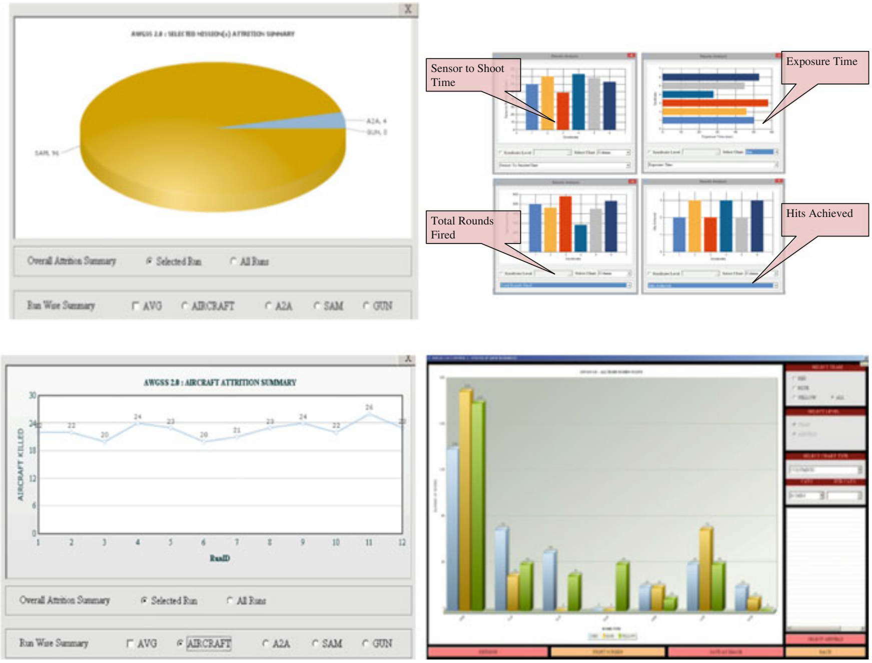
**denotes the Missions planned and executed when considering the Weather conditions*

Table 7 Pilot's attributes considered in the ANFIS

Pilot id	Personality type	Risk taking	Info processing and risk taking	Aviat or skills/experience	Firing skills/experience	Sensor-motor abilities	Personality leadership	Motivation	Reaction to stress	Physiological/medical health
P1	A	High	High	Very High	Very High	High	Excellent	High	Composed	Cat 1
P2	B	Low	Low	High	High	High	Excellent	High	Stressed	Cat 1

Table 8 Pilot attributes and decisions to determine the mission success factor in different training situations

MissionID	Combat aircraft	Mission Comdr	Sorties flown/day	Enemy air/ground defence Threat	Situation awareness	Entropy	Information overload	Combat potential ratio (MAUT) (Own: En)	Combat utility factor (ANFIS) (Own: En)	Subjective mental workload NASA-TLX	Situational decision of pilot (AWSS)	Mission success factor
#001 Sit 1	Multi-Role	P1	3	High	Veiy high	High	High	Static: 1:0.78 Dyn: 1:13	1:1.4	Low	Re-prioritize targets	8.7
#001 Sit 1	Multi-Role	P2	3	High	Very high	High	High	Static: 1:0.78 Dyn: 1:1.3	1:1A	High	Request additional resources	4.3
#002 Sit 2	Multi-Role	P1	2	Very low	Low	Low	Low	Static: 1:0.44 Dyn: 1:0.65	1:-0.3	Low	Lock-on and deliver weapons	7.6
#002 Sit 2	Multi-Role	P2	2	Very Low	Low	Low	Low	Static: 1:0.44 Dyn: 1:0.65	1:-0.3	High	Look for secondary targets	3.2



Sensor to Shoot Time

Exposure Time

Total Rounds Fired

Hits Achieved

Fig. 18 Battlefield experimentation, results analysis and doctrine analysis using data mining techniques

6 Case Study: Joint Warfare Analyses and Integrated Air Defence

Joint Warfare Simulation System has been designed and developed to meet the training and operational analysis requirements of military officers. It provides a platform for deployment of resources, weapon target matching, weaponeering assessment, force planning, force execution, damage assessment, quantitative results analysis and displaying reasoning for generating outcomes. As a training platform it can be used to train military officers in various roles in formulating and evaluating strategies and decision making processes, at tactical and operational levels of warfare. For operational analysis version, this can be used to find out the effectiveness and performance of various weapon systems, weapon delivery platforms, force multipliers, and sensors in a simulated battlefield scenario between two or more opposing forces.

