Paper by Eric Shen for IDS Workshop on Friday, October 23, 2009

• The full paper has not been translated and revised in English.
• A set of slides have been prepared, some of which I will use in the presentation and some that are supplementary. The supplementary slides will be used for reference to respond to questions.
• Please read through the slides before the workshop.
A Sequential Group Decision Process Method for Emergency Response

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• Research on the Diffusion and Control of Panic Psychologies and Behaviors in Emergencies. Supported by the PhD Programs Foundation of the Ministry of Education of China
Crisis and Emergency: one of the key problems in the world. Some examples.

• 1986 Chernobyl Nuclear Power Plant Disaster in the Ukraine
• 1999 Qijiang bridge collapses in Sichuan
• 2001 The September 11 attack in New York
• 2003 SARS in the world
• 2004 Indonesia tsunami
• 2005 Hurricane Katrina in New Orleans
• 2007 Minneapolis bridge collapse
• 2008 Serious snow disasters in south China
• 2008 May 12 Wenchuan Earthquake in China
• 2009 A/H1N1 Influenza
Categories and Reasons for the Emergency

• **Societal security:** The September 11 attack, battles in wars

• **Nature disaster:** Indonesia tsunami, Hurricane Katrina, Serious snow disasters in south China, Wenchuan Earthquake,

• **Public health emergency:** SARS, A/H1N1

• **Disastrous local accident:** Chernobyl Nuclear Power Plant Disaster, Qijiang bridge collapse, Minneapolis bridge collapse
Are there commonalities in Emergencies?

- Characteristics of emergencies?
- Decision problems in emergencies?
- What decisions can be supported by information systems?
Decision-making in emergencies is a sequential group decision process.
• Decision-making for an emergency is not a one step process or making of only one final decision.
• In emergencies, decision makers will face many problems one after another.
• An action at any point will lead to a result. The result leads to a new decision problem with new choices.
• At any moment, an event can lead in different directions based on different conditions and different decisions.
• If all possibilities are taken into account, an event can be described using a tree structure. Predefined reaction plans have a weakness: to be feasible and cost efficient, they consider only branches which have high probability.
Characteristics of Sequential Group Decision Making Problems in Emergencies

- Sequential
- Happen Suddenly
- Similarity to previous events (Cases)
- Unexpected
- Complexity
- Uncertainty
- Time is limited
- Multi-objective
- Imperfect information
- Matters of Life and Death
- Group Decision-making
Which problems can be supported by information systems and how?

• Unexpected, Prior cases, Complexity.
  – Apply Case-Based Reasoning

• Sequential, Uncertainty, Imperfect information, Matters of Life and Death, Multi-objective
  – Do rapid calculations and quick forecast

• Suddenly, Time is limited
  – Reduce response time

• Group Decision-making
  – Rapid consensus building
History Never Repeats but History will be Similar

- In emergencies, human decision makers often draw an analogy between the existing emergency and historical data and then make a history-based decision. Such a method is often helpful.
- Unfortunately, most decision makers do not know the specifics of important historical analogies in order to apply to a specific emergency.
- A specific emergency deals with a specific domain but some decision makers maybe not up on the domain, hence it is very difficult to give analogy conclusions during a time constrained meeting.
One solution: Integrate Case-Based Reasoning (CBR) into a GSS

• When decision makers face an emergency, they usually get imperfect and often not timely information.
• An improved GSS for Emergency Decision-Making (EDM) should not only provide timely, recommendable solutions based on similar events of history, but also help decision makers to predict future situation.
• For meeting such requirements, we integrate Case-Based Reasoning (CBR) into a GSS to find historical analogies, show the outcome of the decisions, and display differences between current emergency and historical analogies. From this perspective, we are doing a Design Science research project to specify, design, build, and test such a GSS.
A Classic Emergency Response Situation is a Battle in a War

• The Battle of Midway is an interesting study of emergency response in a battle.
• The Battle of Midway is a good case study because there are lots of detailed reports.
• The Battle of Midway has many characteristics that are common to emergency.
Case-Based Examples (Analogies) come from History—War examples

- The Art of War (Chinese: pinyin: Sūn Zǐ Bīng Fǎ) is one of the oldest and most successful books on military strategy. It was written by Sun Tzu in the 6th century BC. It is still one of the textbooks at West Point.

- Sun Tzu thought that strategy was not planning in the sense of working through an established list, but rather that it requires quick and appropriate responses to changing conditions. Planning works in a controlled environment, but in a changing environment, competing plans collide, creating unexpected situations.
The Art of War (2)

Another book the Zuo Zhuan (pinyin: zuǒ zhuàn), translated as the Chronicle of Zuo or the Commentary of Zuo, is the earliest Chinese work of narrative history and covers the period from 722 BCE to 468 BCE.

It present war history as cases. These cases are short stories.
Case–based Advise from Art of War that apply in the Battle of Midway

• All we need do is attack some other place that enemy will be obliged to relieve.

• Know the enemy and know yourself.

• Don't spread out your forces! Concentrate your attacks on one target at a time!

• Pride will lead to a fall

• Be constantly on the alert to not be taken by surprise.

• Attack in order to defend.
Battle of Midway as an Emergency Response

Time=T=Mar 1942 (1)

- Japanese succeed in surprising the American fleet at Pearl Harbor on December 7, 1941, Isoroku Yamamoto proposed an advance toward the Midway and Johnston islands after June 1942 and then on to Hawaii.

- The plan was named MI, a plan to conquer the Midway Atoll. He hoped to create a defense buffer so that Japan would be free to transport materiel within these borders.

- Decisions: Sequential & Multi-Objective
Yamamoto's plan was not supported by everyone.

