Chapter 12

Wargaming-Based Crisis Drills

Xiaolei Li and Qing Song

Additional information is available at the end of the chapter

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Abstract

Crisis drills should be held periodically in order to find problems of crisis plans, other than to run into problems during a real crisis. Wargaming is an efficient way for crisis drill with low cost and in a convenient manner. For government authorities, they can make deep research into the crisis management by designing a crisis drill wargame, and they can make proper crisis plans by playing the wargame. For the related duty departments or person, they can practice or adopt the examination of their workflow and professional ability by playing the wargame. The system features and elements of wargaming are introduced firstly, and then the form and process of wargaming-based crisis drill are explained. Also, the evaluation methods and decision models are proposed. At last, a wargame replay is analyzed to show the benefits of wargaming evaluation.

Keywords: wargaming, crisis drills, evaluation, decision, analysis

1. Introduction

With the rapid industrialization and urbanization of the modern society, more and more people and properties are gathering together, especially in China; hence many cities are overcrowded. The loss will be huge, and the daily life will be severely affected in the case of crisis. According to the statistical data compiled by National Bureau of Statistics of China 2016, the most loss is led by earthquake disasters, there are 14 times of earthquakes that are heavier than 5.0 Richter scale in 2015, the direct economic loss is 17,919.18 million RMB yuan, and 813,000 persons died or are wounded which is the most number in recent years. The following most loss is led by marine disasters; the direct economic loss is 7274 million RMB yuan; there are 79 stormy tides, red tides, huge waves, and sea ice disasters happened; and the casualties and missing people is 30 in total. The geological disasters, such as landslide, collapse, mud-rock flow, and land subside, are the common disasters and happened 8355 times with 422 casualties; the direct economic loss is 2505.28 million RMB yuan which is the least loss in recent years, but the investment for prevention of geological disasters is 17,626.63 million RMB yuan which is the most in recent years. **Table 1** shows the statistical data of geological disasters in China in recent years [1].

So, through good crisis management, to take proper measures, such as investment for infrastructure construction, emergency resource schedule, crisis drills, etc., can make obvious effects on crisis prevention. Government authorities or organizations need to do deep research on crises, to grasp their features, and to make good schedules of human power and emergency resources in order to prevent or eliminate the developing of crisis.

A crisis generally has three main features, dynamics, complexity, and interaction [2]. A crisis is always evolving which makes it turn from minor phenomenon to complex event and even severe disaster. Nevertheless, a crisis has complex correlated facts and conflicts, it is very hard to aware of the original incentive at the beginning, and it is also a big challenge to take right measures to eliminate the crisis in time. A crisis is usually not an individual event, that is, it will trigger a series of linkage events, which makes the crisis more complex and severe.

According to the crisis features, crisis managers, such as governmental authorities or related organizations, are required to have abilities of crisis early awareness, dynamic decision-making, and emergency resource assignment. In general, governmental authorities need to make plans for all kinds of crisis, and related people who are in charge should study the plan and perform the plan in case of the real crisis. Crisis drill is a good method to examine the complementary of the crisis plan. It recommends that crisis drill should be held periodically by governmental authorities to optimize the crisis plans, other than to run into problems during a real crisis. At the same time, crisis drills can be held between related responsible people, to train or examine their crisis management skills.

As a matter of fact, organizations do held crisis drills as scheduled, and they need to make good preparations for the drill, including the materials purchasing, human organization, departments' coordination, etc. It is a hard work for the organizers; however, it may be a funny thing for the participators. This type of real drill has some limitations:

Year	Number of geological disasters	Casualties (person)	Direct economic losses (million RMB yuan)	Investment of prevention (million RMB yuan)
2011	15,804	413	4131.51	9280.85
2012	14,675	636	6252.53	10,241.83
2013	15,374	929	10,435.68	12,353.63
2014	10,937	637	5670.27	16,340.39
2015	8355	422	2505.28	17,626.63

Table 1. Statistical data of geological disasters in China.

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- **Patterned scripts:** The drill is strictly controlled by the prepared script. Participants must obey the rules and act as actors. So, the drills are lack of flexibility and are hard to reflect the dynamic property of real crisis.
- **Expensive costs:** The drill needs props, vehicles, labors, etc., and will consume a lot of water, gasoline, electricity, and related resources. And, sometimes the aftermath site needs to be cleaned. In summary, it is usually very expensive to hold a drill.
- **Complex works:** The drill may affect the local traffic and communication; it is also a need to coordinate with related departments before and during the whole drill process.
- **Poor aftereffects:** People are usually interested in the drill process, like some funny persons or events, but ignore to summarize the problems or experiences of the drill.

Wargames originated from ancient strategy games, and modern wargaming originated with the military need for military exercises which remain an important part of military training today. Sometime between 1803 and 1809, the Prussian General Staff developed wargames, with the basic features of moving metal pieces, game table, using dice rolls to indicate random chance, and with a referee scoring the results. Then, that was the so-called wargame [3]. Wargames are best used to investigate processes; either designers or players can learn a lot from the processes [4]. The computer simulation technologies have advantages of accurate calculating and can process huge amount of complex data; then computer technologies are introduced in the modern wargaming systems.

