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Theory and Methodology

Case-based decision support system: Architecture for simulating military command and control

Shu-hsien Liao *

Graduate School of Resource Management, National Defense Management College, P.O. Box 90046-15 Jon-Ho, Taipei County, Taiwan

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Abstract

For a military commander, a system that can offer decision support in the process of command and control, a tool that can provide the space in which to exercise his command and control ability have always been ultimate goals. This is not only because of the complexity of the problem domain but also because of the difficulty in obtaining help from past knowledge and extend past knowledge for solving new problem. This paper intends to present an architecture which incorporates case-based reasoning (CBR) and decision support system (DSS) as a tool for military officers to simulate and to train the military Standard Operation Procedure (SOP) in the decision-making process of command and control. The experiment and evaluation of the case-based decision support system (CBDSS) are also presented.

Keywords: Military command and control; Case-based decision support system; Methodology; Artificial intelligence; Information management

1. Introduction

Military command means to give an order and military control means to ensure that the order is executed in a prescribed manner in order to achieve a goal. Therefore, military command and control includes how to generate an order; how to guarantee that the order is delivered safely, timely and accurately; it also looks at how to remedy the situation if the unexpected happens. In 1979, the US Department of Defense sponsored a three-day symposium on command and control which concluded that 'there is no adequate foundation for a theory of C_2 and hence no principles for overall system and evaluation'. Wohl [25] outlines the functions of C_2 system as follows:

1. Stimulus: data acquisition from sensors or intelligence;
2. Stimulus: sensor data interpretation and data fusion;
3. Hypothesis: situations or threat assessment;
4. Options: decision plans or goal generation for desired outcomes or resource allocation;
5. Response: implementation of plans and monitoring of response/actions to ascertain Success

* *E-mail address*: michael@rs590.ndmc.edu.tw (S.-h. Liao).

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through sensors or intelligence (process returns to 1).

Numerous efforts have been made at each of these levels, but especially in the Stimulus and Hypothesis stage for 'data fusion' and 'situation assessment', by means of AI methods, mainly based on developing a 'blackboard architecture' for problem-solving. For instance: the framework of MAX (Multiple Expert Architecture) [15,10,21] for the requirement of signal understanding and its application project called ARE (Admiralty Research Establishment) [8,9] developed for naval command and control purposes; the framework of ADX (Air Defense threat assessment Expert system) [1] and its later version BLOBS (Blackboard Objects) [13,14,26] as an object-oriented language designed to support both continuous reasoning expert systems and simulation application; the methodology of CTEM (Conventional Target Evaluation Methodology) [4] modified for the allocation of conventional and/or nuclear weapons; Sanja Vraneŝ et al. [17] introduced a blackboard framework that provided a simulation facility for military commanders with the capability of a two-sided interactive air war game for the Yugoslav Army. Luo and Su [12] described the military decision-making procedure as a process of information processing which starts with states somewhere between precise to fuzzy and then moves from fuzzy to precise. Nonetheless, very little progress has been made at the higher levels of functionality, such as 'Options' and 'Response', in terms of plan generation and execution.

Since 1994, more and more researchers have examined the military command and control problem as a problem-solving procedure moving from the Stimulus stage to the Response stage. Chin and Ng [3] addressed the issue of plan execution in their military command and control procedure with a multi-agent decision support system (DSS). Song and Kleinman [19] implemented a DDD (distributed, dynamic, decision-making) simulation system on a network with real-time control, on-line data acquisition, interactive graphical display and a simulated inter-human communication network. Lee and Ghosh [10] have also proposed a novel asynchronous, decentralized decision-making algorithm for military command and control.

From the above military command and control literature review, our concern in relation to this research is why military knowledge, for example, experience of training, exercise, and real combat, not be considered as an aid for plan deliberation and execution during the process from the Stimulus to Options stage, and why new knowledge not be recorded as a case for learning after the stage of Response. This paper also seeks to design an architectural to simulate the planning mechanism on different hierarchy (strategic and tactical levels) during the procedure of military command and control. These are the reasons why we wish to broaden our research horizon to examine military command and control problems as a knowledge-based decision support and learning mechanism. In this paper, the research presents the methodology by incorporating case-based reasoning (CBR) and DSS as an architectural platform to simulate the Standard Operation Procedure (SOP) in the decision process of military command and control.

