ABSTRACT

We suggest the C2 modeling method to develop a simulation model for training command groups which consist of commanders and staffs. By using C2 models in constructive simulation models, combat entities or units directly receive and execute orders from a command group without mediating human role players. We also compare combat results from suggested modeling method with the results of existing models by building and implementing a simulation model with C2 models. Our analysis by comparison demonstrates advantages of suggested method to model C2 for computer assisted exercises.

Key words : Command and Control (C2), Computer Assisted Exercise (CAX), Modeling and Simulation (M&S)

1. Introduction

The purpose of the computer assisted exercise (CAX) is to train a commander and staffs by use of simulation models. We limit the meaning of CAX to the command post exercise even though the meaning of CAX is more wide such that encompasses live exercise, command post exercise, etc[1]. The CAX is performed periodically to train the command group in the US and ROK Army, and it is called the battle command training program (BCTP). The BCTP is the only mean that enables the command group of unit to train how to command and control the unit and assets in the battlefields.

Hence, there should be connecting means between the command post and the wargaming model. In the BCTP, a number of role-players operate a wargaming model as the connecting means. Role players are trained to operate units or combat entities of the wargaming model as they are ordered from the command post. The role players also report to the command post about battlefield situation simulated in the model. The simulated situation includes 1) states of units or combat entities the role players take charge of..
and 2) detected opposing forces.

Role players take charge of one or more minimum-level units, which cannot be operated separately in the model. Which level of unit is the minimum-level unit can be defined differently for wargaming models. It can be said that there is no difference between tasks of role players and company commanders except that units and combat entities a company commander should control are real while a role player controls virtual entities simulated in the model. In this respect, a commander of a minimum-level unit should operate his or her unit in the CAX. However, the commander cannot participate the CAX in most cases since the CAX is an exercise without real maneuver, and thus, the commander should control his or her real troop during the CAX. There are two problems inherent in this system. The first is the possibility that ability of role players to operate the wargaming model affects the combat results. Success and failure of the CAX can be determined by the ability of role players. Another problem is about the cost of role players. Training audiences of a unit select soldiers as role players and train them before the CAX. The role players cannot commit themselves to their duty for period of the CAX, which includes terms of preparation and after action review. If we can train a commander and staffs via CAX without role players, there will be no such problems.

Therefore, we suggest to introduce C2 modeling for wargaming models, which is built for the CAX. Since the purpose of the CAX is to train a command group about how to command and control a unit, what is needed is not to model whole C2 structures and processes for the unit, but to model C2 processes for the minimum-level unit. Higher units than the minimum-level unit should be commanded and controlled by training audiences for the purpose of CAX. If the minimum-level unit is a battalion, we need to model commanders of companies and platoons which belong to the battalion.

The key to model a commander for the CAX is to make the commander understand inputs in the form of tactical control measures. The inputs are results of C2 processes performed by training audiences, and the inputs are given by training audiences without role players’ operation.

Fig. 1 illustrates the concept of C2 modeling for the CAX. If inputs follow the form of tactical control measures, which is used as the order format in real military operations, training audiences can directly operate the wargame model without role players.

This may reduce the number of role players required for the BCTP. In addition, this can eliminate 1) possible errors in communication between training audiences and role players or 2) biases in combat results due to the difference of abilities of role players. For this concept, the commander model should be able to understand the tactical control measures and controls combat entities during the simulation. The roles of the commander model is to 1) receive inputs in the form of tactical control measures, 2) receive reports from combat entities, 3) assess situations based on orders (inputs) and reports, 4) make decisions based on the situations, and 5) issue orders to combat entities.

