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A NEW SIMULATION FRAMEWORK OF OPERATIONAL EFFECTIVENESS ANALYSIS FOR UNMANNED GROUND VEHICLE

[1] LEE JAEYEONG, [2] SHIN SUNWOO, [3] KIM CHONGMAN
[1] Senior Research Fellow, Myongji University, 116, Myongji-ro, Cheoin-gu, Yongin-si, Gyeonggi-do, Republic of Korea
[2] Master's Course, Department of Industrial Engineering and Management, Myongji University, 116, Myongji-ro, Cheoin-gu, Yongin-si, Gyeonggi-do, Republic of Korea
[2] Professor, Department of Industrial Engineering and Management, Myongji University, 116, Myongji-ro, Cheoin-gu, Yongin-si, Gyeonggi-do, Republic of Korea

E-mail: [1]knduljy@hanmail.net, [2]seagullwing@naver.com, [3] chongman@mju.ac.kr

ABSTRACT

Unmanned ground vehicle like robot is one of the most effective weapon systems based on leading edge technology in the modern warfare. However, its efficiency is still a difficult question to answer. Especially, measuring the effectiveness of unmanned ground vehicle quantitatively needs a particular simulation framework to handle many different rule based agent modeling procedure. In this paper, we propose a new simulation framework for how to measure the operational effectiveness of unmanned ground vehicle in a small unit combat scenario. The framework is processed with following three phases. At first, we consider all relational factors for input and output variables in communication network environment of all platforms. Secondly, build a simulation model and select a measure of effectiveness based on purpose of the system performance. Thirdly, execute a simulation model and produce MOE in order to do output analysis.

Keywords: *Operational effectiveness, Modeling & Simulation, Communication error*

1. INTRODUCTION

In previous war-game model, its output results were typically based on the Lanchester-type equations which have many unrealistic aspects to describe a complex war environment. Therefore, in these days, agent-based modeling (ABM) draw attention because they can provide more realistic results according to their own decisions and actions for all platforms in a complex battle environment.

If the agent-based modeling method is applied to the war-game model, the fidelity of the model can be improved since many parameters and their interaction behaviors in the battlefield can be taken into account so that ABM makes war-game results more realistic. Hence agent-based modeling techniques would be more useful in the future simulation field. Additionally, in previous war-game models, communication error effect (CEE) are not considered and their cause and effect results to weapon system effectiveness are not reflected either. However, CEE is the one of the most important factors in network centric warfare (NCW) because all platforms in a battle are connected each other not only to share target and damage information but also to order and report among related units based on chain of echelon. Therefore, in this study, we consider both agent-based modeling and communication error effects in a network centric warfare environment.

2. KEY THEMES OF THE RESEARCH SCOPE

2.1 Wargame Simulation Scope

To build a new simulation framework to measure the UGV effectiveness, we setup a typical combat scenario in a small unit battleground which is different from theater level wargame.

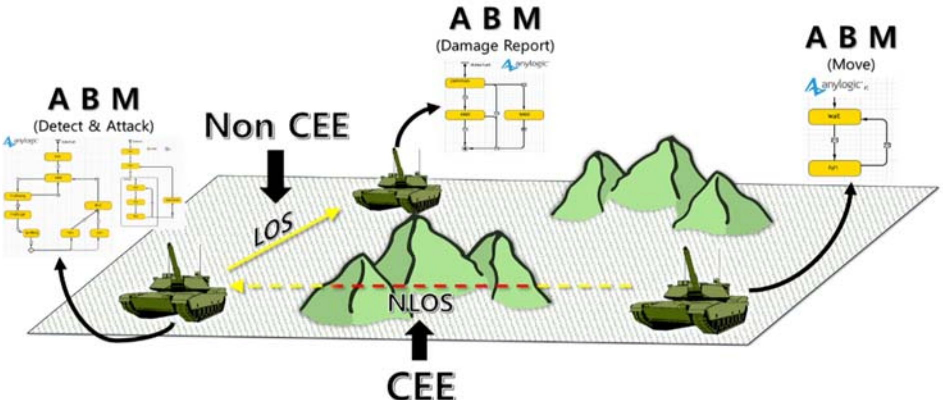

Figure 1: Configuration of a typical battlefield in high resolution

This means that our simulation scope narrows down to high resolution of the battlefield. The simulation framework we propose consists of three key themes such as ABM (Agent Based Modeling), CEE (Communication Error Effect), LOS (Line Of Sight) as shown in Figure 1.