2. The SOP of military command and control

Military command and control is a decision-making process that covers a sequence of tasks which includes planning, directing, co-ordination and control functions. This system is designed to help the commander and his staff to analyze missions, deliberate planning, make decisions, execute orders and accomplish missions. On the other hand, command and control also involves a military problem-solving methodology, which combines the function of planning, decision-making and execution. This process reflects the fundamental principle that a systematic approach promotes thoroughness, clarity, logic and an effective application of military judgement. How a commander chooses to plan, direct, co-ordinate, and control is always a matter of personal choice. Nevertheless, experience confirms that the commander must accomplish the tasks contained in this model, or his command and control will not be as effective as it must be to succeed on the battlefield [24].

With the military problem-solving methodology, the study of SOP through the decision process of command and control can give us a well-established military decision-making framework. For many centuries such a problem-solving procedure has sought to encapsulate the functions of planning, directing, co-ordinating and controlling, as well as bringing the execution of a plan to bear on the process of mission analysis, commander's intent, planning, decision-making and execution (see Fig. 1).

As shown in Fig. 1 [22], the decision-making process attempts to describe how a commander and his staff effectively, efficiently and economically accomplish a mission. This decision-making process is called a SOP for both military commanders and staff in the Taiwanese Army. Although there are different levels of authority within a command and control structure, SOP is a manual system model for strategic and tactical units, which can be used at a battalion level or higher. The decision process of military command and control not only gives guidance to military personnel in order to accomplish a specific mission but is also a generalized decision-making framework for those who want to solve problems with a systematic approach to any organization.

3. The case-based decision support system (CBDSS)

Scott–Morton first articulated the concepts involved in DSS in the early 1970s. The early definition of a DSS identifies it as a system intended to support managerial decision-maker in semi-structured decision situation [18]. Previous research has focused on integrating knowledge into DSS. Incorporating knowledge into DSS has been

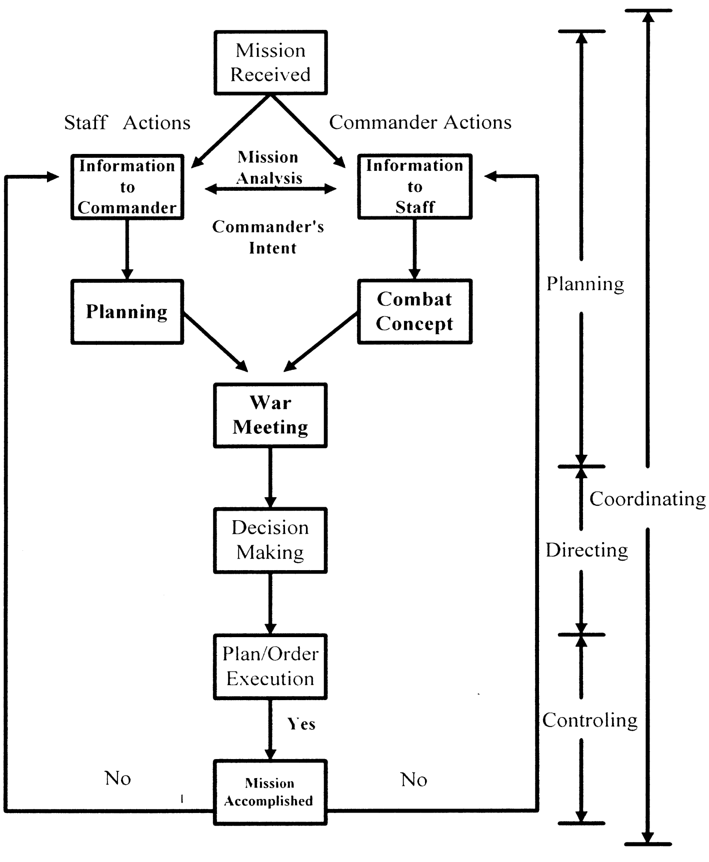

Fig. 1. Military combat decision-making process.

recognized for some time as a means of gaining competitive advantage, formulating better problem-solving processes, improving decision quality and refining business operations [2,5,6]. The phrase knowledge-based DSS (KBDSS) is often used to describe the efforts to integrate DSS architecture with Artificial Intelligence or Expert System methods. A vast literature on DSS/ES already existed [2,23,16]. There is a few on integrating CBR into the architecture of DSS. Rita et al. [16] present a hypothesis for a framework including a case-based and knowledge-base for uncertainty handling in DSS/ES. But the core problem of CBR or Artificial intelligence, learning, has not been considered in their basic framework configuration as an aid for future decision-making or problem-solving. In a case-based system, learning can occur in the process of memorizing new cases, classifying existing cases, and generalizing knowledge from cases [7]. As learning is a by-product of problem-solving for CBR [20], CBR/DSS not only is an alternative method for KBDSS, but also is a necessary beginning for integrating learning mechanism into DSS.