Just as the name of wargaming, the wargaming-based crisis drill will be held in a game form. The game is designed according to the crisis management plan. It provides the players an interaction virtual environment of crisis. The opponents will be the decision-maker vs. the crisis, that is, the decision-maker should battle with the crisis.

2. System features of wargaming

Wargaming is a kind of computer simulation technique with quantitative analysis ability, which can help to model and solve the complex system problem with the form of several components' competitions. Crisis drill is just like a battle fighting process between crisis managers and crisis. The challenges to model the process are the human factors and uncertainties among them. Comparing with traditional computer simulation methods, wargaming method has the following features:

2.1. Back-to-back competition

Wargaming-based crisis drill is not a pure computer simulation program; to be exact, it is a framework for human to take part in the simulation. In formal wargaming-based crisis drill, departments or forces in crisis management as examinees may be divided into several groups and let them in separate rooms. Each of them should play according to their duty to stop the crisis. Similar to a real crisis happens, they can only get partial information around their visual field as the fog of war in computer games. To get more useful information, they must issue orders like search and investigation. Who can get more complement and precise information, and who can make good decision and win the game to pass the examination?

2.2. Round-based gaming process

The crisis drill process will be the wargame playing process following the drill scenario round by round. The round-based mechanism requires the simulation and evaluation of crisis drill to be represented in discrete round mode. This may lead to some conflicts between actions in a round, for example, who will be the offense/defense when two units meet in a round? For a synchronous mechanism, actions are issued simultaneously by all players, and they will be validated at the end of the round. For an asynchronous mechanism, we split one round into several stages and use a round list to control the gaming order. This is more convenient to control the gaming process and guarantee the reality of simulation.

Comparing with the real-time strategy (RTS) game, the simulation model is based on statistical data in round-based wargaming, other than a fixed math or physical model in RTS game. So, wargaming is closer to the real world, and above all, players have enough time for decision-making and analysis between the rounds.

2.3. Chess pieces operation

In wargaming system, chess pieces are the symbols of crisis or anti-crisis forces. Players can represent their strategy by operating the chess pieces in sequence. This is more convenient than the general computer simulation method which emphasizes on tedious parameter setting mode. Each piece has a set of action/command list. Players only need to select the chess piece and choose corresponding command from the list.

2.4. Dicing the uncertainty

One of the difficulties in crisis management is uncertainty. In an entity wargame, the uncertain factors are simulated by dicing, which can produce various probability numbers. For computer algorithm, it can produce random number instead of dicing. In wargaming system, it uses combat result tables to deal with the uncertainty of gaming results. Combat result table is a set of probability table; it calculates combat result based on the combat strength of units and random number, which can provide data close to the actual for crisis management. The parameters in the table are based on statistical analysis other than occasional observation.

2.5. Date analytics and machine learning

Wargaming system provides a knowledge representation and database manager platform for crisis drill. By the usage of database and knowledgebase technologies, the crisis drill process will be logged into database and even can be shared in cloud platform. We can do replay to find problems and do data mining or knowledge discovery to sum up the experiences. This can help people to improve crisis drill skills and to optimize crisis plans. Also, we can develop

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machine learning algorithms to teach computers play in the drill, so as to help people make decisions in a real crisis, just like the AlphaGo learn to play Go that beats the human professional Go players [5].

3. Elements of wargaming system

There are four basic elements in wargaming system: counters, gaming board, rules, and scenario. For a specific crisis drill, the wargaming system needs to be designed according to the special demand and characteristics.

3.1. Counters

Counters represent main entities, for example, action units, materials, facilities, etc., in crisis management. In order to get the information at a glance, they are designed as icons with symbols and numbers. There are two types of counters, units and marks, according to their function. Under a sequence of commands, along with their arrangement and movement, they can reflect the plan or drill process of crisis management.

3.1.1. Units

Units are the chess pieces in wargame. For the convenient of identification and operation, there are some elements in their icons, for example, use different colors to represent their owners, use figure or symbol to represent their function type, and use numbers to represent some attributes' values, such as the mobility, energy capacity, panic degree, etc. **Figure 1(a)** shows the fire brigade unit of red player with information of formation, mobility, and fire-fight ability at a glance.

For crisis drill, it involves many departments or organizations, and they have complex relationship among them such as command, coordination and cooperation, etc. Similar to military drill, players are divided into red, blue, or other teams, so we need to make classification according to the organizational and government forming system.

In wargaming design, we need to establish command and supply relationship among units according to their administrative or commercial association, so as to endow units with the power that the real object it represented can do. For the convenient of gaming process, we may combine several units into one counter to integrate their power and also can be dismissed.

Figure 1. Counters in wargaming system (a) Fire brigade unit, (b) Fire brigade unit with fire-control order mark.

3.1.2. Marks

Marks are used to describe some events or status, such as the damage of a bridge, the cutoff of the grid, and the depth of waterlogging. Marks can also represent the orders issued to units, such as the fire-control order sent to the fire brigade unit in **Figure 1(b)**. In each round, players issue an order or execute an action; an order mark will be produced.

3.1.3. Command

According to the functions and duties of unit, there will be a list of commands that players can assign tasks to the unit. Overall, a sequence of orders on series of units forms a decision plan of the commander. With the gaming process, the effectiveness of the decision plan will be evaluated. **Table 2** shows a sample command list in a hazardous chemical leakage accident wargaming system.