The Headquarters and the top Navy leaders looked more toward the South Pacific as the next step of conquest, looking to seal off Australia (a potential American base) by pushing toward New Caledonia, Fiji, and Samoa.

Group Decision-making & Multi-objective
Time=\text{T+1}= April and May 1942 (1)

• The **Doolittle Raid**, 18 April 1942, was the first air raid by the United States to strike a Japanese home island. The raid caused everyone to support plan MI (main strike at Midway with diversion attack on Alaska Aleutian Islands).

• The Pacific military balance between Japanese and United States is as follow:
The Midway- Aleutian military balance and the loss in the battle

<table>
<thead>
<tr>
<th></th>
<th>Carrier</th>
<th>Battleship</th>
<th>Heavy cruiser</th>
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<th>Submarine</th>
<th>Carrier-aircraft</th>
<th>Land-plane</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Japan possess</strong></td>
<td>8</td>
<td>11</td>
<td>13</td>
<td>10</td>
<td>65</td>
<td>21</td>
<td>396</td>
<td>214</td>
</tr>
<tr>
<td><strong>Japan loss</strong></td>
<td>4</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>322</td>
<td></td>
</tr>
<tr>
<td><strong>US possess</strong></td>
<td>3</td>
<td>0</td>
<td>9</td>
<td>4</td>
<td>28</td>
<td>25</td>
<td>233</td>
<td>120</td>
</tr>
<tr>
<td><strong>US loss</strong></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>109</td>
<td>38</td>
</tr>
</tbody>
</table>

"The end result was the greatest concentration of naval tonnage since the British battle fleet at Jutland, the largest assemblage of sea power to ever sail under the Japanese flag, the biggest yet seen in the Pacific Ocean and the most powerful in all history", said historian Dan van der Vat.
Time=T+1= April and May 1942
Three Possible Plans (A,B,C)

Where to attack. It is a case of Art of war. All we need do is attack some place that he will be obliged to relieve.

• A) Concentrate available forces to attack United states West Coast and United States Pacific Fleet will be compelled to engage in a decisive battle with the Japanese fleet.

• B) Concentrate available forces to attack Midway. If the United States Pacific Fleet tries to save Midway, Japanese fleet will engage the United States Pacific Fleet. Otherwise, they will occupy the Midway.

• C) Divide Japanese forces into two parts: one attacks Midway, the other waits to do battle with the United States Pacific Fleet.
Time=$T+1=$ April and May 1942 (4)

- The final plan to attack Midway and engage the US Pacific Fleet, planned by Yamamoto was called "Operation MI." It had three parts:
  - 1 Nagumo's main attack force containing four fleet carriers spearheaded the northern approach to air attack on Midway and and can meet and attack United States Pacific Fleet if they appear.
  - 2 Main battle force containing seven battleships, two light cruisers, and 12 destroyers headed personally by Yamamoto was to travel 300 nautical miles behind to support Nagumo's fleet and wipe out United States Pacific Fleet if they appear.
  - 3 Diversionary attack on Aleutian Islands by two light carriers, two heavy cruisers, and destroyers.
Time=$T+1=$ April and May 1942 (5)

• Yamamoto thought that the USS Yorktown was sunk in the Coral Sea three weeks earlier, so American fleet had only two carriers Enterprise and Hornet, available to the U.S. Pacific Fleet at the time.

• Only two carriers is imperfect information.

• It contradicts one of the cases of Art of war----Know the enemy and know yourself.
Yamamoto's disperses forces. He believes that the American do not knew where the real attack is coming.

It contradicts the cases of Art of war----Don't spread out your forces! Concentrate your attacks on one target at a time!

Yamamoto's battle plan was exceedingly complex. Plan complex -> operation complex-> progress of a battle ->Complexity, Uncertainty
Time=T+1= April and May 1942 (7)

• On May 27, 1942 the great armada sailed from the fleet anchorage in the Inland Sea of Japan. That day was the Navy Day - anniversary of the great victory of Japan over Russia in the Battle of Tsushima, during the Russo-Japanese war. Japanese were confident that this sortie would end in success also. They knew that the weakened American fleet had only two carriers at hand, whose inexperienced pilots had no chance to win against their more numerous and more experienced foe.

• It contradicts one of the cases of Art of war---- Pride Will Have a Fall
In fact, *Yorktown* had been severely damaged at the Battle of the Coral Sea. Despite estimates that she would require several months of repairs, Chester W. Nimitz organized the Pearl Harbor Naval Shipyard to work around the clock and in 72 hours, she was restored to a battle-ready state.

This was the first *Unexpected* event for Japanese
Time=T+1= April and May 1942 (9)

The second Unexpected for Japanese

In the meantime, the American code breakers were working hard to break the Japanese naval code JN-25. They were able to confirm Midway as the target of the impending Japanese strike, to determine the date of the attack as either 4 or 5 June, and to provide Nimitz with a complete IJN order of battle.

By May 25 Americans knew which ships and units will be involved in this operations, and Japanese had no idea that the US was reading its codes.

But the US Navy had only limited number of ships to try and stop Japanese fleet.
Time $= T+2 = \text{At exactly 04:00 Jun 4 1942(1)}$

Japanese submarine do not find US carriers. Actually, US carriers had passed. Nagumo could make one of three decision:
A) Send scout planes to search for possible US fleet, after receipt of the report from scout plane, then give orders.

b) Send scout planes to search for possible US fleet, at the same time, two carriers attack Midway and two carriers wait to deal with American fleet, if it showed up.

C) Send scout planes to search for possible US fleet. At the same time, all four carriers with their planes attack Midway.
Time=T+2= At exactly 04:00 Jun 4 1942(2)

Nagumo selected the last one. Total of 144 planes took off as a part of the strike against Midway. Each of four carriers contributed 9 fighters while the rest were bombers.