For the representation of communication error effect, we depicted the altitude of the terrain in the model. For this purpose, different altitude level is expressed by each small cell area depending upon geographic surface pattern of the battle ground. When line of sight between two platforms is seen through, no communication error effect would be applied. On the other hand, if line of sight between two platforms is blocked it will break into two cases of LOS descriptions. The Case 1 is called block cell LOS and Case 2 is called round cell LOS. The former assumed that levels of height are all the same in each cell and the latter assumed that levels of height are decreasing as it goes from the center of each cell of the terrain as shown in Figure 3.

We use AnyLogic 7.0 to represent all these conditions and to validate the logic in war-game environment.

2.2 Agent-based modeling

In this paper, we study an agent-based simulation model framework to construct a scenario dependent war-game. In order to build war-game simulation using agent-based framework, rule-based approach must be established. For example, a war-game model requires a digital map called a battlefield agent, and many other types of agents acting on the battlefield such as Tank, APC, UGV, and C2, and each agent has its own acting rule-based framework.

2.3 Communication failure function

To consider the effect of communication error within a war-game model, we use the path loss model, which is one of the functions describing communication in the physical layer between TX(Transmitter) and RX(Receiver), as a method of expressing communication. This model is based on

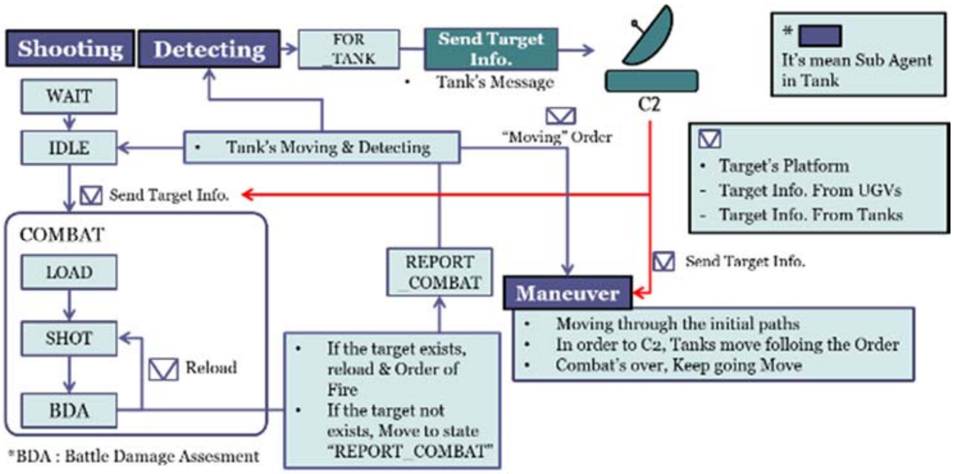

Figure 2: Processing flow of a communication effect

free path loss function and is implemented by the communication channel environment and the distance between TX and RX.

Table 1: Path loss functions applied to evaluate the communication effect

Scenario		Path loss [dB]	Shadow fading Std [dB]	Applicability range, Ant. height default value
C1	LOS	- $A = 23.8, B = 41.2, C = 20$ - $PL = 40.0\log_{10}(d[m]) + 11.65 - 16.2\log_{10}(h_{TX}) - 16.2\log_{10}(h_{RX}) + 3.8\log_{10}(f_c[GHz]/5.0)$	σ= 4 σ= 6	$30\text{m} < d < d_{BP}$, $d_{BP} < d < 5\text{km}$, $h_{TX} = 25\text{m}$, $h_{RX} = 1.5\text{m}$
	NLOS	- $PL = (44.9 - 6.55\log_{10}(h_{TX}))\log_{10}(d[m]) + 31.46 + 5.83\log_{10}(h_{TX}) + 23\log_{10}(f_c[GHz]/5.0)$	σ= 8	$50\text{m} < d < 5\text{km}$, $h_{TX} = 25\text{m}$, $h_{RX} = 1.5\text{m}$