![Fig. 1. The concept of C2 modeling for computer assisted exercise](image)

We limits the scope of C2 modeling in the CAX to entity-level combat modeling. Entity-level models describe detailed behaviors of individual combat entities while unit-level models usually represent loss of a unit's combat power according to attrition rates\(^2\)\(^-\)\(^4\). The attrition rates is obtained from statistical data from real warfare. Lanchester model is a typical example to describe the loss of combat power by time using differential equation\(^5\)\(^,\)\(^6\). Hence, it is difficult to apply C2 modeling to unit-level models.
The simulation results of entity-level models can be intuitively acceptable to training audiences with detailed description while it is sometimes hard to understand the results of unit-level models. On the other hands, entity-level models limit the size of simulated entities and geographic scopes wile unit-level models are computationally efficient\[2,3\]. Even though resolution of modeling for wargaming models of the CAX depends on the objective of models, recent wargame models for the CAX have tendency to aim entity-level modeling since 1) it is useful in distributed simulation environments in terms of interoperability\[7\], 2) it is flexible to respond contemporary warfare which is hard to estimate based on military doctrine, and 3) it enables to easily analyse the causes of combat results.

This paper provides how to model C2 for the minimum-level unit for CAX using the C2 process model suggested in [8]. The C2 process model is able to 1) directly receive orders in the form of tactical control measures from training audiences, 2) process the orders based on decision-making rules established by doctrines, tactics, and simulation scenarios, and 3) make subordinates or combat entities behave as ordered.

Firstly, we propose the concept and method to model C2 for the CAX. We adopt the C2 process model suggested in [8] as following steps: 1) define commanders classes, 2) define communication messages, 3) model commander model (CAM) and interactions between CAMs, and 4) define decision methods and rules. It follows execution framework of C2 process, but the key is to define the communication messages as real-world operational orders.

In addition, we perform a case study for an example. Assuming that we develop a entity-level based wargaming model for the CAX of infantry regiment or brigade, We model C2 process of a company, which is the minimum-level unit in that case. To figure out differences by comparison, we build a simulation model of a company without C2 models. We also investigate simulation results of a unit level model for the comparison.

2. Methodology to model C2 in CAX

We propose to introduce commander models, which can play as commanders and leaders of the subordinate units, to eliminate this discrepancy between the CAX and real exercise. Introducing commander models can also 1) reduce the number of role players required and 2) prevent possible errors in combat outcomes cased by role-players' operational ability. We follows modeling framework for execution in C2 processes in [8]. Planning in C2 processes is the role of training audiences in the CAX.

2.1 Modeling commander class

For the wargaming model of CAX, the level of unit that requires commanders is the one step – lower unit than the minimum-level unit. Commanders of the minimum-level units may be included in a group of training audiences, and thus, they should operate combat entities of their minimum-level units. For instance, if we develop a wargaming model for CAX of infantry regiment, the minimum-level unit is a infantry company, and platoon leaders should be modelled as commanders.

Fig. 2 shows an example of commander class assuming that the minimum unit is a battalion. The battalion commander orders company commanders, and the orders are composed of tactical control measures such as missions, situation of opposing forces, status of friendly forces, tasks the companies should accomplish, and so on. The format of orders varies depending on levels of echelon, types of operation, and so on, however, the format is regulated by doctrines.

2.2 Modeling communication message

In current BCTP, role players operate combat entities via graphical user interfaces of the model, which is designed to receive inputs from the role players. However, the format of inputs is not the form of tactical control measures. The format consists of various command blanks which is required information to make combat entities move, fire, and so on. For example, to make a combat entity move to an enemy,
Fig. 2. An example of commander class when the minimum-level unit is a battalion

role players should 1) input check points to pass through, 2) select engagement mode such as automated engagement and manual engagement, and 3) designate formation of the movement. However, those input measures are far from the reality.

The key to model commanders for the CAX is to define the format of orders like real exercise. Army doctrines define the format of orders which should be included when a commander orders to his or her subordinates. Regulating the format of orders enables the commander and subordinates to understand common meaning of the orders. We call the means of orders tactical control measures. Thus, when a commander inputs orders to control combat entities as a training audience, the input measures should be tactical control measures that is used to order subordinate commanders in real operation and training. Fig. 3 depicts an example of input measures.