Giving a problem in the context of a decision-making SOP, the procedure of problem-solving can be summarized in Fig. 2. Situation analysis is used here to examine the current situation, while CBR is an attempt to match the similarity between the new problem and case base. With his expert knowledge of past cases, the commander analyses the current situation and conditions on a situation map and initiates the commander's intent to his staff as a combat concept. According to the combat concept, the staff deliberate possible solutions from different sources according to their different expert status. Decision-making is a process to identify and select the best possible plan, if any, amongst all the proposals presented as operational plans. Failure to do so would mean that a temporary solution ought to be adapted until the operational plan is identified. Its execution is overseen by the whole command and control procedure across the uncertain environment. Once the mission is accomplished, if the result is important for identifying an outstanding difference amongst the old cases which is useful to our knowledge for problem-solving with a new

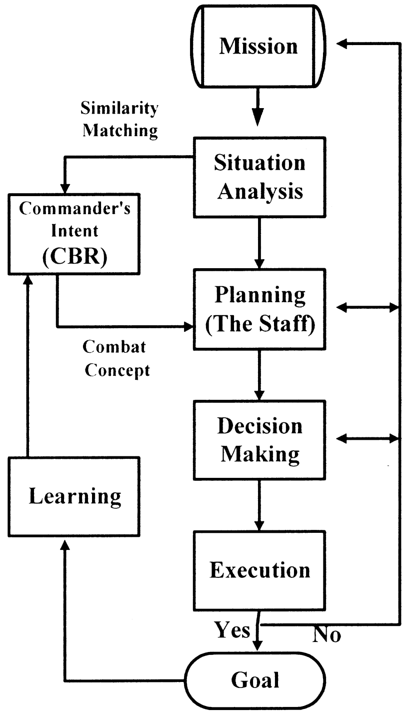

Fig. 2. The problem-solving procedure.

case, then this should be recorded as a case for learning.

4. The architecture

In a dynamic environment, the solution of a problem is always generated by the knowledge acquired from past experience and its extension to fit new situations. Sometimes, with a new problem, knowledge is not good enough to offer the source of a solution. We have to admit that knowledge has its gaps in different situations even in the same problem domain. Unlike expert system or knowledge-based system, where knowledge is acquired from an expert or a single group of experts, the problem-solving methodology considers that experts from all kinds of backgrounds and expertise are assembled in front of the situation map with a top-down hierarchy organization planning mechanism. Only then it is possible to generate the best solution to the problem. This kind of top-down coordinated planning activity requires the support of a parallel architectural platform organized in a sequential control-flow mechanism. In the architectural platform, a system master is installed at the highest level to oversee and co-ordinate the different tasks among the paradigms (situation analysis), retrieve case(s) from case bases as combat concept (strategic planning), search and merge plans from search paradigm agents (tactical planning), exercise whatever selection paradigm needs adapting to finalize the operational plan (decision-making), and hand the result over for command and control execution (plan execution), and record the final result as a new case for learning (case learning). The chains of command are activated by the master of the system and the control is operated from level to level.

This organization enables different control paradigms to function through the system master. In this command and control structure, the human organization hierarchy is revealed. The system master is always in control at process level and reacts to situations on the situation board. Once a situation shows on the board, the control is passed up to the case search paradigm or heuristics paradigm. Case(s) or heuristics formation(s) will produce the strategic formation to the staff who start searching the possible solution path(s) from the initial state to the desired goal on the situation map according to the desired formation (cases). Each tactical search agent is free to work out whatever plan or course of action they see fit. Every solution proposed by agents would have to be merged and integrated before contest and discussion. Decision-making is based on finding an optimum value of the three independent parameters of time, risk/uncertainty and reward. If the situation on the situation map changes during execution, the system master's command and control react with the execution or planning paradigm again. Ultimately, once the result is different from the case, and the difference could be used as a solution to the new problem, it can be recorded to case base as a new case for learning (Fig. 3).

