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Heuristics, Optimization, and Equilibrium Analysis for Automated Wargames

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Abstract

Due to the complexity of the wargaming structure, it may be difficult to completely solve some wargames involving large number of players, player options, system states, mission types, and uncertainties of operation/campaign results. Thus it is important to develop and improve heuristics, which is studied in this paper. In particular, we transform a paper-based six-player wargame into a computer-based one using Matlab programming and its graphical user interface (GUI). We design 2-4 heuristics for each of the players, develop interfaces with user inputs and automation, and run the simulation 1,000 times for each possible combinations of different players' heuristics. In particular, based on the two original heuristics for Player 1 (prioritization based on location and population types), we use human experiences to improve his heuristics (e.g., not only maximizing his short-term payoffs by assigning faction to population cards, but also preventing other players from winning by destroying their resources, especially when the other players are close to their victory conditions). Our results show that the improved heuristics would: (a) increase Player 1's equilibrium winning frequencies from 25% to 94%; and (b) decrease the ending periods, leading Player 1 to win the game faster. Our research provides some novel insights for advancing automatve wargaming.

Keywords: Wargaming, Nash Equilibrium, Heuristics

1. Introduction

Studying scenarios where multiple sides compete within a simulation of an armed conflict [1], wargames are used for gaining insights into dynamic warfare and the associated decision-making processes [4]. Modern wargames, unlike other computer-based simulations, would be interactive [7] and typically involve two or more opposing players facing a series of unknown probabilities and dynamic decisions. Ross [7] specifies three generations of wargames: the first generation is "Mind-on-Mind," which consists of simplistic forces, players, and operating environments with sets of rules; the second generation is "Force-on-Force," which consists of the features from the "Mind-on-Mind" Wargames, but have more complex operating environments that involve "Risk" to the players; and the third generation, "System-on-System," which retains the components of the first two generations, adds environmental functions (e.g. weather) and gaming time conditions. This third generation also allows for some types of intelligence level for players to be aware of their opponent's action in the combat simulations. Currently, the need of the third generation wargames is "confirmed" [7]; however, most wargames that are currently used are still in the second generation. Issues with current wargaming methods were also identified, and the researchers seek to develop improved methods for future wargames and combat mission planning [5].

The wargame that we study is of the third generation, "System-on-System Wargame," and it is named the "Successfully Managing Insurgencies and Terrorism Effectively (SMITE)" [6]. According to [6], SMITE projects develop wargames to provide a modifiable, useful tool for training, educating, and assisting Americans and allied planners to commit counterinsurgency [8]. Based on the SMITE project, [2] developed the "Interactive and Automatic Wargames Training System (IWanTS)," which allows automation and user inputs. Figure 1 shows the design of the IWanTS's user interface.