The communication messages define the format of orders and reports. For wargaming model for the CAX, the communication messages should be the format of tactical control measures that doctrines dictate. Fig. 4 shows an example of instance hierarchy for communication messages when the minimum level unit is a company.

Fig. 3. An example of input measures for a company commander to order platoon leaders

Fig. 4. Instance hierarchy for communication messages for the commanders

When an infantry company commander orders to platoon leaders in an offensive operation, the tactical control measures, which should be included in orders, are 1) final objective, 1) assault readiness position, 3) fire support position, 4) release points, 5) missions of each platoon, 6) positions each platoon should be released, 7) completion time to occupy the last release point before executing the decisive combat. Tactical control measures vary in levels of units, types of operation, and so on. Hence, wargaming models should have all types of input measures so that they can cover all types of operations for the minimum-level unit.

How to model commanders and chain of command can be described as C2 process model proposed in [9]. Instead of detailed explanations for the models, we present an example of commanders and chain of command models amongst commanders and combat entities in the case study.
3. Case study

Assuming that we develop a wargaming model for the CAX of an infantry regiment, the minimum-level unit is an infantry company. A company commander can be a training audience who takes charge of operating combat entities of the company. In this case, platoon leaders should be modelled as commanders. We perform a case study to model C2 of the minimum-level unit to 1) provide an example of C2 modeling for the wargaming model of CAX, 2) show the difference between suggested modeling method introducing C2 models and the existing method, and 3) present advantages of introducing C2 models to the wargaming model for the CAX.

We build two models: 1) an engagement simulation model of the minimum-level unit that is based on the existing model, or M1, which does not have the concept of C2 modeling, and 2) an engagement simulation model that has commanders of platoon leaders, or M2. Behaviors of combat entities are same for both models except that M2 has commanders that control the combat entities. To compare simulation results of M1 and M2 with the result of unit level model, we also use a mathematical model about battle damage by time. The mathematical model, or M3, is a software algorithm of “Jeontoo21” model, which is the engagement level wargaming model for regiments and battalions utilized by the ROK Army[9]. We explain the mathematical model, but we use “Jeontoo21” model to perform the experiment since actual values of coefficients used in the model are not released.

3.1 Experimental Scenario

Attacking an opposing platoon on a hill is a typical example of offensive operation of an army infantry company. Military experts usually estimate huge strength loss on the operation since the opposing platoon defend in the strong hardened position with enough cover and concealment while the attacking company should fire and maneuver across wide open area. This is also the reason why an infantry company, which is normally three times larger than a platoon, is required to attack a platoon.

To minimize battle damages, the commander of attacking company makes efforts to find a vulnerable point along in the line of defense, and concentrate his or her force to the vulnerable point. For this operation, the company commander allocate missions to each platoon such as assault, breach, support platoons. The assault, and breach platoons go to the assault readiness position, which allow the platoons to rapidly rush into the enemy position through the vulnerable point, while support platoon support fire to deceive and fix the enemy. The breach platoon goes first to secure a route by breaching obstacles, and assault platoon move through the secured route to clear the enemy.

This is one of tactics, techniques, and procedures (TTP) to attack opposing forces defending on a hill. However, this TTP is performed by commanders. In the CAX, role players can do this TTP by controlling movement of each entity. “Jeontoo21” model support entity-level combat models, but the model assesses battle damages according to only single shot probability of kill (SSPK) of weapons without considering this kind of TTP[9]. OneSAF, which is a entity level model that supports simulating engagement of up to division, has automated behavior of combat entities, but it does not have commanding entities which can perform the TTP[10,11].

Fig. 5 illustrates experimental scenarios of our models. Figure 5 (a) indicates an offensive operation without the C2 models. Combat entities fire and move along with routes role players designate, and the entities go straight to the final objective if role players do not intervene. On the other hands, Figure 5 (b) shows the operational scenario when the company follows the TTP.