As far as the database is concerned, the data are placed into global and local levels. The global database (the blackboard and situation map alike) is organized as shared memory and accessed mainly by reference for the purpose of update, while allowing the flexibility of transferring the up-to-date information from central database to the local database of paradigms by means of call by value. This configuration enables each paradigm

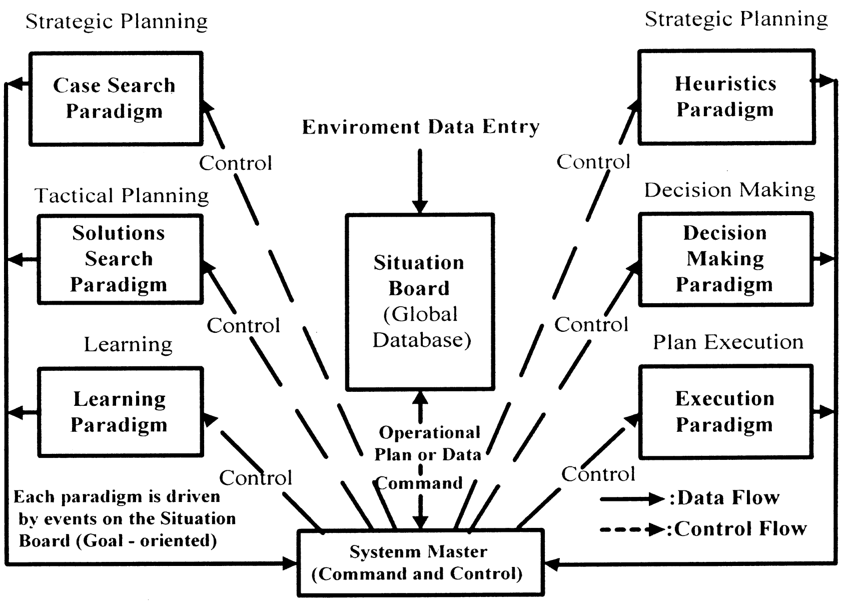

Fig. 3. The architecture of case-based decision support system.

to operate with others independently at the local level and restricts the global communication only at the command and control process level. Actually, the data communication is from the global shared memory to the distributed local memory of each paradigm, and the outcome from each paradigm will be channeled back to the system master for command and control.

This organizational requirement also reveals the need for two kinds of knowledge abstractions for problem-solving. At the strategic level, a case-based paradigm and heuristic paradigm would activate a similarity matching process to identify desired formation(s), while the tactical search paradigm could activate a goal-oriented search, heuristic search or exhaustive search in order to look for a solution path. Each of these reasoning approaches is supported as an independent process with its own case bases or algorithm to find a case or solution. There are two strategic planning paradigms at the strategic level and each of them supports one line of reasoning knowledge (strategic formation). At the tactical level, the search paradigm is supported by a group of tactical agents for the realization of an identified strategic formation. Therefore, the strategic planning is responsible for taking the desired formation to the tactical planning paradigm with an instruction to work out course of actions (COAs) to fulfil the achievable objectives. The strategic planning paradigm could either function inductively with the case bases or deductively with a set of tactical rules. Within the tactical planning paradigm, the tactical agents are supported by their own local database and algorithms to map out the connections between all intermediate states. The algorithm of CBDSS is completely described in Ref. [11].

5. The experiment and evaluation

5.1. Research experiment

The Armed Forces University is responsible for the education of the armed forces of the Republic of China, Taiwan and the development of the strategies, tactics, and computerized war game. Besides, Army Command and General Staff College is responsible for conducting ground tactical education. By obtaining participation of 200 officer students and instructors of Army Command and General Staff College, this research is able to evaluate the architecture. In this project, the research specifies four military scenarios to implement the problem-solving procedure of CBDSS at four experiment stages. Scenario is designed as a simulated war game situation [11]. For a given scenario, a mission is published and the system starts to operate according to the algorithm. The final result of system testing is the operational plan including the intermediate states from the initial attacking state to the desired goal state, which is searched from retrieved cases.

Up to now, decision support has mainly concentrated on a low cognitive level [14]. For example, support often takes the simple form of manipulation of data, with storage and retrieval, consistency checking, small calculations, updating process, developing framework or architecture and so forth. Much less support has been given to the issues in observing the behaviour of training or learning on the process of decision-making and problem-solving. The cognitive aspects of decision-making is one of the essential tasks that mankind deal with decision-making with a specific or preference behaviour. This research deduces the cognitive model from the process of subjects' decision-making for observing their preferential decision behviour model.