- **Imperfect information**—submarine had not supplied right information. *(US fleet had passed when submarine arrived at the sea area)*
- **Uncertainty**—do not know whether scout planes have found the US fleet.
- **Time is limited**—Japanese fleet was already near Midway.
- **Multi-objective**—attack Midway, protect against US planes, and attack US fleet.
Time=T+3= At exactly 7:15 Jun 4 1942(1)

American bombers based on Midway made several attacks on the Japanese carrier fleet. This experience may well have contributed to Nagumo's determination to launch another attack on Midway. At about this time Nagumo got advice asking for the second strike. He still had no indication of the presence of any American surface force. Nagumo had three possible decisions.

A) Keep on going as planned with planes from all carriers.
B) Order two carriers with their planes to be re-armed with bombs to attack Midway, and two carriers with their planes to be in reserve and armed with torpedoes for use against the American fleet, if it showed up.
C) Change Plan B to have reserve planes re-armed with bombs to attack Midway.
Time=T+3= At exactly 7:15 Jun 4 1942(2)
Nagumo selected decision 3 to rearm reserve planes to attack Midway

• Nagumo selected decision 3 in direct violation of Yamamoto's order that the carrier force should keep its reserve strike force armed for anti-ship operations.

• Decision contradicts the cases of Art of war----They were constantly on the alert not to be taken by surprise.
The delayed scout plane from the cruiser Tone signaled the discovery of a sizable American naval force to the east.

Unexpected "The enemy is accompanied by what appears to be a carrier..." All the staff on the bridge was shocked. Nagumo had sent seven scout planes to search for a possible US fleet, six of them find nothing, but the seventh, the delayed one, sends vital, delayed information. Nagumo was now in a quandary.

Two possible decisions.
A) Rear Admiral Yamaguchi Tamon, leading Carrier Division 2 (Hiryū and Sōryū), recommended Nagumo strike US fleet immediately with the forces ready to fly.
Evaluating the Proposed Decision A

**Advantages**
- Seize the chance of winning a battle.
- **Attack in order to defend**---- It is a case of Art of war.
- To avoid being attacked by US planes.

**Disadvantages**
- No fighter screen, so many bombers will be lost.
- If launch bombers to attack US fleet at the time, the planes that were coming back from the attack on Midway, because of a shortage of fuel, will not make it to the carriers.
- The planes ready to go are armed with bombs but not torpedoes. In attacking the US fleet, torpedoes are much better than bombs.
Time=T+4= 8:20 Jun 4 1942 (3)

Evaluating an Alternative Decision

- B) Order bombs to be exchanged for torpedoes, wait for first strike force to be recovered, then launch the reserve force.
- The advantages and shortcomings of alternative B are the opposite of A.
- Nagumo selected decision B.
- Time is limited, Matters of Life and Death.

The battlefield of Midway military balance

<table>
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<tr>
<th></th>
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<td>272</td>
<td>210</td>
</tr>
<tr>
<td>US</td>
<td>3</td>
<td>0</td>
<td>7</td>
<td>1</td>
<td>14</td>
<td>19</td>
<td>233</td>
<td>115</td>
</tr>
</tbody>
</table>
Time=T+5= 9: 18 Jun 4 1942
Proceed with Decision B

Planes from the Midway strike were recovered, and the whole Japanese fleet changed its course to 070 degrees to close in with the American fleet. The planes from the second wave were readied for attack on the US fleet. Planes were brought from hangars to the flight deck, fully fueled and armed. The bombs that were taken off were not returned to the bomb storage aboard the four Japanese carriers; they were left lying all over the hangar deck.
Time=T+5= 10: 22 Jun 4 1942
Decision B Turns out Badly

- Japanese were totally surprised when lookouts spotted enemy dive bombers in a dive. It was too late for Japanese to do anything now. The dive bombers released their bombs from 1,800 to 2,500 feet. The first three bombs missed. A fourth bomb hit, and in an instant turned the whole flight deck into a holocaust! Full of armed and fueled planes, the flight deck of the Kaga burst into flames.

- In only three minutes, three US dive bomber squadrons, VB-6, VS-6 and VS-3, sealed the fates of three Japanese fleet carriers and turned the tide of the whole war!

- Suddenly, Time is limited
The Design of a CBR-Based Sequential Group Decision Process

- The group decision process in a sequential, iterative form is shown in Figure.
- The support system first presents decision makers with recommendations based on limited information.
- Then, decision makers iteratively interact with the system, and estimate future events supported by the State Prediction Model component.
- With estimating result taken into account, the system sorts solutions by comparison with the real situation.
- Once supplementary information or reaction feedback arrives, the new information initiate another round of decision making.
Architecture of the EDM support system

• The system consists of two parts.
• Part 1, Case-Based Reasoning and Candidate Solutions Generation (CBR-CSG).
• Part 2, Hidden Pattern Discovery and Meta-synthesis of Preference Adjustment (HPD-MPA).
The CBR-Based Sequential Group Decision Process
The CBR-based sequential group decision process consists of n stages from “time” T to T+n-1. Each stage is divided into six layers. The Time layer denotes that decision makers implement a round of group decision-making for a specific emergency with the assistant of EDM support system. The Decision layer describes an interactive process between decision makers and the system. Decision makers should finish two tasks. One is estimating future events and proposing candidate solutions. The other is adjusting preferences to achieve consensus.
The EDM support system layer is organized by CBR CSG (Case-Based Reasoning and Candidate Solutions Generation) and HPD MPA (Hidden Patter Discovery and Meta-synthesis of Preference Adjustment). The Supplemental Information layer is additional information and data acquired during the evolution of the emergency. The Actions layer is a set of activities which implement the selected solution. The Observation layer is objective events for the emergency.
The Context Diagram of the System