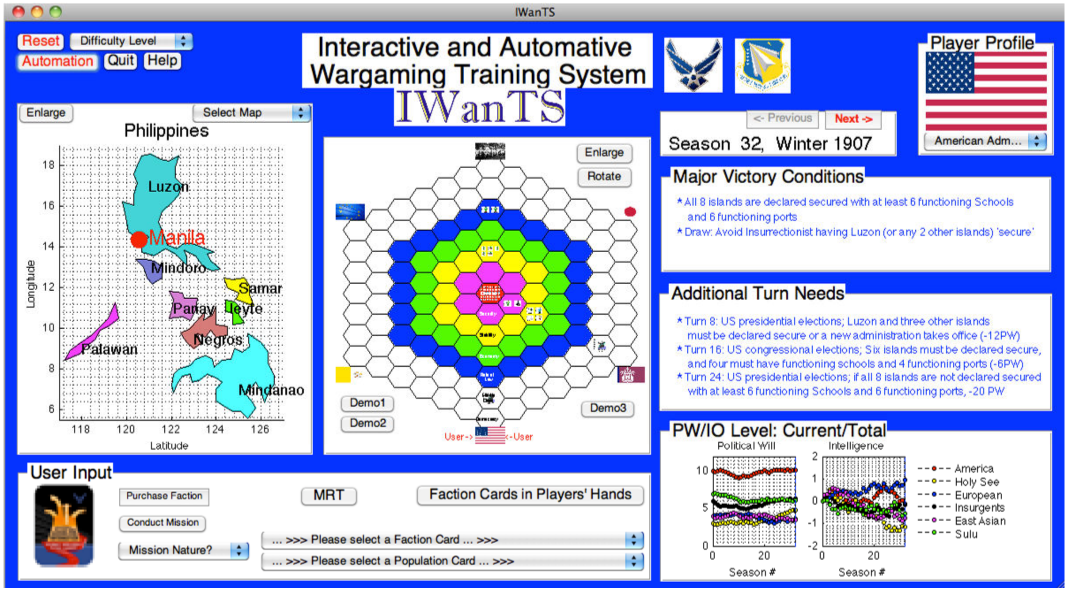

Figure 1: Screenshot of the User Interface of Visualizing Interactive and Automatic Wargames Training System (IWanTS), generated by Matlab GUI programming [2]

In this research, we construct a user-friendly wargame computer program involving six players with conflicting interests. We design 2-4 heuristics for each of the players. In addition to user inputs, we allow automation, which could finish the gaming process quickly and provide the simulation results in a timely manner. We then use the results for analyzing and improving the player heuristics. Our research provides some novel insights for advancing automative wargaming.

The rest of the paper is organized as follows. Section 2 introduces the definitions and game rules introduced in SMITE wargame project [6]. We then show the complexity of the gaming structure which justifies the use of heuristics. Section 3 introduces the wargame user interface, two heuristics of each player, and simulation results. Section 4 presents the improved heuristics for one player, and compares the simulation results with the original ones. Section 5 summarizes the results of this paper and proposes some future directions.

2. Modeling the Wargame

2.1 Terms and Definitions

Based on [6], we use the below notation and abbreviations throughout the paper:

- PMESII: Political (P), Military (M), Economic (E), Social (S), Infrastructure (I_1), and Information (I_2).
- ER: Engagement Rating.
- Population Card: Those population who are present in a wargaming scenario but may not be actively participating in the conflict. In our wargame there are four types of population: Farmer, Government, Church, and Bandit. The Population Cards' PMESII and ER values and names are shown in Table 1, for seven Locations in the wargame.
- Faction Card represents players' team that can be assigned by players to engage (or influence) Population Cards on the game board. The Faction Cards' PMESII and ER values, names, and their corresponding players are shown in Table 2. According to [6], the number of Faction Cards that players could use in each period is limited and specified in the Table 2.
- Faction Deck: The collection of Faction Cards for each of the six players.
- Nature of Mission: The way that the players use Faction Cards to engage Population Cards, including Political (P), Military (M), Economic (E), Social (S), Infrastructure (I_1), and Information (I_2).
- Period: The players' opportunity to engage Population Cards

- Victory Condition: The winning criteria that players seek to fulfill as documented in Table 3). Once a player fulfills his victory condition, he wins the game, and the game ends immediately.

Table 1: PMESII and ER Values for Four Types of Population on Seven Locations [6]

Location 1	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Farmer	1	1	4	7	1	2	1
Government	5	0	3	6	4	3	-1
Church	0	7	0	0	0	0	1
Bandit	0	3	0	0	0	1	2
Location 2	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Farmer	1	1	4	7	1	2	1
Government	5	0	3	6	4	3	-1
Church	0	0	0	0	0	0	1
Bandit	0	7	0	0	0	0	7
Location 3	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Farmer	1	1	4	7	1	2	1
Government	5	0	3	6	4	3	-1
Church	0	0	0	0	0	0	1
Bandit	0	6	0	0	0	1	6
Location 4	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Farmer	1	1	4	7	1	2	1
Government	5	0	3	6	4	3	-1
Church	0	0	0	0	0	0	1
Bandit	0	3	0	0	0	1	4
Location 5	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Farmer	1	1	4	7	1	2	1
Government	5	0	3	6	4	3	-1
Church	0	7	0	0	0	0	1
Bandit	0	3	0	0	0	1	2
Location 6	**P**	**M**	**E**	**S**	**I_1**	**I_1**	**ER**
Farmer	1	1	4	7	1	2	1
Government	5	0	3	6	4	3	-1
Church	0	0	0	0	0	0	1
Bandit	0	3	0	0	0	1	4
Location 7	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Farmer	1	1	4	7	1	2	1
Government	5	0	3	6	4	3	-1
Church	0	0	0	0	0	0	1
Bandit	0	3	0	0	0	1	4

Table 2: PMESII and ER Values for Faction Cards from the Players' Faction Deck [6].