2.4 Terrain Cell

In the communication environment at battle field in the real world, there are highly influencing variables like surface of terrain shape, power of communication, receive/transmission environment etc. In order to consider CEE depending upon the surface of terrain shape, battle field in the model breaks into many small cells and each cell produces its own variable that influences communication environment like altitude and terrain characteristics. Hence, in the early stage model we applied cells describing square altitude (Case 1 in Figure 3), but in the latest model we use cells describing terraced altitude along the radius in each cell (Case 2 in Figure 3). In this way, if agents communicate between two positions, Case 2 has more chance to be communicated than Case 1 has. Basically, Case 2 gets more realistic responses from the battle field than Case 1 does.

3 MODEL DEVELOPMENT

3.1 Multi Agent Based Modeling Concept

To overcome the limitation of simulation for modeling a complex war-game problem, we applied the conceptual method called “MAS (Multi Agent Based Simulation)” which has been introduced for many recent papers. In the Agent Based Modeling, there are two types of agent architectures required: The cognitive agent architecture and the reactive agent architecture.

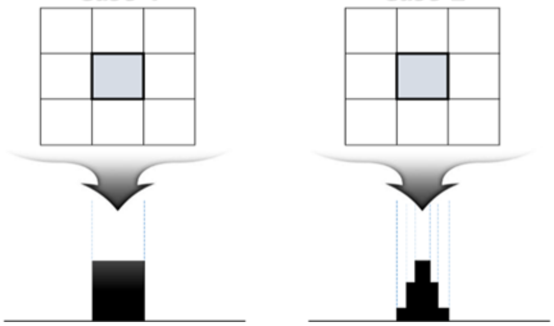

Figure 3: Two different altitude patterns for each terrain cell

3.1.1 Cognitive Agent Architecture

The cognitive agent performs as the sea of data base, which provides and collects the necessary data and knowledge to make plans. Moreover, the agent will interact with other agents to communicate and cooperate for data exchanges in the so called cloud environment. Cognitive agent was categorized as the intentional and deliberate agent since it was operated to follow plans in order to achieve the target. Besides, the cognitive agent also has internal representation and reasoning mechanisms which lead to the independent abilities of each agent to complete the tasks individually. Distinctly, it could predict the possible outcomes of

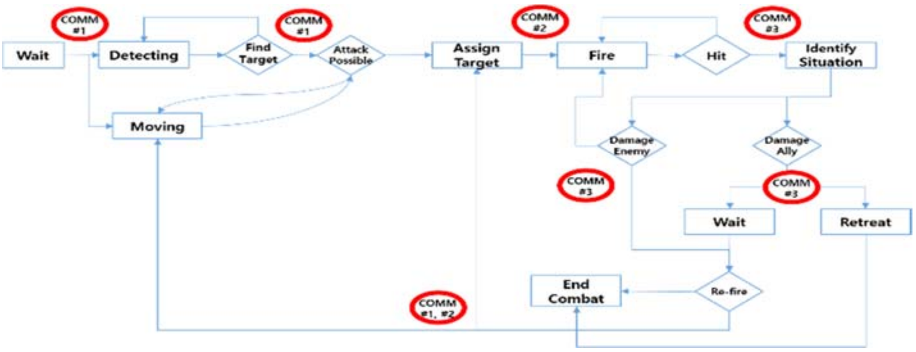

Figure 4: Typical behavior of the combat process in the battle

its actions and then make plans for achieving its goals.

3.1.2 Reactive Agent Architecture

Agents will react between each other and also with the changes in the environment in a stimulus-response. In addition, an intelligent behavior of a system does not require each agent within the system to be intelligent individuals. The intelligent behaviors may emerge from a set of local rules and conditions from internal part, i.e. the agents were forced to actuate follow the paradigm to accomplish the tasks as well as from the external source based on the conditions the agent uses to make its arrangement. In contrary with the Cognitive Agents, reactive agents do not have any representation of their environment and any reasoning mechanism but the info received from other Agents and the environment provided the stimulus actions. Distinctly, reactive agents do not make any plans but decisions. Having limited information exchanges to each other between Agents and environment made them incommensurable with cognitive agent in terms of intelligence, they could only adapt and unfold as the result from their basic interactions. Group level rather than the individual level is the best spectacle describes the intelligence of the reactive agent, swarm intelligence of an ant colony, for instance.