- System Maintenance Information
- System Feedback
- Emergency Information
- Best Solution
- Clustering Results
- Stop Signal

- Modified Emergency Feature
- Solutions Modification
- Candidate Solutions
- Preference Judgments between Every Two Solutions
- Current Distribution
- Similar Case Sets
- Ranking of Solutions
- Conditional Probability

- Decision Makers
- Host
- CBR-based GDSS
- Emergency Inspection Department
Procedure of Part One: CBR-CSG

1. Emergency Information
   - Formalized by represent framework
   - Retrieve Successfully?
     - YES: Update Similar Case Sets
       - Similar Case Sets
       - Conditional Probability Analysis
       - State Prediction
       - Candidate Solution Generation Based on CBR by Decision Maker
       - Candidate Solution Generation Based on Domain Experience by Decision Maker
       - EDM Support System
       - Implement Best Solution
       - Best Solution
       - HPD MPA
     - NO: Retrieve Successfully?
       - YES: Subsequent Case Retrieval
       - NO: Supplementary Information

2. Have Taken Action?
   - NO: EDM Support System
   - YES: EDM Support System

Feedback of Implementation
Procedure of Part Two: HPD-MPA
C is defined as a quadruple consisting of four parts,  \( C = \{T, P, S, R\} \)

\( T = \{T_1, T_2, \ldots, T_n\} \): a classification of the case type

\( P = \{\text{List}[P_1, P_2, \ldots]\} \): where an element \( P_i \) defines a type of property

\( S = \{\text{List}[S_1, S_2, \ldots, S_n]\} \): where an element \( S_i \) defines one solution

\( R = \{R_1, R_2, \ldots, R_n\} \): the evaluation of the decision
Case Retrieval

It is an N-ary task to retrieve cases in a case base. The k-nearest neighbor (KNN) method, a kind of lazy learning algorithms, is widely used to complete N-ary tasks. KNN retrieves the k least distant (i.e., most similar) cases of a given query. The quality of KNN therefore depends on its distance function. A general procedure of KNN-based methods can be described as follows:

The input of KNN is a query case \( q \) (the emergency). The output is a set of cases similar to \( q \). Each case \( x = \{x_1, x_2, ..., x_{|F|}\} \) in the case base \( X \) is mapped to a point in multidimensional space.
$F$ is a set of features describing the case. KNN computes the distance $d(x, q)$ between $q$ and $x$ using the following equation:

$$d(x, q) = \left( \sum_{f \in F} w(f) \cdot \delta(x_f, q_f)^r \right)^{\frac{1}{r}}$$

where the function $\delta(x_f, q_f)$ defines the difference between $q$ and $x$ on a given feature $f$, and $w(f)$ defines the feature weighting function. $r$ is a positive integer. The equation defines an Euclidean distance when $r = 2$.

Then, using the distance threshold $\mathcal{E}$ given by decision-makers based on the application and emergency characteristics, the system
retrieves all the cases whose distance to $q$ are less than the given threshold and displays them to decision makers, i.e.

$$\text{CaseSet} = \{ x_i \mid x_i \in X, d(x_i, q) < \varepsilon \}$$

We further introduce the concept of similarity function based on the distance function $d(x, q)$. There is a negative correlation between similarity function and distance function, that is, the smaller the distance, the larger the similarity. When $r=1$, we define the similarity function as follows:

$$SIM(x, q) = 1 - d(x, q) = \left( \sum_{f \in F} w(f) \cdot SIM_f(x_f, q_f)^r \right)^{\frac{1}{r}}$$
Similarity Calculation Methods for Different Attributes

We classify all the case attributes into three categories: Crisp numeric (CN), Crisp symbolic (CS), Fuzzy linguistic (FL), and Fuzzy Attributes. For different categories, the system calculates the similarity using different methods.

1. Crisp Numeric (CN)

\[ SIM_{CN} = 1 - d(x, y) = 1 - \frac{|x - y|}{\text{max} - \text{min}} \]

Examples: wind scale, temperature, influence population, casualties

e.g.: emergency wind scale x=9, history case 1 wind scale y=9, wind scale range[0,12]:
\[ SIM_{\text{wind scale}} = 1 - \frac{|9-9|}{12-0} = 1 \]
2、Crisp Symbol (CS)

\[ SIM_{CS} = \begin{cases} 
1, & x = y \\
0, & x \neq y 
\end{cases} \]

Examples: terrain, disaster cause, weather, secondary disaster
e.g.: emergency terrain \( x=\text{plain} \), history case 1 terrain \( y=\text{plain} \):
\( SIM_{\text{terrain}} = 1 \)

3、Fuzzy attribute: We use fuzzy sets to describe fuzzy attributes.
(1) the percentage of fuzzy coverage:

\[ SIM_1(x_i, y_i) = \frac{S(x_i \cap y_i)}{S(x_i \cup y_i)} = \frac{S(x_i \cap y_i)}{S(x_i) + S(y_i) - S(x_i \cap y_i)} \]

(2) linguistic midpoint distance:

\[ SIM_2(x_i, y_i) = 1 - d(c_{x_i}, c_{y_i}) = 1 - \frac{|c_{x_i} - c_{y_i}|}{\max_i - \min_i} \]

Similarity: \( SIM_{FL,FNI}(x_i, y_i) = \epsilon_i SIM_1(x_i, y_i) + (1 - \epsilon_i) SIM_2(x_i, y_i) \)
The following equation and figure define a **general trapezia form** of a fuzzy attribute in fuzzy set.

\[
\mu_M(x) = \begin{cases} 
  L\left(\frac{m-x}{p}\right), & x \leq m \\
  1, & m \leq x \leq \bar{m} \\
  R\left(\frac{x-\bar{m}}{q}\right), & x \geq \bar{m}
\end{cases}
\]