Our experimental scenarios are restricted to isolated single unit fight since this case study is an example of modeling the minimum-level unit for the CAX. We also assume that combat service support is not available while implementing the simulation models.
3.2 Description of Simulation

We model platoon leaders as commanders. Fig. 6 displays the commander class of the platoon leaders. Once a company commander inputs orders using tactical control measures as a training audience, the model, M2, instantiate commanders for each platoon with appropriate fields values. Field values of each platoon are set by the commander's orders according to the missions except ‘friendlyForces’ and ‘opposingForces’, which are obtained from reports of combat entities.

The ‘midObjective’ of field values is a position where the platoon should occupy before the final objective, i.e. 1) assault readiness position for assault and breach platoons and 2) fire support position for support platoon. Behaviors of the commanders are same as described in Section 2.

In addition, we discuss about communication messages when the minimum-level unit is a company in Section 2 (see Fig. 4). The key of M2 model is the input measures that allows the company commander to order like real operation as described in Section 2 (see Fig. 3).

We use the DEVS coupled model to specify commanders as suggested in [8]. Fig. 7 shows the model structure of M2 (CAXEngagement) specified using the DEVS coupled model. The structure of the M1 is same as the structure of M2 except for commanders of platoon leaders. The M2 consists of blue force model (BlueForce) and red force model (RedForce). The BlueForce has three platoons which missions are 1) assault (Blue-Assault), 2) breach (BlueBreach), and 3) support (BlueSupport). Each platoon has a platoon leader model (PlatoonLeader) and soldiers models (BlueSoldier). We assume that the red force (RedForce) is composed of only soldiers (RedSoldier) since the red force defend in the strong hardened position without movement according to the scenarios. A commander's role in that case is not significant.

A human commander, as a training audience, issues orders to virtual platoon leaders via input measures of CAXEngagement model. Based on the orders, platoon leaders control combat entities according to their own commanders' operation. Platoon leaders also communicate with each other by reporting their states. A PlatoonLeader model sends report messages about its status to other two PlatoonLeader models.
Commanders' operation of platoon leaders are based on doctrines, tactics, and scenarios. Scenarios are created by training audiences according to purpose of exercise. Commanders representing platoon leaders check their missions first, and continuously update 1) their states, 2) status of friendly forces, and 3) status of opposing forces.

We set scenario parameters according to the army doctrine for the infantry rifle company. In addition, we adopt values detailed in the US Army JANUS model specifications for other parameters. We also vary values of 1) probability of hit (PH) and 2) breaching time (BT) in the experimental design to figure out their effects on the combat effectiveness.

3.3 Mathematical model for battle damage assessment in "Jeontoo 21"

"Jeontoo21" model is based on unit-level combat modeling. It also supports the battle damage assessment by combat entity level, but the assessing algorithm is same as our M1 without movement. Thus, we introduce the mathematical model, M3, of battle damage assessment by unit level. The battle damage assessment by unit level is based on the Lanchester loss equation. The Lanchester attrition rate is determined by 1) weapon effectiveness index (WEI), 2) weighted unit value (WUV) based on WEI, and 3) other circumstances of the battlefield.

3.4 Experimental design

We perform virtual experiments to analyze combat effectiveness by soldiers' training levels for the M1 and M2. We consider two types of training levels, that are, 1) the probability of hit (PH) of the blue soldiers which indicates soldiers' marksmanship and 2) the breaching time (BT). Table 1 describes the virtual experiments setting.

| Experiment variable name | Levels | Implications |
|--------------------------|--------|--------------|
| Probability of Hit (PH)  | 0.2, 0.4, 0.6, 0.8 | 4 levels of blue soldiers marksmanship |
| Breaching Time (BT)      | 2, 4, 6 minutes | 3 levels of average delay time to breach obstacles |
| Total number of cells    | 24 | 2 models×4×3 cases |

3.5 Simulation results

24 cells are formed according to the experimental design as in Table 1. The experiment cells are for the M1 and M2, and we obtained samples of simulation results.
data by replicating each cell 30 times. We perform only one time for the M3 since the M3 is deterministic.

