Simulating Urban Environment for assessing impact of Alternative Command & Control Netcentric Maturity Models within Asymmetric Scenarios

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ABSTRACT

This paper focus on the development of a simulation framework for assessing the effectiveness and efficiency of different alternative Command, Control, Communications & Computers (C4) solutions in an urban environment affected by asymmetric warfare.
The authors presents their approach in developing Intelligent Agents Computer Generated Forces (IA-CGF) non conventional framework (NCF) for project CGF C4 IT; in this context it is critical to measure the effectiveness of different C2 (Command and Control) Maturity Models involving local and coalition forces, police and other resources in an oversea urban framework; in fact this it is one of main goal for the CGF C4 IT project that it is devoted to investigate alternative C2 models for guarantee agility in complex scenarios. The CGF C4 IT Federation is an High Level Architecture simulator, designed by the authors, and currently devoted to support Italian Army Simulation Capabilities; this represents an innovative and effective solution for investigating by experimental analysis the C2 Agility concepts within complex framework with special attention to Human Behavior Models.

Keywords: CGF, IA, C2, Agility, M&S, HBM

INTRODUCTION

Since C2 (Command and Control) in a Network-Centric Environment introduces challenges with many entities interacting, complex phenomena, significant influence of many stochastic and human factors, it is usually necessary to develop advanced simulation models to face these aspects. In fact, currently, it is very critical to develop Modeling & Simulation (M&S) assets able to support experimentation in this framework to evaluate new and alternative approaches. In fact the authors propose an approach developed to model of C4 (Command, Control, Communications & Computers) within complex scenarios; this paper focus in particular on asymmetric warfare in overseas urban environments; the authors propose the use of their IA-CGF (Intelligent Agents Computer Generated Forces) Libraries, Units and NCF (Non Conventional Frameworks) as building blocks to create a federation able to study these phenomena in order to support different aspects such as training, simulation based acquisition and experimentation & testing; in fact the use of IA-CGF allows to run multiple scenarios quickly driven by intelligent agents, in this way it becomes possible to investigate alternative solutions and parameters influences as well as to estimate critical target functions such as reliability, efficiency and effectiveness over credible complex scenarios.

IA & C4 IN NETCENTRIC URBAN ASYMMETRIC ENVIRONMENTS

In fact, the aim of this research is to develop an interoperable simulator based on CGF (Computer Generated Forces) to create complex scenarios devoted to support evaluation and training on different C4 solutions such that ones proposed by N2C2M2 (NATO NEC C2 Maturity Model). Therefore, usually, development of innovative C4 solutions have a strong technological focus and don't pay too much on people and organizations, therefore on urban asymmetric scenarios the presence of HBM (Human Behavior Modifiers) at individual and organizational level have a very strong influence on the operations; it is evident that in addition to the technology network it is necessary to include effective models of human factors impact on the C4; this becomes even more important in NEC, in fact in this context mature models need to consider each single entity in relation to the entire information flow;

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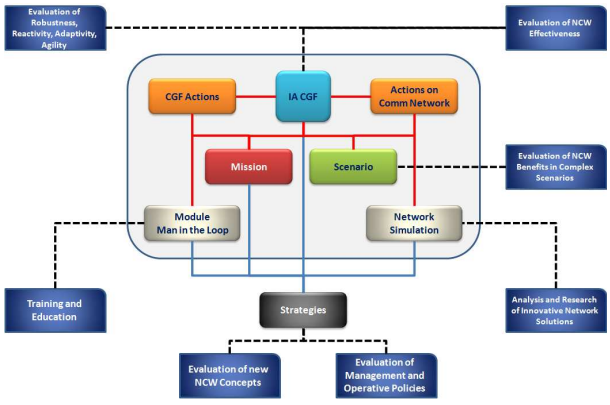
in addition, C2 is effective only if information flows result to be usable, reliable, consistent and influential for the elements of the network; in this sense a mature model must take into account the HBM and Social Networks in addition to the different approaches and methodologies designed to identify inaccurate or non-influential pieces of information. Thus, different architectures need to be tested, reproducing "intelligent" information processing. Considering these aspects, interoperable CGF designed to direct entities and to operate C2 in NEC need to demonstrate some intelligent capability in order to support the simulation of complex processes related to information sharing, processing and decision making; the authors propose to introduce intelligent agents able to apply various criteria and to define tasks, activities as well as to identify the most appropriate C2 policy duringt he dynamic evolution of the context. The authors defined how intelligent CGF have to be and how to use them to create and develop scenarios for verifying the real performances of C4 solutions in term of robustness and considering in-network functions (i.e. in-network data fusion, aggregation and routing).