3.1.3 Hybrid Agent Architecture

As mentioned above, only one type architecture has limitations for solving problem. So, if we mix the two types, it can express in the real world better. For the combat simulation of small battalion, we use 2 dimension architecture as shown in Figure 5. In the 1D layer, there is reactive agents layer like detection agent for the detected the enemy, communication agent for the interaction. And in upper layer, it's cognitive agent layer.

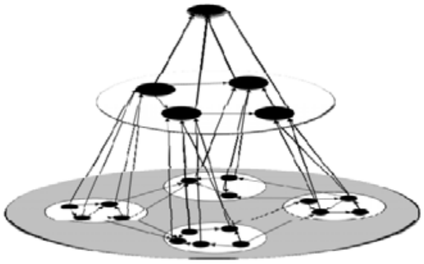

Figure 5: Two dimension architecture

3.2 Agent components for Multi Agent Based Simulation Model

3.2.1 Maneuvering Agent

In case of the Maneuvering Agent, it can be applied to maneuver for Tank, APC, UGV. It has a role to move to the enemy space using the nearest path detected by detection agent. During the situations of combat, maneuvering agent moves to enemy or detected by enemy, and ends up to the upper layer agent (Unit agent).

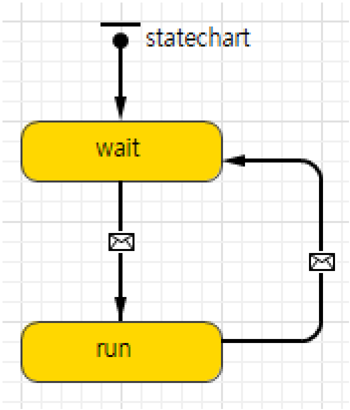

Figure 6: Statechart for maneuvering agent

3.2.2 Shooting Agent

Shooting Agent takes a role to shoot to the target which is a detected enemy, it applied only to tank because tank is the agent for combat. If detect agent gets information of detected enemy by itself or UGV, it receives the message like "fire to target" and create "cannon agent" that calculates a BDA results, probability of hit in environment. After shooting (create cannon agent) it searches for another target for the follow-up attack. If the target is destroyed, it sends a message to upper layer agent saying "end combat" and turns to be an idle state.

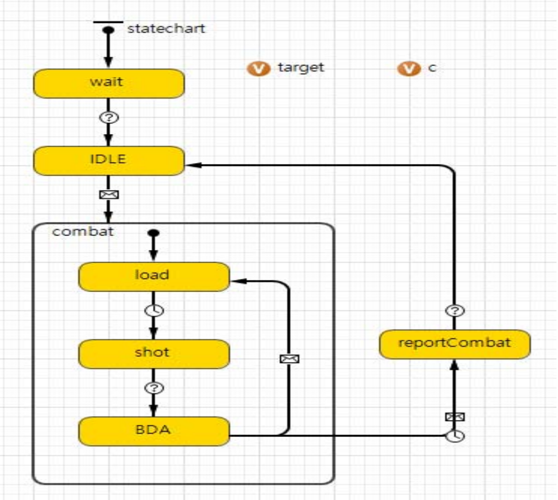

Figure 7: Statechart for shooting agent

3.2.3 Detection Agent

Detection Agent can be a sensor for all agents. Its main role is detecting enemies and sending to other agents that need target information. If it detects a target, it sends a message "fire to target" to C2 agent using communication. And when upper layer unit is busy for another engagement, it has to wait until its state becomes idle.