Player 1 (5)*	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Headquarters	6	1	3	4	4	3	5
Artillery	0	8	0	0	0	0	0
Army	0	7	0	0	0	0	4
Marines	0	9	0	0	0	0	5
Volunteers	0	5	0	0	0	0	3
Scout	0	6	0	0	0	4	6
Constabulary	0	0	0	6	0	6	6
Navy Cruiser	2	2	1	0	1	1	9
Navy Destroyer	1	1	1	0	1	1	8
Navy Transports	0	0	0	0	0	0	7
Civil Administrations	5	0	3	3	2	3	4
Civil Engineers	0	0	1	0	5	1	1
Department of State	7	0	0	0	0	0	7
Player 2 (1)*	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Bishop	3	0	2	7	5	4	4
Priest	0	0	0	6	1	2	1
Missionaries	0	0	0	3	0	1	4
Player 4 (3)*	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Headquarters	8	1	1	4	1	1	3
Irregulars 1	0	6	0	0	1	1	4
Irregulars 2	0	7	0	0	1	1	4
Regulars	0	7	0	0	3	0	5
Shadow Party	7	0	1	0	1	2	6
Padrones	2	0	4	4	0	0	3
International Contacts	0	0	2	0	1	2	9
Player 3 (1)*	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Embassy	3	0	2	2	0	1	8
German	6	0	0	1	0	3	4
French	5	0	0	2	0	3	4
Player 5 (1)*	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Embassy	2	0	2	2	0	1	8
Nippon	0	6	0	0	0	0	3
Diplomats	5	0	0	2	0	2	4
Player 6 (1)*	**P**	**M**	**E**	**S**	**I_1**	**I_2**	**ER**
Sultans Palace	4	1	4	4	1	1	3
Religious Leader	3	0	0	7	2	3	2

*: The values in the brackets are the number of Faction Cards that players could use in each period.

The game board consists of 127 hexagonal cells that combine into a big hexagon as shown in the center of Figure 1. The Population Cards are initially placed in the center of the game board, and then moved from cell to cell as game evolves. Each vertex represents one home cell of each of the six players. The closer one Population Card to one vertex, the larger influence that the Population Card receives from the corresponding player.

2.2 Gaming Processes

Following [6], we assume that there are at most 32 periods. At the beginning of each period, Player 1 decides which Faction Cards (as shown in Table 2) from their Faction Deck to engage which Population Card using what Nature of Mission, with an objective to fulfill his victory conditions. Similarly, each one of Players 2-6 sequentially repeats the same steps as Player 1 has done using each of their available Faction Cards (as shown in Table 2), which completes one period. The six players repeat these steps, until period 32, or until when one player fulfills his Victory Conditions.

2.3 Complexity of Gaming Processes

As we introduced in Section 2.1 and Table 2, for each period Player 1 could use 5 out of 13 Faction Cards to engage 28 Population Cards, at one out of six mission types. Therefore, there are $\binom{13}{5} = \frac{13!}{5!8!} = 1,287$ ways for him to choose Faction Cards; $(6 \times 28^5) \approx 10^8$ possible choices to assign the Faction Cards to the Population Cards with one Nature

Table 3: Victory Conditions for Each Player in the Wargame

Player	**Victory Conditions**
Player 1	All Population Cards move to lower part of game board (2+ steps from center).
Player 2	All 7 Churches move to the region within 3 steps from P2's home cell.
Player 3	One or more Population Cards move to P3's home cell and P2 fulfills his victory conditions.
Player 4	Population Cards from three Locations (including #7) move to upper game board (2+ steps from center).
Player 5	One or more Population Cards move to P5's home cell and P6 fulfills his victory conditions.
Player 6	Every Population Cards from Location 5 move to P6's home cell.

of Mission. After the decisions above, we need to consider the uncertainties of the mission results, which is specified in a Mission Result Table [6]. There are 10 different possible results for each of the five missions, leading to 10^5 possible mission results. In summary, there are $10^5 \times 10^8 \times 1287 \approx 10^{16}$ possible results after Player 1's choices for each period. This number will be even bigger when we consider other five players and multiple periods. Therefore, it is almost impossible to completely solve such wargames, justifying the need for studying heuristics.