TESTING NETCENTRIC ENVIRONMENTS vs. HUMAN FACTORS

A very important aspect in this context is related to the effect of human factors affecting elements in the organizations involved in C2 (i.e. stress, fear). It is evident that a C2 Mature Model should consider the HBM (Human Behavior Modifiers) in order to evaluate the man in the loop, the humans mistakes and to evaluate how people skills affect the overall complex system. In this paper it is proposed an innovative methodology based on the use of interoperable models integrated in an M&S environment aiming at testing the N2C2M2. The key to obtaining successful results is to create a Networking M&S environment that interoperates with intelligent CGF; the proposed CGF are the IA-CGF by simulation team that have been developed for experimentation and training on complex scenarios, taking care of technological, functional, operational & procedural aspects considering human factors.



In fact the Netcentric Evolution in Defense requires to develop Scenarios where to test effectiveness of Alternative Solutions in term of Infrastructures, Architecture and Management; Italian MoD launched in 2010 a new project on this subject titled CGF C4 IT, coordinated by Simulation Team MISS DIPTEM and involving directly and indirectly several entities such as: CAE, Mast, Selex Elsag, University of Genoa, University of Catania. CGF C4 IT goal is to develop and test a federation involving Intelligent CGFs (Computer Generated Forces) able to act as new technology enabler and to support coordinate actions on the battlefield in order to test NEC (Network Enabled Capability) solutions from technological and functional point of view; the intelligent CGF are expected to dynamically react to the Net Centric Resource Availability by using intelligent agents and with the benefits of previous researches carried out by Simulation Tema Genoa; the Italian MoD (Ministry of Defense) involved CESIVA (Center for Simulation and Validation of Italian Army) as opportunity to test the initiative within a military structure. In order to test different solutions the authors developed the CGF C4 IT federation that allows to test a complex scenario related to urban asymmetric warfare in an oversea mission environment.
The authors defined the elements to be included in the CGF C4 IT Scenario that include the following elements:

- Friend, Foe, Neutral and unknown Entities and Unitis on the Area
- Actions on the scenario affected by different Net Centric Frameworks and HBM
- Reactions to the dynamic evolution of NCW (Net Centric Warefare) and Communication Network Situation Evolution
- Actions devoted to restore, damage or compromise Communication Network for NCW

In addition CGF C4 IT projects allows to investigate different integration and interoperability solutions for Simulators with special attention to HLA (High Level Architecture) in term of effectiveness; in fact the IA-CGF used as agents are originally designed as HLA federates.
The CGF C4 IT project is based on several parts:

1. Feasibility Analysis related to the development of an environment where Intelligent Agent Computer Generated Forces (IA-CGF) operate within a Scenario affected by Human Factors, HBM, Communication systems and Network Centric Warfare (NCW) policies
2. Creation of a CGF C4 IT Demonstrator by developing an HLA Federation
3. Ad Hoc Metrics Development to tailor VV&A (Verification, Validation and Accreditation) on Simulation Involving CGF and C2 (Command & Control) in innovative Net-centric Environments