There are five different **relations between two fuzzy sets**, as shown in the following figure:
Calculating Similarity between Fuzzy Attributes

**Step 1:** calculate the midpoint of the fuzzy set (assuming $c_{x_i} < c_{y_i}$):

$$c_{x_i} = \frac{m_{x_i} + \overline{m}_{x_i}}{2}, \quad c_{y_i} = \frac{m_{y_i} + \overline{m}_{y_i}}{2}$$

**Step 2:** calculate the coordination of the intersection point $M$ for two fuzzy sets (Graph b).

$$x_M = \frac{q_{x_i} m_{y_i} + p_{y_i} \overline{m}_{x_i}}{p_{y_i} + q_{x_i}}, \quad y_M = 1 - \frac{x_M - \overline{m}_{x_i}}{q_{x_i}}$$

**Step 3:** if $y_M < 0$, then the intersection is null, $S(x_i \cap y_i) = 0$, $SIM1(x_i, y_i) = 0$ (Graph a)
Step 4: if $y_M > 0$, firstly calculate the area of each fuzzy set

$$S_{x_i} = \frac{2\bar{m}_{x_i} + q_{x_i} - 2\underline{m}_{x_i} + p_{x_i}}{2}, \quad S_{y_i} = \frac{2\bar{m}_{y_i} + q_{y_i} - 2\underline{m}_{y_i} + p_{y_i}}{2}$$

If $y_M < 1$, then the intersection is a triangle (Graph b), the area of this triangle is

$$S(x_i \cap y_i) = \frac{(\bar{m}_{x_i} + q_{x_i} - \bar{m}_{y_i} + p_{y_i}) \times y_M}{2};$$

Otherwise, if $\bar{m}_{x_i} + q_{x_i} < \bar{m}_{y_i} + q_{y_i}$, $\underline{m}_{x_i} - p_{x_i} < \underline{m}_{y_i} - p_{y_i}$ and the fuzzy sets don’t contain each other, then the intersection is a trapezium (Graph c) and the area of the intersection is

$$S(x_i \cap y_i) = \frac{2\bar{m}_{x_i} + q_{x_i} - 2\underline{m}_{y_i} + p_{y_i}}{2};$$

Or, if one of the fuzzy set contains the other one (Graph d and Graph e), $S(x_i \cap y_i) = \min(S(x_i), S(y_i))$. 
Step 5: calculate $\varepsilon_i$, the equation is following:

$$
\varepsilon_i = \min\left(\frac{\bar{m}_y + q_y}{\max_i - \min_i} - \frac{m_x - p_x}{\max_i - \min_i}, 0.9\right)
$$

Step 6: calculate $SIM1(x_i, y_i)$, $SIM2(x_i, y_i)$, and $SIM(x_i, y_i)$ based on the equations defined previously.

Examples: temperature variance, air pressure, height, fuzzy attributes with linguistic values such as “very”, “high”, “small”, “low”, “usually”, and so on
State Prediction Model

$EI_t$: The observed variable of an emergency at time $t$.

$\theta_t$: The state of an emergency at time $t$.

$D_t$: The action adopted at time $t$, which affects the state $\theta_t$;

$S_t$: Defines the conditional probability of $EI_t$ given the state $\theta_t$ at time $t$, i.e., $S_t = P(EI_t | \theta_t)$.

The state-space of $\theta_t$ is $S$ which is composed of two dimensions, $T$ represents all the case types in the case base, and $L=\{I, II, III, IV, V\}$ represents the disaster degree. $S = T \times L$, and is recorded as $\{t_i, l_j\}, \quad t_i \in T, \quad l_j \in L$. Let $m = |T|$, representing m case types in the case base. While $|L| = 5$, there are $5m$ states in case base.
Observation Likelihood Function

\[ S_t = P(EI_t | \theta_t) \] is called an Observation Likelihood Function. In the system, \( S_t \) is estimated by the decision makers subjectively with their experience and knowledge, with reference to the similar case set, their similarity and current case. \( S_t = (s_i)_{5 \times 1}, s_i \in [0,1] \). \( s_i \) represents the probability of retrieving the current observation in the \( i \)th state of state space \( S \), while \( S = T \times L \). Each decision makers will make \( m \) estimates.
Transition probability

In this system, \( A_t = \left( a_{ij}^t \right)_{5m \times 5m} \) is the statistical conclusion from history cases. For each case in the case base, there probably exist subsequent cases. Assuming there are \( N \) types of cases and \( M \) subsequent cases in the case base, while \( N_k \) cases (let them be \( C_{i_1}, C_{i_2}, \ldots, C_{i_{N_k}} \)) can be attributed to \( k \)th type, and their respective subsequent case sets are \( SC_{i_1}, SC_{i_2}, \ldots, SC_{i_{N_k}} \) (\( SC_{ij} = \Phi \) if there is no subsequent case), the type can be represented as \( T_{i_1}, T_{i_2}, \ldots, T_{i_{N_k}} \).
And the state transition probability from kth state at time t to state in time t + 1 can be represented as the following:

\[
a^t_{kk_i} = P(\theta_{t+1} = k_i | \theta_t = k) = \frac{\sum_{j=1}^{N_k} |\{k_i\} \cap T_{ij}|}{\sum_{j=1}^{N_k} |T_{ij}|}
\]

If \( |\{k_i\} \cap T_{ij}| = 1 \), the \( k_i \) th case type is included in the subsequent case set of \( i_j \) th case.