3. The User Interface, Heuristics, and Simulation Results

3.1 User Interface

Figure 2 shows the user interface for the six-player wargame, which allows automation and manual user inputs. There are four panels as discussed below:

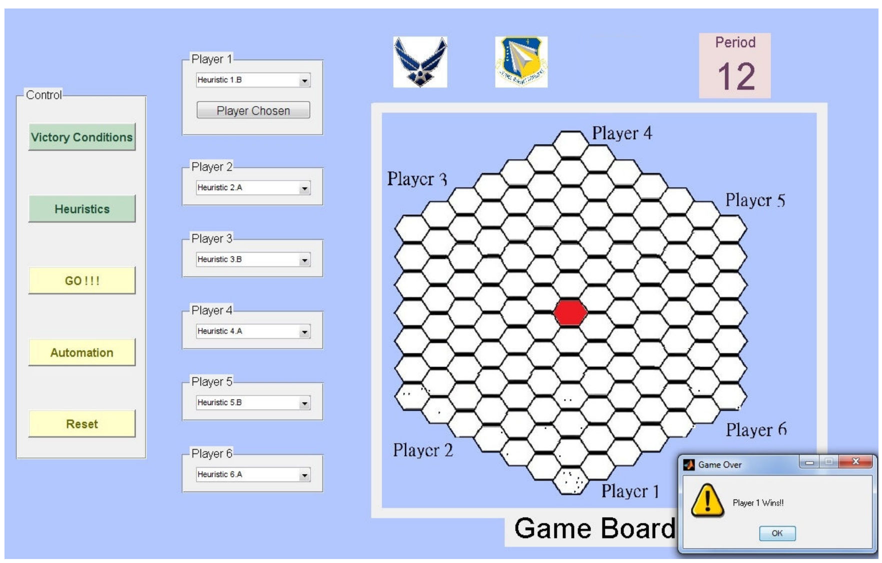

Figure 2: Six-Player User Interface (Main Interface)

- "Player" panels: One panel for each of the six players. At the panels the users could choose heuristics (described in Section 3.2) using the pop-up-menus. At the "Player 1" panel, user could also click the "Player Chosen" button to pop up a new window, where he could choose Faction Cards to engage Population Cards using one of the six Nature of Missions (as described in Section 2.1).
- "Control" panel, consisting of five functions which controls the whole game:
  - "Victory Conditions" describes the players' victory conditions in Table 3.
  - "Heuristics" describes every available heuristic introduced in Section 3.2 for each player.
  - "Go" runs the simulation for one period with the selected heuristics.
  - "Automation" plays and finishes the game automatically with selected heuristics.
  - "Reset" set the game to original status.

- "Period" panel illustrates the current number of period. There are at most 32 periods.
- "Game Board" panel illustrates the Location of the 28 Population Cards (corresponding to 7 Locations for 4 types of population in Table 1). Each vertex corresponds to one of the six players.

3.2 Description of the Heuristics

This subsection documents two heuristics for each of the six players. In general, those heuristics are developed based on the following principles: (a) players would like to use their Faction Cards with relatively high PMESII values as his Nature of Mission to engage Population Cards; (b) players would like to use their Faction Cards to engage Population Cards as his Nature of Mission; and (c) players would like to engage Population Cards, especially if those that are close-by or mentioned in their own or other players' Victory Conditions.