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4. Development of Innovative Procedures and Best Practices in NEC for evaluation of different policies, strategies and doctrines by using CGF C4 IT Demonstrator
5. Introduction in the simulation of factors affected by C2 Software, quantity and type of communications to/from Command Centers and related Information Dissemination Policies (IDP)
6. Development of a Module interacting with IA-CGF for generating alarms to the Command Posts related to network problems and possible solutions
7. Investigating the possibility to Demonstrate the capability to stimulate the C2 by alternative methods (i.e. Gateway, Demonstrator PNRM 37/05 BIT Fase 2 and/or SIACCON2 Database)

STATE OF ART IN INTELLIGENT CGF MODELING HUMANS

Current military missions need simulation models able to capture and foresee the behavior of humans acting in social units, ranging from small groups, cultural and ethnic groups, and entire societies. Individual, Organizational, and Societal (IOS) models are needed to understand adversary and non-adversary behavior and to forecast the effects of alternative courses of action on that behavior.

A number of research efforts on human behavior modeling aimed at understanding complex behaviors are under way to analyze the effects that diplomatic, information, military, and economic (DIME) actions will have across the full range of the political, military, economic, social, information, and infrastructure context (PMESII). An important part of today's missions focus on courses of action (COAs) for influencing the attitudes and behaviors of noncombatants.

Predicting the response to integrated DIME COAs requires the analysis of the effects that a set of DIME actions will have across the full range of PMESII variables. A successfully analysis lays in the development of behavioral models which allow the simulation of the full range of PMESII variables and how they are affected by specific DIME actions. Hybrid models combining different paradigms at different levels of modeling offer considerable promise for the simulation of large-scale societal behavior. Then, different classes of models are used in the field of human behavior simulation and three levels of modeling are generally considered:

- Macro level, macroscopic models abstract away from individual behavior in favor of a broader more holistic view of behavior.
- Meso level, meso models are often referred to as meso-level models. Typically the models represent interactions and influences among individuals in groups and cover both individual and group phenomena with their interrelations.
- Micro level, microscopic models emphasize the description of the behavior of individuals rather than the description of global characteristics.

At the macro level, we consider interactions between macro-level variables, such as unemployment, crime, education, poverty, and resources. Formal macro modeling approaches principally based on dynamic system paradigm enable one to identify feedbacks and to see global effects without getting bogged down in details. At the other extreme, one can model the cognitive or affective processes of individual actors or at least their individual decisions and actions. These more micro modeling approaches include cognitive models from psychology, expert systems models, and rational choice models, which include game theory and decision theory. Over time, social scientists have come to appreciate the importance of the level in between—the meso level.

These three levels of models used different modeling paradigms such as: concept maps, social network models, influence diagrams, discrete event models, differential equations, causal models, Bayesian networks, Petri nets, event-based simulation, and agent based simulation. The need for a variety of modeling paradigms also stems from the fact that the different domains of knowledge needed to represent human behavior cannot be done by only one paradigm.

At the same time in 2007 it was demonstrated the result of a EDA Project, coordinated by Simulation Team MISS DIPTEM, related to Intelligent Agents reproducing civil disorders; the demonstration was based on applying PIOVRA agents into a civil environments by interoperating with a constructive theater simulator creating a multi level scenario, where agents was dealing with town evolution combining paramilitary, military, population and health care units and the constructive framework was simulating strategic planning ; in these case the use of G-DEVS/HLA Models was devoted to reproduce the agents structure, while AI (artificial intelligence) techniques was used for soft computing the emotional and rational behavior and perception of the units .

As follow up of this project there was presented RATS (Riots, Agitators, Terrorist Simulators) where warlords and civil disorders models was further extended. Currently the authors are developing new CAPRICORN agents devoted to consider not only the parameters related to psychological and social aspects but even to direct these perception among the different players (i.e. attribute the fear of some specific event to some of the parties playing the game).