If \( |\{k_i\} \cap T_{ij}| = 0 \), the \( k_i \) th case type is not included in the subsequent case set of \( i_j \) th case.
Posteriori and Priori Probabilities

**Posteriori of** $\theta_t$:

$$L(\theta_t | EI_t = C_N, \theta_{t-1}) = P(\theta_t | \theta_{t-1}) P(EI_t = C_N | \theta_t) = A_{t-1} S_t;$$

normalize the vector to obtain the posteriori of $\theta_t$: $P(\theta_t | EI_t)$

$$L(\theta_1 | EI_1 = C_N) = P(EI_1 = C_N | \theta_1) = S_1 \text{ at } t=1$$

**Priori of** $\theta_{t+1}$:

$$P(\theta_{t+1}, \theta_t | EI_t) \propto P(\theta_{t+1} | \theta_t) P(\theta_t | EI_t) \propto A_t A_{t-1} S_t;$$

normalize the vector, The maximum value of $P(\theta_{t+1}, \theta_t | EI_t)$ can be expected to be the subsequent event which is most probable to occur in the future.
Algorithms in Part Two

Definition 1  Preference utility value  Let \( R_r \) denote the preference relation of \( DM_r \) on \( X \). Let \( x^i R_r x^j \) denote that comparing \( x^i \) with \( x^j \) (\( x^i, x^j \in X \)), \( DM_r \) tends to choose \( x^i \). According to the needs of the decision-making, let \( \theta_r(x^i, x^j) \), a real number, denote the quantificational difference of \( DM_r \)’s preference degrees on the two schemes \( x^i \) and \( x^j \).
## Preference Judgement

<table>
<thead>
<tr>
<th>$\theta_r(x^i, x^j)$</th>
<th>the signification to $DM_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$x^i$ and $x^j$ has equal preference degree</td>
</tr>
<tr>
<td>3</td>
<td>Compared with $x^j$, $x^i$ is a little better</td>
</tr>
<tr>
<td>5</td>
<td>Compared with $x^j$, $x^i$ is better</td>
</tr>
<tr>
<td>7</td>
<td>Compared with $x^j$, $x^i$ is much better</td>
</tr>
<tr>
<td>9</td>
<td>Compared with $x^j$, $x^i$ is absolutely better</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>The middle state’s corresponding utility values of the judgments</td>
</tr>
<tr>
<td>reciprocal</td>
<td>Compared $x^j$ with $x^i$, the utility value of preference $\theta_r(x^j, x^i) = \frac{1}{\theta_r(x^i, x^j)}$, $\theta_r(x^i, x^i) = 1$</td>
</tr>
</tbody>
</table>
Consistency Index from AHP

\[ CI_r = \frac{\lambda_{\text{max}}^{(r)} - s}{s - 1} = \frac{\lambda_{\text{max}}^{(r)}}{s - 1} - \frac{s}{s - 1} \]

Let \( CI_r \) denote the \( r^{th} \) decision maker \( DM_r \)'s preference judgment consistency. \( CI_r \) is an indicator to measure whether the decision maker’s judgment is careful. The smaller \( CI_r \) is, the better it is. Specially, when \( CI_r = 0 \), the preference judgment matrix \( P_r \) is a complete consistency matrix, which represents the complete consistency of \( DM_r \)'s preference judgment.
Definition 2

Suppose $DM_i$ denote the $i^{th}$ decision-maker, let $G$ be the decision group, $G = \{DM_i: i=1,2,...,n, 2 \leq n \leq +\infty \}$, let $x^k$ be the $k^{th}$ scheme, suppose $X$ be scheme group, $X = \{x^k: k=1,2,...,m, 2 \leq m \leq +\infty \}$, let $p_{ik}$ be the $i^{th}$ decision-maker prefer to the $k^{th}$ scheme, then the preference matrix is

$$P = \begin{bmatrix}
p_{11} & p_{12} & \cdots & p_{1m} \\
p_{21} & p_{22} & \cdots & p_{2m} \\
& \cdots & \cdots & \cdots \\
p_{n1} & p_{n2} & \cdots & p_{nm}
\end{bmatrix}$$

where

$$0 \leq p_{ik} \leq 1, \quad \sum_{k=1}^{m} p_{ik} = 1 \quad \{k : k=1,2,\cdots,m, \quad i : i=1,2,\cdots,n\}$$
Definition 3

The Euclidean preference distance between the $i$th and the $j$th decision-maker in the scheme group $X = \{x^k : k = 1, 2, \cdots, m; \ 2 \leq m < +\infty\}$ is that

$$d_{ij} = \sqrt{\sum_{k=1}^{m} (p_{ik} - p_{jk})^2} \quad (2)$$

where $d_{ij}$ denotes the consensus difference between the $i$th and the $j$th decision-maker in the scheme group $X = \{x^k : k = 1, 2, \cdots, m; \ 2 \leq m < +\infty\}$. 
Definition 4
Let a \( n \times n \) matrix denote consensus difference of \( n \) decision-makers, suppose \( n = 6 \), then the consensus difference matrix is

\[
d = \begin{bmatrix}
0 & d_{21} & 0 \\
d_{31} & d_{32} & 0 \\
d_{41} & d_{42} & d_{43} & 0 \\
d_{51} & d_{52} & d_{53} & d_{54} & 0 \\
d_{61} & d_{62} & d_{63} & d_{64} & d_{65} & 0 \\
\end{bmatrix}
\]

where \( d_{ij} \) is non-negative, if the consensus extent of the \( i \)th and the \( j \)th decision-maker is higher, \( d_{ij} \) is smaller, otherwise \( d_{ij} \) is bigger. When \( d_{ij} = d_{ji} \) and \( d_{ii} = 0 \), thus we get the matrix (3).
Definition 5