Unit	Unit code	Command list	Command code
All	U_{all}	Move	O01
The government headquarters	U1	Establish headquarters	O11
		Rescue command	O12
		Disaster-level assessment	O13
		Relief report	O14
The public security troop	U2	Crowd evacuation	O21
		Site security	O22
		Traffic control	O23
		Site investigation	O24
The medical aid troop	U5	Search and rescue	O51
		Site rescue	O52
		Wounded transfer	O53
The chemistry and epidemic prevention troop	U6	Environment monitoring	O61
		Isolate and decontaminate	O62
		Purify water quality	O63
The emergency and rush repair troop	U7	Equipment maintenance	O71
		Living guarantee	O72
		Site recovery	O73
The transportation troop	U8	Goods transfer	O81
		Waste disposal	O82

Table 2. A sample command list.

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3.2. Map

For crisis management, a map can show the distributions of human forces, materials, and crisis spot with detailed geographic information, and this can help to get overall knowledge and make right decision. Counters are placed into the map to represent the distributions of crisis and anti-crisis forces. Players can issue orders to their counters to express their crisis management plan or crisis drill actions; meanwhile, one important thing is to study the map to get detailed information, and the map will be updated round by round. A map should have basic elements like scales, terrains, and position. For the simulation requirement, a map should be gridded into square or hexagon lattices with proper scales [6, 7]. Each grid has terrain information, for example, water, desert, swamp, forest, road, etc., which will affect the actions of units. The absolute or relative position of the elements can be located based on the grid coordinates.

3.3. Rules

Rules can be theoretical laws to players' actions, and they come from mathematical models and expert experiences. Following these rules, the units' actions can be executed and evaluated. There are some rule sets in wargaming system, action rule set, decision rule set, and evaluation rule set.

For action rule set, often used in the ordering phase, some orders are preprocessed to validate the operation. For example, when issue "Move" order in **Table 2** for a car unit, it cannot enter the terrain of water, but for a boat unit, it can only move following water terrain.

For decision rule set, the final result of an action will be calculated, and the result will be updated to all clients and be logged into database. Based on the round-based gaming mechanism, decision tables are often used to process the stochastic factors and produce reasonable results. For example, the decision table in **Table 3** shows the fire extinction results of a fire fighter unit.

In **Table 3**, the relative ability refers to the ratio that the fire fighter unit remained; the dice number is the random number from 1 to 6. Different combinations of a relative ability and a

Dice number	Relative ability				
	≤1/1	1/2	1/3	1/4	≥1/5
1	1	1	1	0.8	0.5
2	1	1	0.8	0.7	0.4
3	1	0.8	0.8	0.6	0.3
4	0.9	0.8	0.7	0.5	0.2
5	0.9	0.7	0.6	0.4	0.1
6	0.8	0.6	0.5	0.3	0

Table 3. Typical decision table in wargaming system.

dice number will produce a reasonable decision result considering the unit's current state with randomized affect.

For evaluation rule set, a more comprehensive evaluation of the action will be calculated and will be iterated like some back-propagation algorithms to get reasonable reward function values. This can help to produce justice drill score and help to make AI-based decision-making.

3.4. Scenario

Scenario is the scripts or story of a crisis drill. On one hand, scenario introduces the aim, task, and basic information of this drill; on the other hand, scenario initializes the condition of crisis, counters, and resources.

By reading the introduction of a scenario, players can learn the basic information of the drill. The examiner or specialist can also add or activate some special events to increase the drill difficulties or make the simulation closer to the real society, which is exactly the advantage of wargaming-based crisis drills.

4. Form and process of wargaming-based crisis drill

4.1. Setting of player seats

There are three main actors in wargaming-based drill system, judge, red players, and blue players. A crisis drill sometimes can be an examination for crisis management abilities. Judge, the judgment group as examiners, can get all information in the map. Generally, they are also the designer of the drill plan, and they can monitor and adjust the gaming process or even lead in new affairs to make adaptive test for specific drillers. Red players as examinee are the anti-crisis forces in crisis management. Their duties are to eliminate the crisis, protect people's life and properties, and so on. In back-to-back mode, players may be divided into groups and isolated in different rooms. Each group can only get partial information around them, just like they are located in a real crisis. They should issue orders like "search," "scout," and "communicate" to their units to get more detailed information. Blue players, the control group, play the role of crisis developing. Although most of the simulation works can be processed by computers, we still need the blue players to help to control the crisis expanding and subsidy affairs in a more comprehensive economic and social background. The system can also provide viewer's seat for visitors to watch the drill process and results, but has no authority to issue orders.

4.2. Wargaming framework

The wargaming provides the platform for modeling, simulation, and evaluation of crisis management; besides, it maintains the data produced in drilling which can provide potential support for crisis management study. **Figure 2** shows the framework of wargaming-based crisis drill.