In 1995, four stages of the experiment were conducted in Taiwan. Through stage one to stage three, the research wants to examine if the process of military command and control and different kinds of military strategy and tactics can be implemented on designed military scenario games. Those three experiment stages are designed to investigate if SOP of military command and control can be systemized to CBDSS. The final stage of experiment seeks to investigate if the architecture of CBDSS is feasible for simulating and training the military command and control. There were 200 military officers who participated in this research as subjects.

In the first stage, military officers play scenario one, against civilians. The research aim of this stage is to investigate whether military officers have a better chance of winning because they used military knowledge during the game (see Fig. 4).

In the second stage, two groups of military officers play scenario two. The objective is to observe whether officers have preferential strategies or tactics on the exercise of scenario game according to their different military branches (Infantry, Artillery and Cavalry) (see Fig. 5).

In the third stage, one group of officers (research course) who have undertaken military strategy and tactics education play scenario three, against another group of officers (regular course) who do not have a knowledge of military strategy. The research aim is to examine whether the former group of officers have a better chance of winning the game because they have superior military knowledge (see Fig. 6).

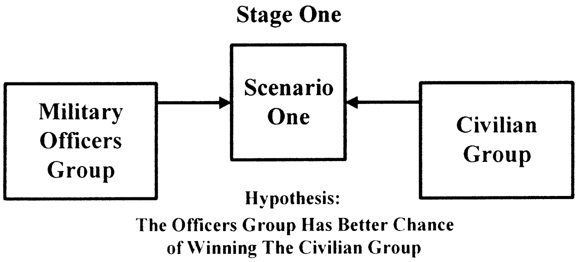

Fig. 4. The first stage of the experiment.

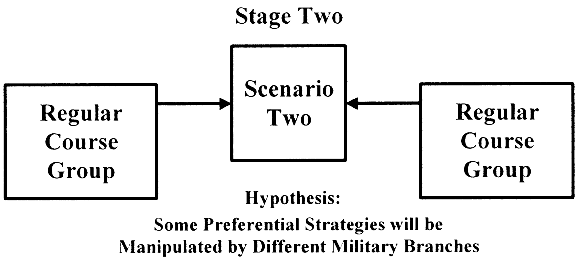

Fig. 5. The second stage of the experiment.

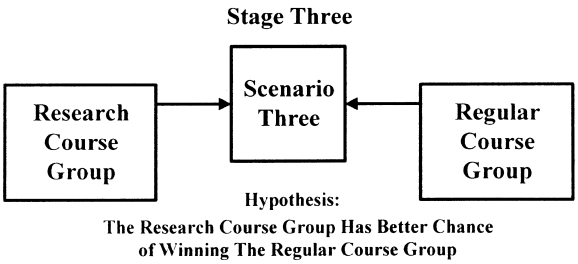

Fig. 6. The third stage of the experiment.

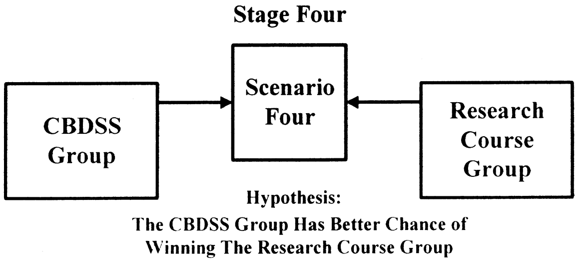

Fig. 7. The fourth stage of the experiment.

In the fourth stage, one group of subjects plays scenario four, using the CBDSS against the group of officers possessing a knowledge of military strategy and tactics (see Fig. 7).

If it can be shown that CBDSS improves the chance of winning the war game, then it means that the research framework can be extenuated as a tool for training officers to command and control military strategy and tactics on a simulated test-bed, because the system has a better knowledge than the officers in the problem domain.

5.2. Research evaluation

5.2.1. Experiment stage one

There were 34 officers at experimental stage one, who won the scenario one. Twenty-five out of the 34 winning officers used their military knowledge during their game-play. This shows that 73.53% of winners won their scenario games with the help of their military knowledge. At the same time, there were 15 officers who did not use any military knowledge and lost their games.

The research aim at the first stage was to investigate whether the group military officers could have a better chance of winning than the civilian group because the officers can use their military knowledge instinctively during game-play. From the results of both the experiment and the statistical test, it is shown that officers have a higher chance of winning than civilians when officers use their military knowledge in game-play. With this significant result, the research could be extended to investigate if military officers are able to employ their special knowledge in military scenario games, and to observe if different military branches officers have different preferential strategies.