Let $C = \{c^w : w = 1, 2, \cdots, m; \quad 2 \leq m < +\infty\}$ be the experts group G’s preference classification of scheme group X, suppose $\epsilon$ be the classification distance which is appointed by the group decision organizer or convoker, if the $d_{ij} \leq \epsilon \in c^w$, thus the $c^w$ is a classification, that is, the group decision come to consensus $c^w$. 
Definition 6 With respect to the decision-makers $DM_i$ and $DM_j$, if

$$(d_{ij} \leq \varepsilon) \in c^\omega \subseteq C,$$

we call that $DM_i, DM_j$ come to partial consensus in $c^\omega$. As to

$$(d_{rq} \leq \varepsilon^k) \in c^k, \ (d_{ij} \leq \varepsilon^l) \in c^l,$$

if and only if

$$\varepsilon^k = \varepsilon^l = \varepsilon \text{ and } d_{ri} \leq \varepsilon, \ d_{rq} \leq \varepsilon, \ d_{iq} \leq \varepsilon, \ d_{jq} \leq \varepsilon,$$

we call $c^k = c^l$ is the same cluster.

Example 1. Suppose there is an initial preference utility value matrix as follows,

$$\Lambda = \begin{bmatrix}
0.1 & 0.3 & 0.2 & 0.4 \\
0.2 & 0.4 & 0.1 & 0.3 \\
0.3 & 0.1 & 0.4 & 0.2 \\
0.4 & 0.2 & 0.3 & 0.1 \\
0.3 & 0.3 & 0.3 & 0.1 \\
0.2 & 0.2 & 0.2 & 0.4
\end{bmatrix} \quad (4)$$
calculating with formula (2), we can get the consensus difference matrix as follows,

\[
d = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
0.2 & 0 & 0 & 0 & 0 \\
0.4 & 0.447 & 0 & 0 & 0 \\
0.447 & 0.4 & 0.2 & 0 & 0 \\
0.374 & 0.316 & 0.245 & 0.141 & 0 \\
0.141 & 0.245 & 0.316 & 0.374 & 0.346 \\
0.141 & 0.245 & 0.316 & 0.374 & 0.346 & 0
\end{bmatrix}
\] (5)
（1）let $\varepsilon^1 \leq 0.15$, thus $d_{61} = d_{54} = 0.141 \leq \varepsilon^1$

we can get the results $DM_1, DM_6 \in c^1$ and $DM_4, DM_5 \in c^2$, although $d_{61} = d_{54} \leq \varepsilon^1$, but according to definition $5$, $\min\{d_{65}, d_{64}, d_{51}, d_{41}\} = 0.346 > \varepsilon^1$, thus $c^1$ and $c^2$ are not the same classification, so they come to partial consensus separately. $DM_2$ and $DM_3$ haven’t come to consensus with others as shown in figure 1.

![Figure 1](image-url)
Suppose $\varepsilon^2 \leq 0.2$, thus $d_{61} = d_{54} = 0.141 \leq \varepsilon^1$, $d_{21} = d_{43} = 0.2 \leq \varepsilon^2$ that is $DM_1, DM_2 \in c^3$ and $DM_3, DM_4 \in c^4$ come to consensus separately based on that $DM_1, DM_6 \in c^1$ and $DM_4, DM_5 \in c^2$ has come to consensus, here $c^3$ and $c^4$ are not the same classification, as shown in figure 2.

![Diagram](image1)

Figure 2
(3) Let $\epsilon^3 \leq 0.25$, thus $d_{61} = d_{54} = 0.141 \leq \epsilon^1$,

$$d_{21} = d_{43} = 0.2 \leq \epsilon^2, \quad d_{62} = d_{53} \leq \epsilon^3 = 0.25$$

then $DM_1, DM_2, DM_6 \in c^5$ and $DM_3, DM_4, DM_5 \in c^6$ have come to consensus $c^5$ and $c^6$ separately, as shown in figure 3.

Figure 3
Definition 6
For the whole decision-makers, suppose \( \max\{d_{ij}\} \leq \varepsilon \), \( \{j : j = 2, \cdots, n; \ i : i = 1, 2, \cdots, n - 1; \ j \neq i\} \), then the decision-makers come to the whole consensus.
In the Example 1, let \( \varepsilon^4 \leq 0.45 \), and \( \max\{d_{ij}\} = d_{32} = d_{41} = 0.447 \leq \varepsilon^4 = 0.45 \) in the consensus difference matrix (5), then the whole decision-makers come to consensus \( C^7 \) when \( \varepsilon^4 \leq 0.45 \), as shown in figure 4.

![Figure 4](image-url)
Definition of the Cluster Center

$k$ clusters are being sought after clustering with given $\varepsilon$. Assume there are $\hat{l}$ elements in one of the $k$ clusters, $c^\omega$. To those clusters that have more than 2 elements $(2 \leq \hat{l} \leq s)$, we define the cluster center as

$$\hat{\pi} = \frac{1}{\hat{l}} \sum_{i=1}^{\hat{l}} \pi_i$$
Distance to the Cluster Center

The Euclidean distance of preference between a decision-maker $DM_r$ and the specified cluster center is defined as

$$d_r = \sqrt{\sum_{k=1}^{s} \left| \pi_r(x^k) - \hat{\pi}(x^k) \right|^2}$$
Certainty Indicator

\[ H(p_1, p_2, \cdots, p_n) = -k \sum_{j=1}^{n} p_j \ln p_j \]