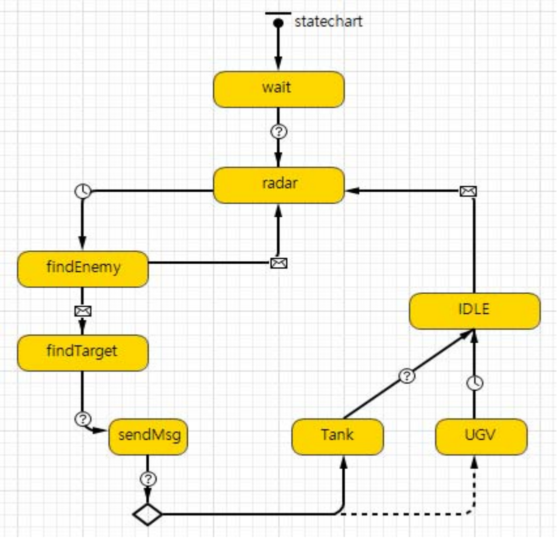

Figure 8: Statechart for detecting agent

3.2.4 Communication Agent

Communication Agent is a lower layer agent (reactive agent) that can be a role as a channel of information exchange for transmitting and receiving all commandments. For example, a command "fire target" by the detecting agent which can exist in a Tank, UGV, or C2.

The overall process of communication agent is as follows. Both TX and RX can create communication agent having an information. And TX sends to RX a message that "communication start". Rx received the message transmitting an Acknowledgment (ACK) message saying that the corresponding message is received from TX. Then both channels open to communicate and now it is possible to send an information/order like a specific coordinate or message. While this process is successful, communication agent created in the TX, RX is deleted after passing the command.

There is another role for communication agent. If transmission fails within 2 seconds, transmission is attempted again. If this process is not performed within 3 times, we assumed that transmission / reception is regarded as failed.

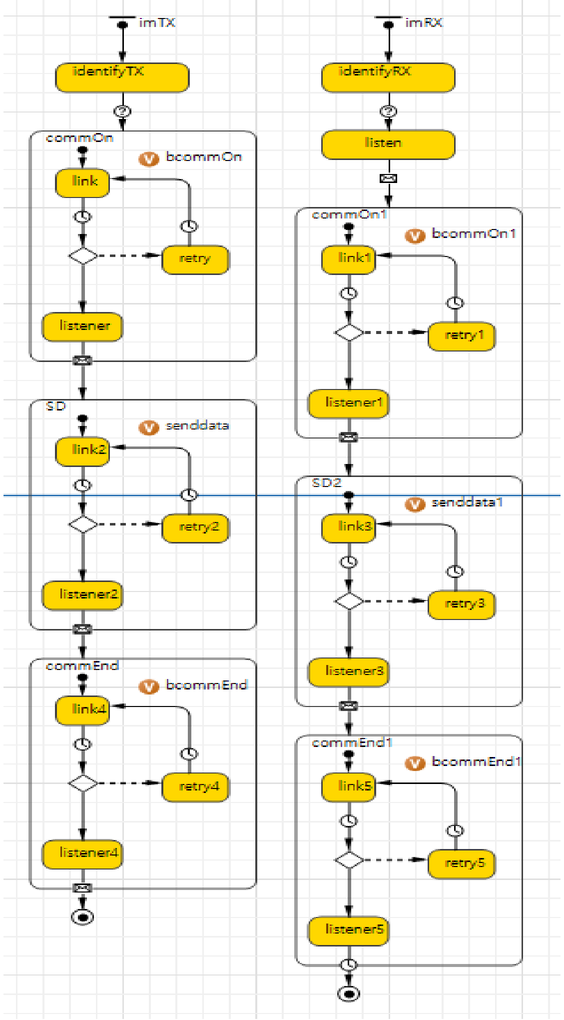

Figure 9: Statechart for communication agent

3.2.5. C2 Agent

C2 agent delivers all kinds of messages either to send orders or receive information needed via communication agent. It belongs to one of lower layer agent and give orders to tanks, and UGV. It also collects enemy target related intelligence. For example, as for UGV, when it finds enemy target its information goes into C2 agent with a message “Find”. Then C2 agent runs inner process and gives an order either “Move” or “Fire”.