NET CENTRIC COMMAND AND CONTROL MATURITY MODELS

The concept of Net-Centric was established in military sector and introduced in the early '90. This concept is used to describe an operational paradigm that exploits information and technological infrastructure to increase

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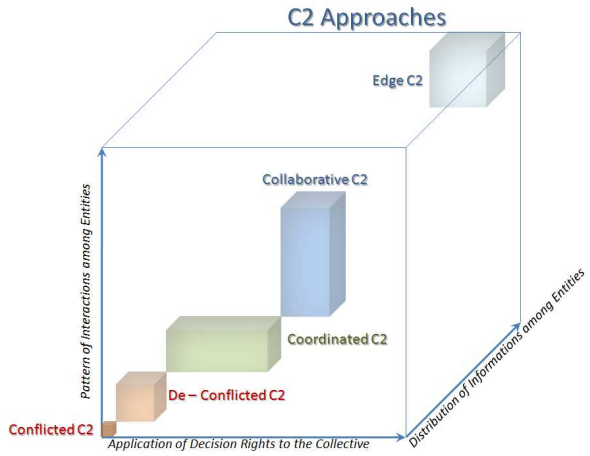
speed of command, resulting faster and more agile in carrying out operation and a sharing of knowledge. During recent years it was critical to consider how different C2 solutions are able to reproduce different maturity levels (i.e. conflicted, de-conflicted, coordinated, collaborative and edge).

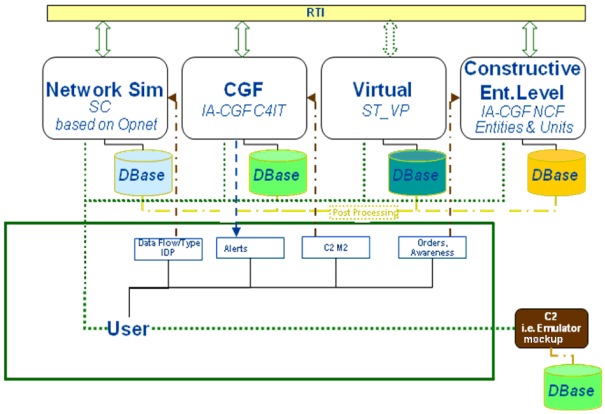


Nowadays, the critical issue on this matter is to develop experiments to support investigation about characteristics of C2 solutions such as robustness, resilience, agility. A major concept related to NecC2M2 (Netcentric Command and Control Maturity Model) is represented by the idea that in the same scenario over time, it could make sense to have different C2 maturity levels evolving based on the needs. Another important aspect is to test critical conditions or events that requires to adapt the C2 maturity level.

– Flat Model: IA-CGF Entities simulate units on the field (patrolling an area or checking critical points) and manages threats. Operative units are able to exchange messages in order to communicate and to transmit information about a potential threat or a particular event. For instance if a unit detects a threat (i.e. a suspicious vehicle or a potential explosion threat), it sends a message to the correspondent headquarters and/or to other units in the scenario.
– Hierarchical Model: In this case units transmit information in an hierarchical way directly to the relative chief or headquarter. If a unit detects a threat (i.e. a suspicious vehicle or a potential explosion threat), it sends a message to the higher level node, that sends the information to the involved operative units.

CGF C4 IT FEDERATION

The architecture for CGF C4 IT demonstrator is based on HLA (High Level Architecture) Architecture in order to create keep it flexible & expandable. Following the federation configuration:



The IA-CGF C4 IT Federation includes:

– IA-CGF C4 IT federate that is in charge of the simulation of the town including agents for each individual, social networks and human factors (developed by Simulation Team)
– IA-CGF C4 IT Entities & Units including the intelligent agents that are driving all the units and entities on the scenario (developed by Simulation Team)
– ST_VP Virtual Simulation Environment for demonstrating virtual interoperable capability in reproducing a urban NCW (developed by Simulation Team)
– SC Simulation of the Communications Networks (developed by Selex Elsag)

A real C2 integration was originally expected, therefore these external components evolution was delayed and it is currently in evaluation to just use some mockup or emulator on interconnection to demonstrate the concept; database structure is specific for each component considering the R&D Nature of the project, while obviously in case of further development it could become possible to automatically align the initial setup of the terrain DBases.