Accordingly, we define the entropy of a decision maker on the alternatives set as

\[ H_r = -k \sum_{i=1}^{s} \pi_r(x^i) \cdot \log \pi_r(x^i) \]
Optimization of Weight Allocation based on Data Analysis

\[ \min F(w) = \sum_{r=1}^{l} (Cl_r^* + d_r^* + H_r^*)w_r^2 \]

\[ w_r \geq 0 \quad (r = 1, 2, \ldots l) \]

\[ \sum_{r=1}^{l} w_r = 1 \]
$$L(w, \xi) = \sum_{r=1}^{l} [CI_r^* + d_r^* + H_r^*]w_r^2 + 2\xi(\sum_{r=1}^{l} w_r - 1)$$

$$\begin{cases} 
\frac{\partial L}{\partial w_r} = 2[CI_r^* + d_r^* + H_r^*]w_r + 2\xi = 0 \\
\frac{\partial L}{\partial \xi} = \sum_{r=1}^{l} w_r - 1 = 0 
\end{cases}$$
\[
\begin{align*}
\begin{cases}
    w_r &= \frac{-\xi}{[CI_r^* + d_r^* + H_r^*]} \\
    \sum_{r=1}^{l} w_r &= 1
\end{cases}
\end{align*}
\]

\[
\begin{align*}
\xi &= -\frac{1}{\sum_{r=1}^{l} \frac{1}{[CI_r^* + d_r^* + H_r^*]}} \\
\begin{cases}
    w_r &= \frac{1}{[CI_r^* + d_r^* + H_r^*] \cdot \sum_{r=1}^{l} \frac{1}{[CI_r^* + d_r^* + H_r^*]}}
\end{cases}
\end{align*}
\]
Discrete Time Markov Chains

\[ T\{E_{n+1} = j \mid E_n = i, E_{n-1} = i_{n-1}, \ldots, E_0 = i_0\} = T\{E_{n+1} = j \mid E_n = i\} \]

\[ T_{ij} = T\{E_{n+1} = j \mid E_n = i\} \]

\[ T_{ij} \geq 0, \quad \sum_{j=0}^{\infty} T_{ij} = 1 \]

Chapman-Kolmogorov equation for a discrete-time Markov chain is

\[ \pi^{(n+1)} = \pi^{(n)} T \]
Hidden Pattern of Group Preference Change Based on Markov Chain

After the $t$ rounds adjustment, the preference utility values in all the rounds for decision-maker $DM_r$ are

$$\pi_r = \begin{bmatrix}
\pi_r^1(x^1) & \pi_r^1(x^2) & \cdots & \pi_r^1(x^s) \\
\pi_r^2(x^1) & \pi_r^2(x^2) & \cdots & \pi_r^2(x^s) \\
\vdots & \vdots & \ddots & \vdots \\
\pi_r^t(x^1) & \pi_r^t(x^2) & \cdots & \pi_r^t(x^s)
\end{bmatrix}$$
In this matrix, each row stands for the preference utility value vector in each round. Comparing the $k^{th}$ row with the $(k + 1)^{th}$ row ($\{k = 1, 2, \cdots, t\}$), if there exists $\pi_r^{k+1}(x^i) \downarrow \iff \pi_r^{k+1}(x^j) \uparrow$ we set the state variable $E_{ij} = E_{ij} + 1$, which shows that the decision-maker has ever changed his preference from the scheme $x^i$ to $x^j$. For each decision-maker, there are at most $t - 1$ times of adjustment. Packing all the adjustment for the group together, we have

$$T_r = \begin{bmatrix}
1 - \sum_{j \neq 1} \frac{E_{1j}}{E_r} & \frac{E_{12}}{E_r} & \cdots & \frac{E_{1s}}{E_r} \\
\frac{E_{21}}{E_r} & 1 - \sum_{j \neq 2} \frac{E_{2j}}{E_r} & \cdots & \frac{E_{2s}}{E_r} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{E_{s1}}{E_r} & \frac{E_{s2}}{E_r} & \cdots & 1 - \sum_{j \neq s} \frac{E_{sj}}{E_r}
\end{bmatrix}$$
Where $T_r$ is the preference state transition matrix for decision-maker $DM_r$, $E_{ij}$ denotes the preference transition times from $x^i$ to $x^j$ and $E_r = t - 1$ is the sample space for the state transition times. Define the overall state transition matrix of the decision-making group in the $t$ rounds adjustment procedure as

$$T = \frac{1}{l} \sum_{r=1}^{l} T_r$$

the equation shows that the overall state transition probabilities matrix is the mean value of the matrices of transition probabilities of each decision-maker, thus the group property is implied in the individual properties. Therefore, we can use the Chapman-Kolmogorov equations, to get $\pi^{(n+1)}$ at “time” $t_{n+1}$ from $\pi^{(n)}$ at “time” $t_n$. 
Conclusions

1) From the Battle of Midway, we find a lot of commonalities in Emergencies and some Common problems can be supported by information systems. Information systems could improve emergency response in applying Case-Based Reasoning, finishing rapid calculations and quick forecast, reducing response time and speeding up consensus building.

2) In emergencies, human decision makers often draw an analogy between the existing emergency and historical data and then make a history-based decision. However, it is difficult and sometimes even impossible for most decision makers to grasp the specifics of historical events in order to make an analogy and apply it to a specific emergency in limited time, therefore, cases-based GDSS is useful.
3) Based on historical analogies, the system automatically finds the transition probabilities of events from one state to another. Such information helps decision makers analyze and evaluate the differences between current emergency and historical analogies. Integrating transition probabilities and domain expertise of decision makers, the system predicts the next possible state and help decision makers put forward a correct candidate solution.

4) We finished the analysis, design and most of the implementation of the cases-based GDSS. A Flood cases base have be constructed, including about one hundred previous events. We are now conducting an experiment at China Executive Leadership Academy-Pudong.
5) Our current GDSS mainly supports numerical computation. In near future, we plan to formalize the emergency representation framework using description logics and semantic web related technology in order to further support logic reasoning.
Thank You
Supplementary slides

- Example of CBR-CSG
- Example of HPD-MPA