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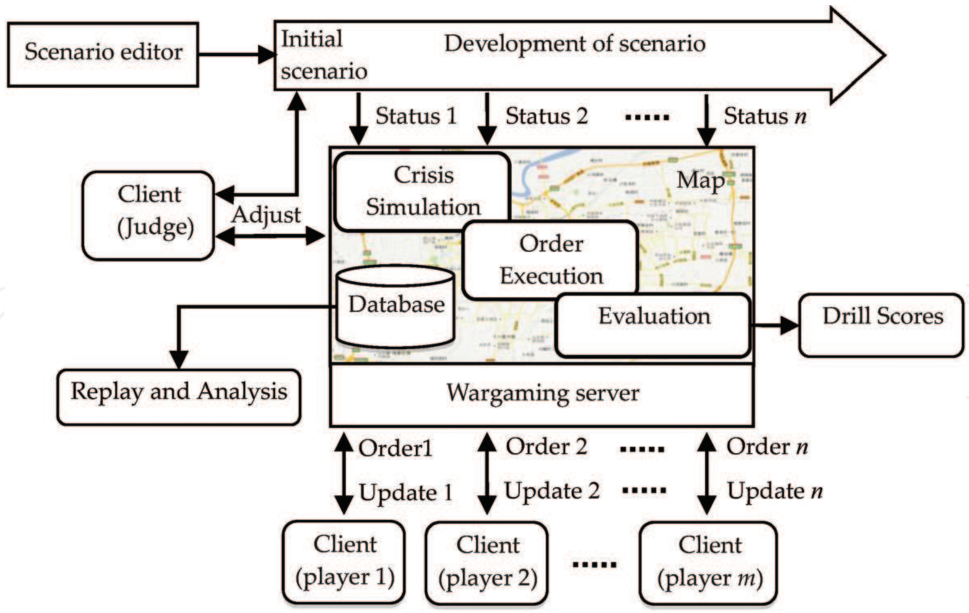

Figure 2. The wargaming framework of crisis drill.

Scenario editor can help to transform the crisis management plans into drill scenarios. For organizations, the scenario is the test paper they need to make, and then the gaming process will start from the initial scenario and develop following the scenario. Players select proper seat and login the system from clients while loading the scenario, and then the gaming process is performed round by round. In each round, players study the current situation and issue orders to their counters, so all orders are simultaneously uploaded into the wargaming server. The server will simulate the crisis, execute the orders, and evaluate their effects. Similar to the real world, some orders may be partially executed or canceled because of the interference of other players' actions or the influences of undetermined environment. The judge can examine the simulation results to find out the unbalanced data or wrong data and adjusts them to a reasonable value to keep the authenticity of the gaming process. Then the gaming process puts forward to the next round.

The end of the gaming can be evaluated by several conditions that meet the drill destination. For example, if the blue player's counters are all eliminated from the map which means the crisis has been controlled, so red players win the game. For a fire-control drill in a factory, if the factory is exploded, then red players fail the game. Since the process of the gaming is logged into the database, we can carry out more analysis works to find out the weak point, the bottleneck, or better schemes to help players to improve their decision ability for the drill, on the other side, to help the organizers to improve the crisis management plan.

4.3. Flow control of wargaming system

There are two main stages in wargaming flow: operations on clients and adjudications on server. During the operation stage, the order validity is checked on clients. Then players can know whether the orders can be issued or not, but they cannot know the execution results.

During the adjudication stage, the orders are executed with taking consideration of all the wargaming factors to guarantee the adjudication results reasonable. The flow control of wargaming system is shown in **Figure 3**.

5. Evaluation methods of wargaming

For wargaming system, evaluation is also processed following with gaming. Evaluation methods are based on some mathematical models, and utility theory is applied to estimate the dynamic sequential affects. During the gaming process, actions and orders issued by players will be evaluated till the end of wargame. The computer summarizes the utility of all decision orders by weighting, which are the scores of players' performance in the crisis drill.

5.1. Command evaluation

According to counters' order forms, evaluation of commands can be divided into four types, movement, position, effect, and impression. Each category has different specifications and needs different ways to score.

5.1.1. Evaluation of movement-type index

In wargaming system, many continuous variables, such as the speed and time, need to be discretized into some point values to characterize the ability of a unit. When a unit piece executes the "move" command in the map, a certain amount of maneuvering point values will be consumed. What is more, the properties of terrain, weather, and unit capacity will affect how much point value it will be consumed at the time of passing through a hexagonal grid. The unit will not be able to move anymore as the mobility point value of the unit is used up.