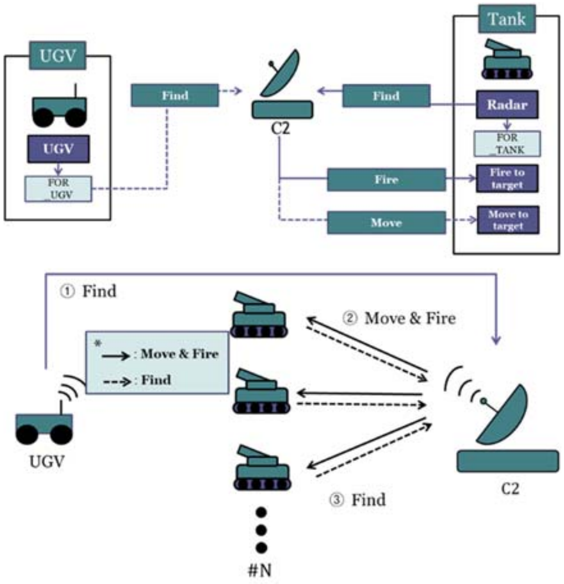

Figure 10: Role of C2 Agent

3.2.6. BDA Agent

When the battle occurs we need to do battle damage analysis, what is called DBA, which produces casualties of both Red and Blue forces. BDA agent also belongs to lower layer agent group and do assessment to calculate the casualties during the battle. When a platform was hit by adversary weapon it turns out one of three cases such as M-Kill, A-Kill, and T-Kill as follows.

1) M-Kill: mobility kill, it cannot move but is able to fire to enemy targets.
2) F-Kill: fire kill, it cannot fire to aiming targets but move to other location.
3) T-Kill: total kill, it is the case of total destruction in both mobility and firing capability.

Hence, in M-Kill case, it stays there and keep on doing the firing mission whenever needed to do it. Maneuvering agent is automatically disconnected with M-Kill agent.

On the other hand, in F-Kill case, shooting agent is disconnected and keep on moving based on mission whenever needed to go to other places.

When T-Kill case happens, it disappears in the battlefield until the end of that replication of wargame.

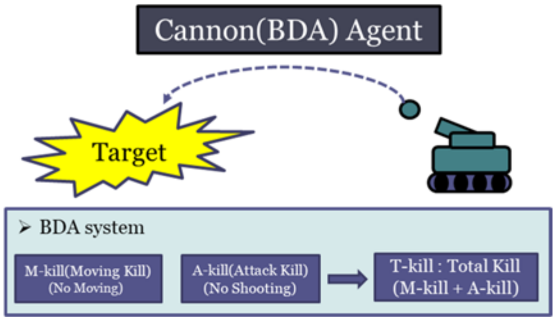

Figure 11: Role of BDA Agent

3.3 Properties of the sequence selection

There are three kinds of agents implemented to war-game simulation. At first, a battlefield agent is established. The battlefield agent has several variables such as battlefield environment, cell-based terrain, altitude, topography type, etc., Secondly, a unit agent is used to describe to act on the battlefield: the unit agent refers to all agents operating in the battlefield. For example, in this war-game model, the unit agent is represented by tank, UGV, and C2. Finally, we use the sub-agent which constitutes the unit agent. The sub-agent is created to assist the function of the unit agent. For example, in case of tanks, they have many function based actions such as maneuvering, detecting, and shooting, etc.... And all unit agents have their own rules that are automatically activated in the battlefield agent.

3.4 Communication implementation

In order to represent for communication error in war-game model, it was implemented based on path-loss model and this is called a communication agent in the model. As shown in Fig 3, we used 2 types of functions according to terrain environments, distance between TX and RX, and availability of LOS.

3.5 Measure of Effectiveness

To analyze the effectiveness of UGV in a simulation model, we need to determine a measure of effectiveness (MOE) showing the level of operational effectiveness in a battle. The BSR and RSR are calculated in the following two processes.

1. Remaining assets (BT / RT) are calculated at the end of engagement for both sides.
2. Compare them to initial assets (B0 / R0) and count their ratio for both sides.
3. BSR/RSR were calculated by equation (1)

$$BSR = \frac{B_T}{B_0} \times 100 , RSR = \frac{R_T}{R_0} \times 100 \qquad (1)$$

Hence, BSR and RSR represent the ratio of survival assets compare to its original assets respectively. In other words, they are nothing but Blue survival ratio and Red survival ratio after the battle is over. The condition of the battle termination is supposed to be predefined before the simulation run.