As anticipated the IA-CGF C4 IT simulator is the federate that is in charge of population management and human behavior modeling; the federate is based on IA-CGF Libraries and it represents a specific IA-CGF NCF ad hoc for the mission environment under analysis.

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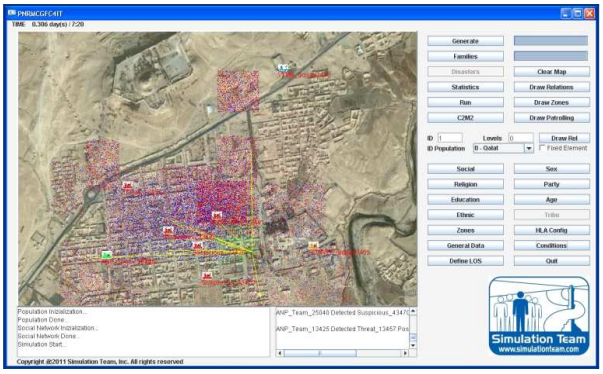
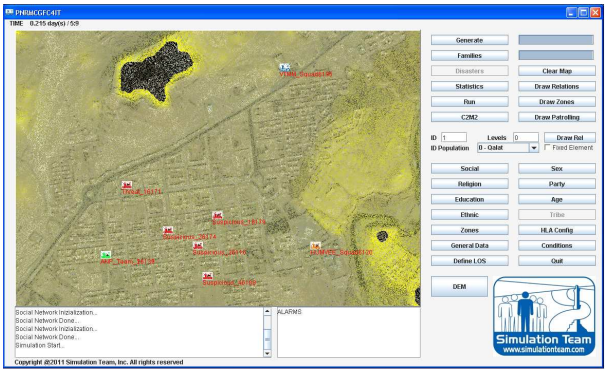


In fact based on the location chosen (i.e. in this case a 12'000 inhabitants town located in Afghanistan) and the reference local data inserted (i.e. different tribes and groups, statistical distribution in term of sex, ethnic, social level, education, religion, etc) IA-CGF C4 IT generates statistically the population for the specific scenario and based on user hypotheses; an agent for each individual of the population is generated and the model, after creating population, sets, based on similitude algorithms and parameters, the social connections among people (i.e. father, mother, son, daughter, friends). Referring to these connections the psychological parameters of each person evolve taking in consideration their specific social network and based on this fact every single individual influence other people as it is supposed to be happen in reality.

When the simulation starts people began to become alive (i.e. go to work, meet friends etc.) and they evolve based on events taking in consideration regular life, critical events, military presence and operations; even the units on the area (i.e. terrorist cells, snipers, squad, teams, platoons, etc.) are driven by IA-CGF Entities & Units. In fact IA-CGF Entities and Units federate drive the military operations and threat events:

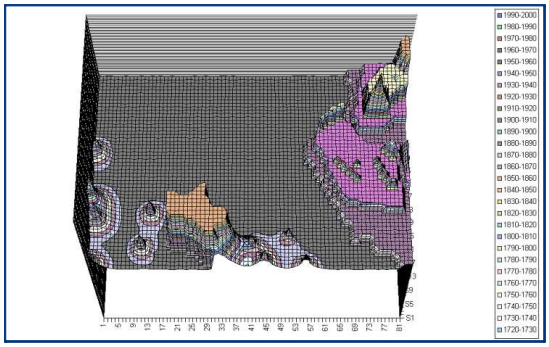
- COA (Coalition)
- ANA (Afghan National Army)
- ANP (Afghan National Police)
- Demonstrations and Riots
- Asymmetric Threats (i.e. Snipers)



For instance, the Sniper threat acts in order to maximize the impact of its actions; as intelligent agent, it is capable to attract military force by deploying and activating an IDE (Improvised Explosive Device) and the decide to attack selected targets or to retire based on its perception of the scenario that consider HBM and estimation on the measure of success probability; obviously similar process is applied by military units, and their activity depends on NecC2M2, military coordination and the coordination depends on communication. The communication is managed by SC (SC Simulatore delle Comunicazione CGF C4 IT) based on OPNET Technology.