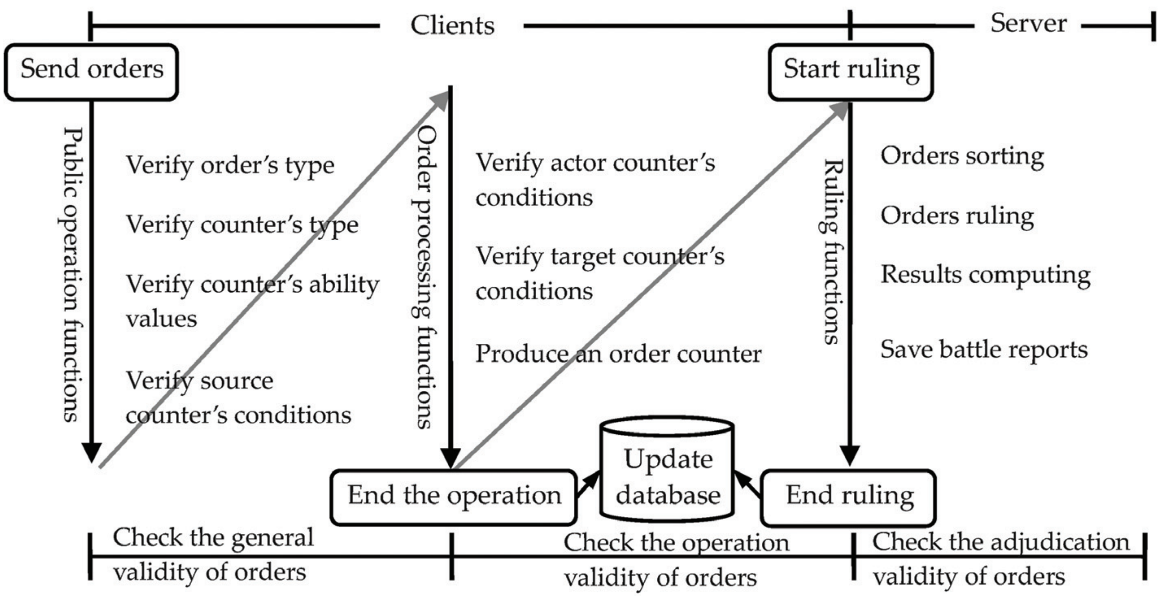

Figure 3. Flow control of operations and adjudication.

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Here, we use the ratio of movement point value consumption to the initial movement point value to measure the effect of the command. The evaluation template of movement-type index is shown in **Table 4**.

In **Table 4**, the movement point value is the moving capability of units, and the movement points consumed are the efforts that units contribute to finish the task. In general, the faster the unit moves to the target, the better quality it finishes the job with less movement points consumed. So, we use a third order function to evaluate the effect of movement-type command:

$$f(x) = 1 - x^3, x \in [0,1] \tag{1}$$

where, $x = \frac{x_c}{x_0}$, $x_c > 0$, $x_c \leq x_0$, x_c is the movement point value consumed to complete this operation; x_o is the initial movement point value of the unit.

5.1.2. Evaluation of position-type index

The position-type index mainly concerns the target location of the command. In wargaming system, the hexagonal grid with corresponding coordinates is used to indicate the position of the element in the map. When players issue orders, a reference position, desired interval, and maximum allowable interval should be set. Then the hexagonal grid number of intervals can be determined by calculating the distance from the target position to the referenced position of the unit's command. Considering that some referenced location cannot be entered directly, such as the fire site, we set x_o to represent the expected interval between actual position and referenced position, x_{min} represent the minimum allowable interval, and x_{max} represent the maximum allowable interval. The evaluation template of position-type index is shown in **Table 5**.

The scoring function of the position-type index is as the following formula:

$$f(x) = \begin{cases} 1 & x = x_o \\ \dfrac{x - x_{\min}}{x_o - x_{\min}} & x \in [x_{\min}, x_o) \\ \dfrac{x_{\max} - x}{x_{\max} - x_o} & x \in (x_o, x_{\max}] \\ 0 & x = \text{others} \end{cases} \tag{2}$$

where $x = \max(|c_{xd} - c_{xr}|, |c_{yd} - c_{yr}|)$ is the number of hexagonal grids between the actual location and the reference location. (c_{xd}, c_{yd}) represents the coordinates of target location of action, and (c_{xr}, c_{yr}) represents the coordinates of referenced position set by drill designer.

5.1.3. Evaluation of effect-type index

Effects of a command execution can be evaluated by the related gain or loss results. According to the command property, the result may be the number of casualties, the number of destroyed hexagonal grids, or the number of polluted hexagonal grids. The effect degree can be divided into three levels, for example, the degree of personnel casualty can be divided into death, heavy injury, and slight injury, and the destruction or pollution degree of hexagonal grids can be divided into heavy, medium, and light levels. The three levels from heavy to light are level I, level II, and level III. The evaluation template of effect-type index is shown in **Table 6**.

Properties	Variables	Command list			
		Movement	Wounded transfer	Goods transfer	…
Command code		O01	O53	O81	…
Action unit		U_{all}	U5	U8	…
Initial movement points	x_0				
Movement points consumed	x_c				
Score	$f(x)$				

Table 4. Scoring of movement-type index.

Properties	Variables	Command list		
		Establish headquarters	Crowd evacuation	…
Command code		O11	O21	
Action unit		U1	U2	
Target location	(c_{xd}, c_{yd})			
Referenced location	(c_{xr}, c_{yr})			
Expected interval	x_o			
Minimal interval	x_{min}			
Maximal interval	x_{max}			
Score	$f(x)$			

Table 5. Scoring of position-type index.

The scoring function can be represented by an exponential function:

$$f(x) = e^{-0.1\beta x}, \quad \beta > 0 \tag{3}$$

where $x = 5x_1 + 3x_2 + x_3$, $(x_1, x_2, x_3>0)$ is an equivalent value that represents the gain or loss degree of the action; x_1, x_2, x_3 represents the gain or loss value in level I, level II, and level III; and β is a correction coefficient, mainly to compensate the error caused by different map scales or something else.