3.6 Scenario

To design the experiment, we use the following three scenarios which are different from the type of LOS existence. In Scenario 1, each cell has same altitude in all region in that particular cell. However, in Scenario 2, unlike Scenario 1, an altitude is decreasing as a point location moves to the outer edge of that particular cell from its central point. Scenario 3 has simply clear LOS without any obstacle.

TABLE 2: SCENARIO TYPE AND THEIR ASSETS

Type	Scenario 1	Scenario 2	Scenario 3
Blue (Attack)	Tank 30, UGV 2	Tank 30, UGV 2	Tank 30, UGV 2
Red (Defense)	Tank 15	Tank 15	Tank 15
Remarks	Block Cell LOS	Round Cell LOS	Clear LOS

4 OUTPUT RESULTS

4.1 Modeling Implementation

We are currently developing an agent-based simulation model. As we explained in section 3, multi-agent based simulation modeling approach was applied to build the model. Basically, upper layer agents represent the platforms like tank, UGV, C2 and lower layer agents represent each functions like move, fire, search and detect, send and receive both ordering and reporting messages.

Therefore, we are supposed to use this modeling methodology to analyze the results.

In addition, we consider the effect of communication error in the model as a distinction from other research. To do that, we use several communication path loss functions that consider different situations of terrain condition. The different terrain conditions we considered are either city or country which varies the level of LOS in communication among platforms. Figure 12 shows the results of varied MOE level depending upon each LOS condition respectively. The values in vertical line (y-axis) represent BSR in different LOS cases.

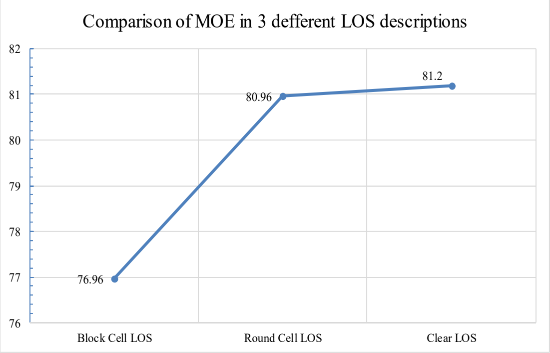

Figure 12: Simulation results for three scenario types

4.2 Model output analysis

As we expected, as shown in Figure 12, BSR values are different from each LOS situation. The better LOS they have, the higher value of BSR they get after battle termination. This means that communication effect is highly depending upon the level of LOS. In other words, Clear LOS situation improves BSR sharply compared to Block Cell LOS situation, but slightly higher than Round Cell one.

Based on this output results we can presume the following three perspectives.

At First, as we expected, LOS is the most important factor to affect communication success rate. This means that we have to consider LOS issue related to platform communications no matter what kind of ground battle situation.

Secondly, the level of detail in describing terrain condition is another key factor to cause to make the difference in MOE calculation. Therefore, the more breakdown in LOS situation, the more accurate results we can observe in a ground combat scenario.

Thirdly, the pattern of altitude level in each cell terrain have to be carefully defined since its sensitivity according to its MOE value seems to be high enough.

5 SUMMARY AND FURTHER RESEARCH

We proposed a new simulation framework using multi-agent based modeling procedure. To show the operational effectiveness of UGV in a nearly real situation of the battlefield, we consider both communication error effect and line of sight depending upon the altitude of terrain cell.

The MOE values we made show that LOS and CEE are highly correlated each other based on perspective to operational effectiveness of UGV. This means that Clear LOS scenario gets higher value of BSR compared to Block cell situation, but slightly better to Round cell one. However, this particular result pattern may not always be the same in all environment of the ground battle situation.

Therefore, we need further research to describe more detail terrain surface description and apply to the simulation framework we proposed. As for the detail description for terrain cell data, the following two issues have to be taken into account.

1) The first issue is how many cases to describe each terrain cell have to be considered. This is the number of cases breakdown into different scenario in each case.

2) The second issue is what kind of pattern to describe each cell terrain because terrain environment is supposed to be very different and sometimes unique.

Both issues above are highly correlated to the level of fidelity in a ground battle description.

Not only that but also we need to compare the results from using different types of path-loss function by considering communication error effect. This is quite clear because success rate patterns are different from each path-loss function.

< ACKNOWLEDGEMENTS >

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