5.2.2. Experiment stage two

There were 100 officers who participated in this stage with scenario two. The research selected 50 Infantry officers, 35 Artillery officers and 15 Cavalry officers for the experiment's sample group. According to the experimental design, the research organized different military branch officers in a series scenario games, i.e. Infantry versus Artillery or Infantry versus Cavalry (Infantry officers in one group and Artillery and Cavalry officers in the other group).

The experiment finds that Infantry officers had a better chance than Artillery officers of winning their games when Outer Line Operation was used by both groups. Artillery officers had a better chance of winning with Outer Line Operation if Infantry officers used Inner Line Operation. Finally, Cavalry officers defeated the Infantry officers mostly by using Outer Line Operation when the Infantry officers used Inner Line Operation. At this second stage, the aim of the experiment was to investigate if military officers can employ their knowledge in the designed scenario games. The research also sought to observe if different military branch officers had different preferred strategy formations. From the results of both the game-play and the statistical tests, it is shown that different military branch officers do have preferred strategy, and that most subjects can employ their military knowledge in game-play. By obtaining these results, the research could extended to investigate if a group of officers who have undertaken both military strategy and tactics education have a better chance of winning than a group of officers without training in military strategy.

5.2.3. Experiment stage three

There were 100 officers who participated in this stage with scenario three. Half of them were student officers on the regular course, and the others were officer students of the research course at the Army Command and Staff College.

The research course group (who had undertaken strategy training) won 56% of their games. There were 19 out of 28 game winners (67.85%) in the research course group who used Outer Line Operation, and 15 out of 22 game losers who employed Inner Line Operation. Of the regular course group, 14 (63.63%) won games by using Outer Line Operation, and 53.57% of loser (15) lost their games by using Inner Line Operation. All military branches (Infantry, Artillery and Cavalry) preferred using Outer Line Operation at stage three. By obtaining these results, the research can be extended to investigate whether CBDSS can offer decision support to different kinds of subjects. The aim is to show that a group using CBDSS has a greater chance of winning than the officers of the research course group (the same as in the third stage of the experiment).

5.2.4. Experiment stage four

This experiment investigates if the architecture of CBDSS can simulate the SOP of military command and control and can be extended as a tool for training. For testing the CBDSS, the research design requires stage four to conduct scenario four with different background groups of military instructors, officer students and civilians. There were 50 research course officer students against 10 Army College instructors, 30 regular course students and 10 civilians. The results show that 33 subjects with the aid of CBDSS won their games.

From the experiment results, it can be seen that CBDSS provides better knowledge than that of the officer students group and leads to a greater chance of winning. It could be deduced that cases represent the necessary knowledge at a strategic level and the system generates the operational plans at a tactical level. Hence, CBDSS is a source of better knowledge and experience compared with the officer students group.

At the end of experiment, from questionnaire survey, it shows that (1) 120 out of 193 subjects think that scenario game is similar to a war game. (2) There are 156 out of 192 subjects who agree or definitely agree that it is possible to employ military strategy and tactics on the scenario game. (3)

There are 140 out of 193 subjects who agree or definitely agree that scenario game playing is helpful in the training of military command and control. Finally, 132 out of 192 subjects agree or strongly agree that the architecture is possible to become a kind of war game simulator. This research proposes that the value of CBDSS as a practical military training mechanism can be investigated.

6. Conclusion

For a military commander, a system that can offer decision support in the process of command and control, and a tool that can provide the space in which to exercise his command and control ability, have always been ultimate goals. Due to the complexity of the battlefield, real situations are constantly changing from time to time, and the expense of a battlefield exercise is much too great. In this research the architecture proposed is a CBDSS. The research investigates the integration and functionality of both CBR and DSS. CBR offers an interface to help solve problems using reasonable knowledge from past cases. DSS is used to help solve problems within a dynamic environment. The CBR represents the knowledge that a commander possesses for planning on a strategic level. The DSS offers the tactical planning component of the process.

This paper has shown that the use of the architecture of CBDSS for simulating the military SOP of command and control is feasible. Also, this research can be offered to implement military scenario game on CBDSS for officers training and war game simulation. Finally, this project offers the student officers and instructors a valuable case-study of the development of a war game training system.

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