5.1.4. Evaluation of impression-type index

Some commands may have subjective features that need experts to make evaluation directly. Based on their experiences, experts make overall judgment by watching the gaming process. To avoid the subjectivity of these experts, there will be *m* number of experts that give their rating of the command. The scoring table of impression-type index is shown in **Table 7**. The final score is the average of these rating values, and sometimes the minimal and maximal values will be neglected.

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Properties	Variables	Command list			
		Search and rescue	Prevent leakage	Purify water	…
Command code		O51	O31	O63	…
Action unit		U5	U3	U6	…
Level I	x_1				
Level II	x_2				
Level III	x_3				
Correction coefficient	β				
Score	$f(x)$				

Table 6. Scoring of effect-type index.

No.	Command code	Action unit	Experts rating					score
			1	2	3	…	*m*	
1			r_{11}	r_{12}	r_{13}	…	r_{1m}	f_1
2			r_{21}	r_{22}	r_{23}	…	r_{2m}	f_2
…	…	…	…	…	…	…	…	…

Table 7. Scoring of impression-type index.

Level I index (objective)	Level II index (plan)	Level III (action)
Crisis management ability (A)	Crisis responsibility (B_1)	The time that corresponding units reach the target site (C_{11})
	Command decision capacity (B_2)	Creation of headquarter (C_{21})
		Action coordination (C_{22})
		Judgment of crisis damage (C_{23})
	Emergency rescue capacity (B_3)	Search and rescue trapped people in time (C_{31})
		On-site rescue of the seriously wounded (C_{32})
		To send wounded people to designated medical institutions in time (C_{33})
	Crisis disposal capacity (B_4)	Containment of hazardous article leaks (C_{41})
		Extinguish fire source and deal with explosion accident (C_{42})
		Look for leaks, repair damaged equipment (C_{43})
		Decontamination of contaminated waters (C_{44})
	Monitoring and early warning capacity (B_5)	Continuous monitoring of the environment (C_{51})
		Contamination monitoring and decontamination of the wounded (C_{52})
		Alert the public timely (C_{53})

Level I index (objective)	Level II index (plan)	Level III (action)
		Inform the media about the crisis disposal (C_{54})
	Emergency support capacity(B_6)	Contact providers to provide emergency resources (C_{61})
		The requested resource arrives at the demand location in time (C_{62})
		Identify and classify the resources achieved (C_{63})
		Ensure the communication system is working properly (C_{64})
		Ensure the normal supply of water, electricity, and gas (C_{65})
	Social control capacity (B_7)	Organize the evacuation of the surrounding masses (C_{71})
		To warn of potentially dangerous areas (C_{72})
		Guide vehicles to avoid traffic congestion (C_{73})
	Restoring and rebuild abilities (B_8)	Decontamination of on-site equipment and all personnel involved in the rescue (C_{81})
		Clean-up of contamination and transport to waste disposal site (C_{82})
		Maintenance and restoration of basic living conditions (C_{83})
		Investigate the cause of the accident (C_{84})
		Summarizing experiences and lessons in crisis (C_{85})

Table 8. A sample index system for crisis drill.

5.2. The creation of index system

An index system needs to be created according to the practical condition in crisis management. The index system can be hierarchical structure; then organizations can score the drill process in a categorized way to represent the specific abilities of players. Level I index is the total score for the drill objective, level II index is the criterion for crisis disposal plan, and level III index is the score that specific action accomplished.

To create the index system, organizations need to analyze the crisis plan, crisis disposal process, department responsibilities, national standards, etc.; then, according to the drill objective and the wargaming process, sometimes need to consult with experts; and make the detailed index system. **Table 8** shows a sample index system of a hazardous article leakage crisis.

6. Decision models for wargaming drills

A behavior tree (BT) is a mathematical model which can create very complex tasks composed of simple tasks and widely used in computer games [8]. In wargaming-based drill system, the scenario and action rules can be represented easily and understandable in a graphical way by

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using BTs; meanwhile, some autonomous factors like fire expansion, typhoon moving, etc., can be created based on BTs. Also, the gaming process becomes efficient based on BT, and it makes preparation for the application of artificial intelligent for some algorithms which are based on decision trees, etc.

Hierarchical behavior trees can be created in wargaming-based drill system. Upper level behavior trees are composed of main policies according to level I or level II indexes. Lower level behavior trees are the standard BTs according to level III indexes. That is, the upper level illustrates the strategy for wargaming, but the lower level represents the tactical implementations of the drill actions.

Figure 4 illustrates a sample BT for an outbreak public security incident plan. For behavior trees, every node may have three states, succeeds, fails, or running. A sequence node has the