Fig. 8 demonstrates the strength loss, or personnel loss since each force consists of only soldiers with rifles, by time for M1 (Fig. 8 (a)), M2 (Fig. 8 (b)), and M3 (Fig. 8 (c)).

In M1, most of the blue soldiers are killed when they encounter the obstacles. They go straight to the objective without any tactics, and thus, they are dispersed and each of them tries to breach separately in the line of defense. This makes the blue soldiers to be defeated in detail by the red force. On the other hands, the loss of the blue soldiers for M2 has two decreasing points; 1) when the support platoon engages the security detachment of the red force and 2) when they breach obstacles at a point in concentration and clear the red soldiers inside the defending boundary of the red force. In M3, the blue and red soldiers are almost equally decreases at regular intervals since we set the coefficient values of the blue and red forces on equal terms except for the number of soldiers.

From the strength loss graphs, we can abstracted one advantage of applying the C2 models to a wargaming model. Only M2 enables training audiences to analyse the combat in details when they perform the after action review (AAR). If we use M1 or M3, which it is difficult to evaluate 1) which actions and conditions in the battlefield are related to combat results and 2) how they affects the result.

We also analyse the loss exchange ratio (LER) by soldiers’ training levels according to the experimental design. Fig. 9 displays the changes of the LER of M1 and M2. The most interesting insight is the difference between analysis results of the M1 and M2. The graph of M1 does not show any significant relations between the LER and soldiers' training levels. There is a tendency that high probability of hit(PH) increase the LER, but it does not consistently come into existence. Moreover, the breaching time (BT) does not influence the combat effectiveness according to the simulation results from M1. On the other hands, M2 shows that high level of soldiers’ marksmanship show high combat effectiveness. This implies marksmanship of individual soldiers is a critical factor in combat. It is also shown that fast breaching time (BT) is beneficial although minor differences of breaching time.

We also analyze and compare the simulation results from M1 and M2 by a statistical mean. We use the meta-modeling with the linear regression model. Table 2 summarizes the analysis results. The meta-modeling analysis also supports the results of graphical analysis (Table 2).

Table 2. Meta-model analysis on simulation results. Standardized coefficient for sensitivity of factors, and P-value for robustness of factors (*: p < 0.01)

| Experiment variable name | M1          | M2          |
|--------------------------|-------------|-------------|
| Probability of Hit (PH)  | 0.6033*     | 0.7292*     |
| BreachingTime (BT)       | 0.0325      | -0.2536*    |
| Adj. R-square            | 0.3615      | 0.5951      |

Fig. 8. Strength (Personnel) loss by time for (a) M1, (b) M2, and (c) M3
The graphical and meta-modeling analyses also indicate another advantage of the C2 models. Analysis results from models that encompass C2 models are reasonable and interpretable with the TTP dictated in the army doctrines. The results are understandable and acceptable to training audiences, and this enables them to nd out improvement points in the AAR.

4. Conclusion

We propose how to apply C2 modeling to wargaming models for the computer assisted exercise (CAX). We suggest that C2 models are required for the minimum-level units in the CAX. Our proposition can reduce the role-players and possible errors by misoperation of role players. The key of our suggestion is introducing C2 models that can 1) understand inputs, or orders, in the form of tactical control measures from training audiences, 2) process the orders according to tactics, doctrines, and simulation scenarios, and 3) make combat entities in the model behave as they are ordered.

A number of further works are remained to realize the suggested method in developing wargaming models for the CAX. Order formats should be dened in details by types of operations and units according to doctrines to specify input measures. In addition, C2 processes by different order types should be defined. This requires model developers to scrutinize a number of doctrines, and thus, the order formats and C2 processes will generate a number of combinations. In addition, it will be time-consuming works to encode the investigated knowledge into models.

Nevertheless, we believe that these advantages compensate for the difficult and time-consuming works to completely embed the C2 models into wargaming models for the CAX. Therefore, due to the notable benefits of our suggestion, we encourage wargaming model developers to introduce C2 models.

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