This federate allows to know if the message/ information are properly distributed in communication networks: it simulates communication and networking component performances that in many scenarios (i.e. in the mobile and tactical scenarios) are often unpredictable due to:

– Effects of the land orography
– Low bandwidth available
– Presence of noise (environment or intentional jamming)
– Communication and networking devices probability failure
– Low availability of communication infrastructures



Integrated in the federation there is also a complex alarms manage system directly connected with the federation.

Alarm Module generates alarms to the headquarters based on messages and data from IA-CGF Entities & Units about network behavior and conditions, and specific solutions to be performed in such cases:

– Loose a communication node
– Inconsistent and incoherent formation
– Not allowed or broken Communication

The CGF C4 IT Simulator have been already successfully passed the integration test and preliminary demonstration running in a joint configuration involving IA-CGF C4IT, IA-CGF Entities & Units, and SC

AFGHAN COMPLEX SCENARIO & METRICS

The scenario proposed in this paper is bases on an Urban Area where units Communication Squad, Patrolling Units, Local Army, Police, Population, Terrorists, Blue Forces operates as a network of Intelligence, Surveillance and Reconnaissance (ISR) assets. The simulation cover several aspects including Communications, C2M2, Operative Actions, Terrorist

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Actions, False Alarms, Cooperation among friendly forces etc.

The IA-CGF are able to deal autonomously with their task, therefore the user is enable to inject events or to assign specific orders; an example of COA (course of action) to be investigated is proposed in the following as intelligent driven simulation scenario evolution:

- A Communications Group is deployed within an urban area in order to provide communication support to Friendly Forces
- Coalition Units provide Patrolling the Urban Area (i.e. 1 or 2 teams)
- On the Field also operate local army units and local police forces
- Town population evolve based on their life cycles on the area
- In the urban area there are threats and also suspicious activities
- Based on ROE (Rules of Engagements) and C2M2 (Command and Control Maturity Models) the units communicate and operate together in order to proceed in the detection, identification, classification and engagement of Threats
- Communication Units operates in order to guarantee communications
- Local Police and Local Army control the Territory and interact
- Threats operate in order to implement their plans
- Town population react based on their perceptions and scenario awareness.

All these entities and units as well as the town population are driven by IA-CGF; the authors defined the metrics for this scenario in order to support the VV&A of the CGF C4 IT Federation as well as to evaluate the effectiveness and efficiency of different C2M2 approaches within this NCW framework and even considering Urban disorders. Current the scenario involve Patrolling Units, Command Posts (PC) from Coalition and ANA as well and Police Forces (ANP) that will share information considering different C2M2 (i.e. Conflicted and De-conflicted).

In the current experimentation the threats are representing snipers within the Urban Context, urban disorders as well as IDE used to generate critical conditions by insurgents. Even in this simple scenario it is pretty complex to create an effective experimental analysis considering all the possible alternatives; in fact it is recommended the combined use of performance Metrics and Design of Experiments (DOE) in order to evaluate the effectiveness of different alternative C2 M2 (Command and Control Maturity Models) by the CGF C4 IT Demonstrator; it is evident that a main aspect in applying experimental techniques, in such a complex problems, it is to obtain the maximum quantity of information and knowledge about the scenario behavior with the minimum number of simulations runs; so in this case it is proposed to use:

- Means square pure error: in order to quantify the experimental error as measure of the risks and uncertainty on the simulation results in term of confidence bands
- Sensitivity analysis: by this approach it is possible to put in evidence what are main factors and their interactions that mainly influence variation of model outputs
- Metamodelling: approximate the real system behavior with metamodels able to support optimization on some controlled variable

Obviously for this kind of evaluation it is necessary to define the specific Measure of Effectiveness (MOE); for the proposed case study the MOE could result in something like: "to determine the capability of Forces to manage the threats in the proposed scenario through different policies, organization and infrastructures in terms of exchanging data, sensors, information and management reports and in terms of handling responsibilities, actions and tasks". In this case, for the sake of simplicity, the authors propose a set of Measure of Performances (MOP) that support the estimation of the above mentioned MOE and correlate the available forces with their effectiveness in term of time response and success issues.

By this approach the MOE and MOP address C2M2 respect Detection, Identification, Engagement & Agility capabilities in term of:

- Effectiveness
- Lead Time
- Success Probability
- Casualties
- Efficiency
- Private and PC Workloads
- Alarm Avoidance

Metrics are defined in order to measure operative effectiveness and communication network efficiency. MOP (Measurement of Performance) examples:

- Time to detect
- Time to engage
- Success rate
- Casualties
- Bandwidth Occupation
- Info processing workload
- Latency to delivery info

In fact the combined MOP for the CGF C4 IT experimentation are proposed by following relations.

$$MOP_d = k_{Act}\left(\frac{FEL_b}{FEL_{ref}}\cdot\frac{t_d}{t_{Act}}\right)^{-1}$$

$$MOP_i = k_{Id}\left(\frac{FEL_b}{FEL_{ref}}\cdot\frac{t_i}{t_{Act}}\right)^{-1}$$

$$MOP_e = k_{Eng}\left(\frac{FEL_b}{FEL_{ref}}\cdot\frac{t_e}{t_{Act}}\right)^{-1}$$

$$MOP_c = k_{Clr}\left(\frac{FEL_b}{FEL_{ref}}\cdot\frac{t_c}{t_{Act}+\Delta t_{Clr}}\right)^{-1}$$

$$MOP_{All} = MOP_d + MOP_i + MOP_e + MOP_c$$

$MOP_{d,i,e,c}$	Performance Index on the Target Function (TF): detection (d), identification (i), engagement (e), clearance (c)
$t_{d,i,e,c}$	time of achievement of the TF, in case of failure $\rightarrow\infty$
t_{Act}	expected threat activation time
Δt_{Act}	reference delta time expected to engage and clear the threat
$k_{d,i,e,c}$	Coefficient for Target Function
FEL_b	Blue Force Equivalent Level
FEL_{ref}	Reference Force Equivalent Level
MOP_{all}	Overall Performance Index

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The overall performance index allows to compare quickly different C2M2 alternative respect a specific mission environment; the authors are currently developing experimental analysis on a specific Afghan town representing an interesting case study.

CONCLUSION

The use of innovative IA-CGF, introducing new characteristics in Simulation Scenarios, enables advanced applications for testing in complex scenarios ideas, alternatives, solutions. In fact as proposed in this paper the Intelligent Agents driving CGFs provide a Competitive Advantage for using Simulation in Exercise/Planning & Operation Support respect existing tools and packages.
Obviously it is critical to define specific application frameworks, as proposed in R&D (Research and Development) Projects, in order to support the necessary activities for validating and verifying the effectiveness of different methodologies in creating specific interoperable solutions; for instance CGF C4 IT project provided an opportunity to integrate human factors, asymmetric urban warfare, communication networks and N2C2M2 in a complex interoperable simulation. The success of this initiative is strongly based on the experience acquired in using IA (intelligent agents) as well as on the availability of IA-CGF Libraries, Units and NCF. The authors are considering to further extend these models to cover new mission environments.

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