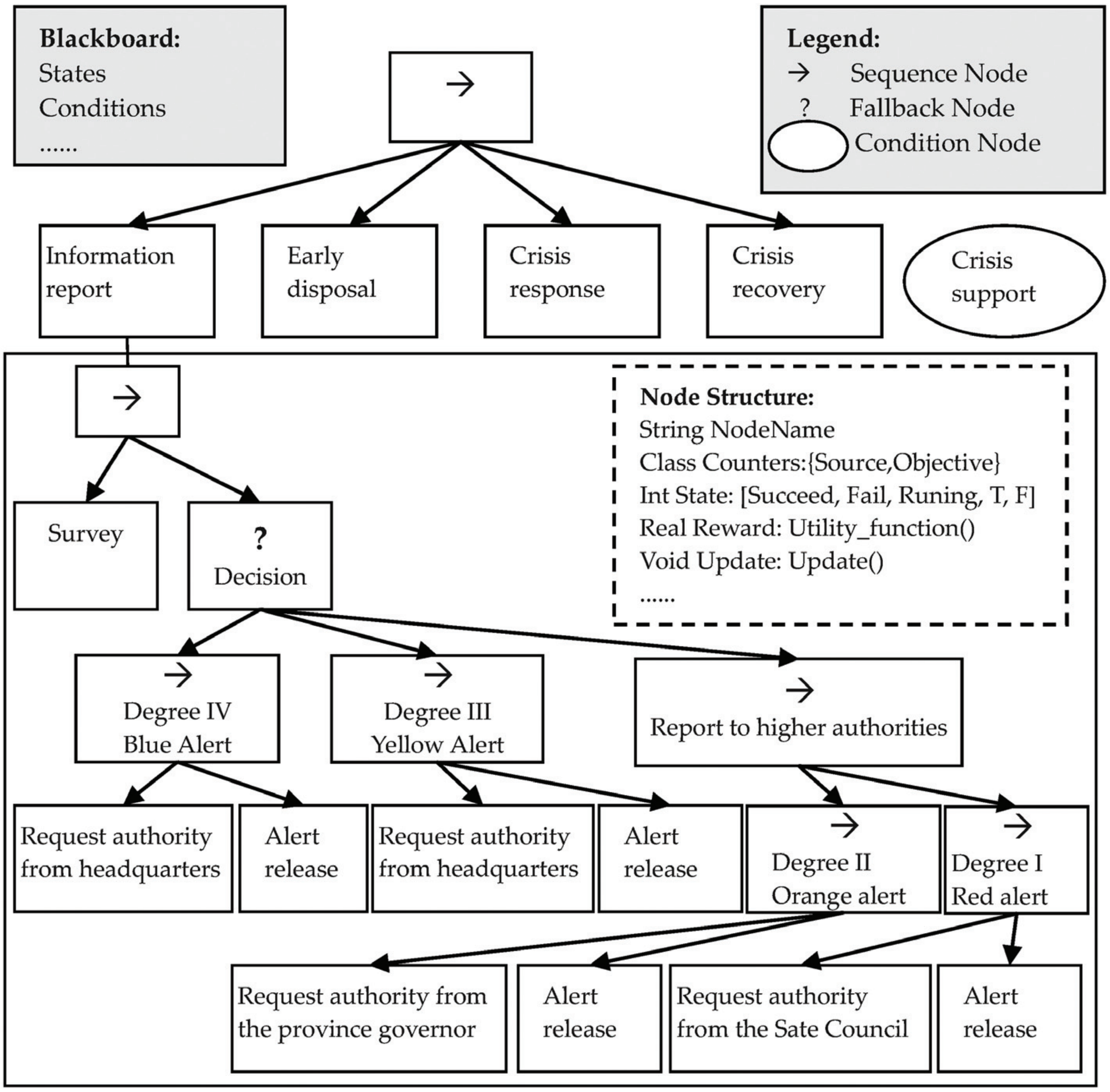

Figure 4. Sample behavior tree for a crisis plan.

process logic of "AND," that is, if all children succeed, the node succeeds; if one child fails, the node fails; if one child is running, the node is running. A fallback node has the process logic of "OR," that is, if one child succeeds, the node succeeds; if all children fail, the node fails; if one child is running, the node is running. A condition node can be a proposition or precondition for an action; it returns success or failure depending on the condition satisfaction. It gives a behavior tree more controllable functions. More decorator nodes may be needed to describe a complex behavior. User can define custom policy for the decorator node. For the convenience of data sharing in programming, a blackboard is used to share data between modules.

In practice, every node will be represented by a structure or class according to object-oriented programming languages, such as C/C++, Java, Python, etc. With the processing of tree node, states will be updated, and a reward will be evaluated at the same time. The reward value can be calculated according to the evaluation models described above. In fact, the reward can be evaluation scores when we focus on the examination function of the crisis wargaming; on the other hand, the reward can be utility values for optimal decision searching when we focus on the decision support function of the crisis wargaming. With the rapid progress in artificial intelligent (AI), especially the success of AlphaGo, we can believe the machine can sometimes give more reliable decision than average humans. The basic mechanism for AI algorithms, such as reinforce learning, is that they always pursue to maximize the rewards. So, the crisis wargaming has the nature form for the implementation of AIs.

7. A case study

Here, we give a replay of an oil pipeline leakage accident. Based on wargaming system, the disposal process is replayed and evaluated. Especially, the process is studied, and the gaming scores show the reason of crisis disposal failure.

7.1. Background

At around 2:30AM November 22, 2013, there was an oil pipeline leakage accident corresponded by Sinopec China at Qingdao City. Due to the improper disposal, an explosion occurred during the repairing process at around 10:30AM, and it caused 62 dead and 136 wounded people with 0.75 billion RMB yuan direct economic losses.

7.2. Gaming and evaluation

According to the record of the disposal process lateral published by the government, we replayed the process in the wargaming system as **Figure 5**. Then we can get the evaluating scores of the disposal process at that time, which are shown in **Tables 9–12**; for the command codes and unit codes, please refer to **Table 2**.