JWSS has been designed and developed as a test-bed to simulate wide range of military air operations such as counter air missions, counter surface force operations, air defense missions, and combat support operations [2] between two or more opposing forces. It provides a platform for deployment of resources, weapon target matching, weaponeering assessment, force planning, force execution, damage assessment, quantitative results analysis and displaying reasoning for generating outcomes which is crucial for debriefing and learning purpose. It also computes the attrition rates, statistics of various operations & in-depth history of various events generated during the simulation which helps in analysis and validation of tactics and various operational objectives. This application when configured in training mode, trains military officers in planning missions to meet the objectives such as destruction of a synthetically generated target like an airfield, vital bridge, nodal point, or army installations. It uses extensive set of game rules to simulate wide range of operations. This application can also be configured as an analytical tool for operational analysis at the tactical levels for decision making. In the first phase of conducting any wargame exercise, the mission objectives are outlined to define which facets of enemy activity are to be affected by the mission. Based on these tactical objectives, with the study of target folder, suitable target damage criteria, force and ordnance requirements are defined to achieve the desired level of damage. In the third phase, combat models are used to define the type and quantity of weapons needed to produce the required level of damage, based on the desired mean point of impact and target elements. The outputs of this phase are essential inputs to execution planning. The Execution Planning phase assign missions to specific units, perform attack and support force packaging, determine attack timing, and outline communications and coordination requirements (C2/C3 structures). Detailed mission planning is also done in this phase. In Force Execution and Combat assessment phase, the missions are executed in simulation manager using game rules, acquisition models and damage assessment models and the results are assessed to determine if the objectives have been met, or re-strike is required. Some of the salient features of this simulation system are: Multi-Team War Scenario Analysis System, Training Toolkit, Tactical Deployment Evaluation & Decision Making Tool, Operational Analysis Tool to Evaluate Performance & Effectiveness of Aircraft, sensors, Weapon Systems and Missions, Electronic Warfare & Logistics Support, Weather and Terrain effects with customized GIS, Quantitative Evaluation of Mission Objectives and Plans, "What-If" Scenario Analysis. Screen shots of the JWSS software are show in Fig. 19.

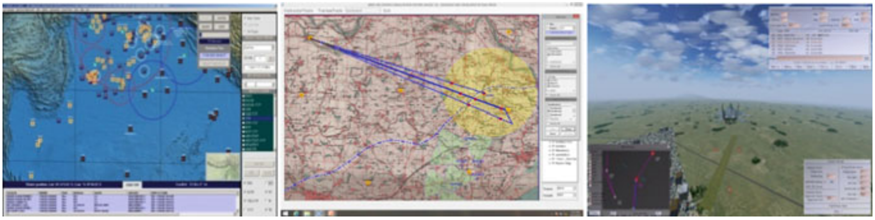


Fig. 19 Joint warfare simulation system as a common test-bed for multiple training products

7 Conclusions

In this paper, we have presented a Joint Warfare Simulation System, a digital battlefield test-bed, in which a war scenario between two or more opposing forces can be simulated. The planners plan various offensive and defensive emissions which are gamed against the perceived threat using the JWSS to assess the mission effectiveness. Some of the major components of the design are the joint forces scenario databases, military ontology, resource databases that contain the performance characteristics of weapons, sensors, missiles, aircraft, naval platforms, air and ground defence systems, target analysis, resource deployment, mission planning, target damage assessment and results analysis. Fuzzy sets and systems are used to represent the damage assessment techniques, game rules are designed using adaptive neuro-fuzzy systems, software agents are used to build on-board intelligent pilot model, where the pilot agent uses mission ontology to plan his mission automatically. An automated decision tool to generate the decisions of the pilot in various situations is also built in the system by considering the cognitive and behavioural characteristics of the selected pilot from the pilot database. Fuzzy Cognitive maps to represent the pilots' plans are implemented and NNs to model the pilots decision making ability. Mission Plans are automatically generated by specifying the mission objective, which in turn generates all the plausible courses of action, with varying mission costs and risks and utilising resource in the inventory. Military logistics planning is also done by the system to automatically generate the most efficient routes using AI techniques. This utilises the entire road/rail/air data during peace times and war times. Generation of automated mission plans, evaluating the effectiveness of mission plans, Red-teaming, Threat perception of the enemy, modeling counter-insurgency operations, are designed using computer generated forces and semi-automated forces with propositional, probabilistic and possible world approaches and evolutions using swarm optimisation techniques. Ontology to represent the common knowledge-base and representation of the adaptive lesson plans is implemented as part of the system. The conventional damage models built using cookie-cutter approximation are replaced by Fuzzy damage functions. These models are built and implemented as Joint Warfare Simulation systems that can be customised to meet the varying needs of the trainees. Weather and Environment variables are an important factor to consider in the assessment of mission plans and generate results. These are modeling using ANFIS. A Weapon-Platform-Target system that helps in matching and assigning the resources to targets is an important part of the Wargames that is matched using fuzzy inference systems. A Weaponeering tool that estimates the number of weapons to destroy a target with a given assurance level is developed. A Weapon target matching using GA and a tool to aid the planner in Optimal Deployment of sensors and resources is implemented using GA.

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