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Figure 5. A partial screen capture of wargaming.

Properties	Variables	Command list				
		Move	**Move**	**Move**	**Move**	**Move**
Command code		O01	O01	O01	O01	O01
Action unit		U2	U1	U3	U6	U7
Initial movement points	x_0	20	20	20	20	20
Movement points consumed	x_c	5	9	8	15	13
Score	$f(x)$	0.984	0.909	0.936	0.578	0.725

Table 9. Score of movement-type index.

	Variables	Command list	
		Establish headquarter	**Crowd evacuation**
Command code		O11	O21
Action unit		U1	U2
Target location	(c_{xd}, c_{yd})	(33,23)	-
Reference location	(c_{xr}, c_{yr})	(33,25)	-
Expected interval	x_o	3	-
Minimal interval	x_{min}	1	-
Maximal interval	x_{max}	6	-
Score	$f(x)$	0.5	0

"-" represents the command need to be done but the player failed to issue.

Table 10. Score of position-type index.

	Variable	Command list	
		Prevent leakage	Purify water quality
Command code		O31	O63
Action unit		U3	U6
Level I	x_1	1	1
Level II	x_2	1	2
Level III	x_3	3	6
Correction coefficient	β	0.8	0.8
Score	$f(x)$	0.41	0.26

Table 11. Score of effect-type index.

7.3. Results

Above all, we make individual evaluations of the action units and the accomplishment of their commands. In the form of three-level index system, based on the evaluation of individual action units, the overall evaluation results of crisis management ability can be obtained according to a linear weighted model, that is, the comprehensive score of higher level can be calculated by summarizing the production of the lower level index scores with their weights. The total index weighted scores by the linear weighted model is shown in **Table 13**.

Comparing with **Table 7**, the level II indexes of B3, B6, and B8 are ignored since our replay stopped till the explosion happened which means the game is over.

According to the aforementioned evaluation methods, the results are scored from 0 to 1; then, the three-level indexes are all from 0 to 1, and higher score means better capability. In this

Command code	Action unit	Experts' rating					Score
		1	2	3	4	5	
O12	U1	0.725	0.475	0.65	0.675	0.475	0.6
O13	U1	0.725	0.475	0.65	0.35	0.425	0.525
O71	U7	0.275	0.275	0.375	0.425	0.25	0.325
O61	-	0	0	0	0	0	0
O42	-	0	0	0	0	0	0
O43	-	0	0	0	0	0	0
O22	U2	0.85	0.55	0.725	0.625	0.875	0.725
O23	U2	0.875	0.675	0.75	0.85	0.85	0.8

"-" represents the command need to be done but the player failed to issue

Table 12. Score of impression-type index.

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Level I index	Level II index	Level II index weights	Level III	Level III index weights	Level III index score	Level II index score	Level I index score
A	B1	0.146	C11	1	0.826	0.826	0.471
	B2	0.310	C21	0.114	0.5	0.558	
			C22	0.479	0.6		
			C23	0.407	0.525		
	B4	0.376	C41	0.285	0.41	0.326	
			C43	0.364	0.325		
			C44	0.351	0.26		
	B5	0.053	C51	0.381	0	0	
			C53	0.458	0		
			C54	0.161	0		
	B7	0.115	C71	0.368	0	0.478	
			C72	0.364	0.725		
			C73	0.268	0.8		

Table 13. Index weighted scores in the first round.

incident, the overall score is 0.471 which means the crisis management ability is poor. Referring to **Table 8**, the responsible authority failed to perform monitoring and early warning actions, since index B5 scores 0. In fact, the lack of monitoring environmental condition (C51) action lost the opportunity to avoid explosion, and the actions of alerting the civilian (C53) and reporting the disaster disposal information to the media (C54) ought to reduce the loss in incident. The crisis disposal capacity (B4) is poor since it scores 0.326, and the action of cleaning the polluted water (C44) scores 0.26 as the worst one, which is the direct reason of explosion while the oil in polluted water was on fire.

To sum up, by replaying the Sinopec oil pipeline leakage accident wargaming, we can make quantitative evaluation of the unit's action which can show their capacities in crisis disposal. Furthermore, by creating a three-level index system, we can evaluate the crisis management capacity of departments or decision-makers in level II indexes. In fact, level II indexes take into account the decision sequence and cooperation among units, so they are comprehensive evaluations. Overall, the level I index is the total score of the crisis drill.

8. Conclusion

We introduce a novel crisis drill mode—wargaming. It provides a platform for system modeling, drill evaluating, and decision-making. It makes the crisis drill just like playing computer games. During the drill process, most of the factors are quantized and saved into databases, which can help to carry out deep research and AI-based planning. For government authorities, they can make good crisis plans by gaming a crisis drill once and again, to find the best assignment of emergency resources, the best human resource management, the best crisis disposal workflow, and so on. For the related duty departments or person, they can practice or adopt the examination of their workflow and professional ability in a crisis drill.

Author details

Xiaolei Li* and Qing Song

*Address all correspondence to: qylxl@sdu.edu.cn

1 School of Control Science and Engineering, Shandong University, Jinan, P. R. China

2 School of Electrical Engineering, University of Jinan, Jinan, P. R. China

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