- Player 1:
  - Heuristic 1.A: Player 1 chooses his Nature of Mission randomly for each period. He always engages Population Cards in the order of Locations from 1 to 7. For each Location, we assume that when Player 1 chooses "Political," "Military," "Economic," "Social," "Infrastructure," and "Information" as the Nature of Mission, he will engage the Population Cards in the opposite orders of the Population Card's PMESII values specified in Table 1; i.e., respectively, (Bandit, Farmer, Church, Government), (Government, Farmer, Church, Bandit), (Government, Bandit, Church, Farmer), (Bandit, Church, Government, Farmer), (Farmer, Church, Bandit, Government), and (Government, Bandit, Farmer, Church).
  - Heuristic 1.B: Player 1 chooses his Nature of Mission in the order from Political, Military, Economic, Social, Infrastructure, to Information, and repeat this sequence. We assume that when Player 1 chooses "Political," "Military," "Economic," "Social," "Infrastructure," and "Information" as the Nature of Mission, he will engage the Population Cards in the opposite orders of the Population Card's PMESII values (similar as Heuristic 1.A above). For each type of Population Cards, he engages Population Cards in the order of Location from 1 to 7.
- Player 2:
  - Heuristic 2.A: Player 2 chooses "Political" as his Nature of Mission (since the highest values of his Faction Cards are P values) for each period and only engages "Church" Population Cards (since his Victory Conditions focus on churches), in the order of Locations from 1 to 7.
  - Heuristic 2.B: Player 2 chooses "Political" as his Nature of Mission for each period and only engages "Church" Population Cards, in the order of Locations from 7 to 1.
- Player 3:
  - Heuristic 3.A: Player 3 chooses "Political" as his Nature of Mission (since the highest values of his Faction Cards are P values) for each period and only engages "Bandit" Population Cards (since "Bandit" Population Cards have relatively low P values) from Location 7 to his home cell; does nothing if "Bandit" Population Cards from Location 7 are at his home cell.
  - Heuristic 3.B: Player 3 chooses "Political" as his Nature of Mission for each period and engages "Bandit" Population Cards from Location 7 to his home cell; engages "Bandit" Population Cards from Location 6 to his home cell if "Bandit" Population Cards from Location 7 are at his home cell.
- Player 4: Similar to Player 1's heuristics
  - Heuristic 4.A: Player 4 chooses either Political or Military for each period. He chooses Political twice in a row first, chooses Military twice in a row after, and repeat the sequence. When he chooses Political, he engages populations in the order of (Bandit, Farmer, Church, Government), and for each type, he engages populations in the order of Locations from 5 to 7. When he chooses Military, he engages populations in the order of (Government, Farmer, Church, Bandit), and for each type of Population, he engages populations in the order of Locations from 5 to 7.
  - Heuristic 4.B: Player 4 chooses either Political or Military for each period. He chooses Political twice in a row first, chooses Military twice in a row after, and repeat the sequence. When he chooses Political, he engages populations in the order of Location from 5 to 7. For each Location, he engages populations in the order of (Bandit, Farmer, Church, Government). When he chooses Military, he engages populations in the order of Location from 5 to 7. For each Location, he engages populations in the order of (Government, Farmer, Church, Bandit).

- Player 5: Similar to Player 3's heuristics:
  - Heuristic 5.A: Player 5 chooses "Political" as his Nature of Mission (since the highest values of his Faction Cards are P values) for each period and only engages "Church" Population Cards (since "Church" Population Cards have relatively low P values) from Location 7 to his home cell; does nothing if "Church" Population Cards from Location 7 are at his home cell.
  - Heuristic 5.B: Player 5 chooses "Political" as his Nature of Mission for each period and engages "Church" Population Cards from Location 7 to his home cell; engages "Church" Population Cards from Location 6 to his home cell if "Church" Population Cards from Location 7 are at his home cell.
- Player 6:
  - Heuristic 6.A: Player 6 chooses either Political or Social as his Nature of Mission. He chooses Political twice in a row first, Social twice in a row after, and repeat the sequence. Player 6, with using both Social and Political, engages the populations in Location 5 in the order of (Church, Farmer, Bandit, Government).
  - Heuristic 6.B: Player 6 chooses either Political or Social as his Nature of Mission. He chooses Political five times in a row first, Social five times in a row after, and repeat the sequence. Player 6, with using both Social and Political, engages the populations in Location 5 in the order of (Church, Farmer, Bandit, Government).

3.3 Simulation Results using Original Heuristics

For each of the 64 heuristic combinations (each of the six players have two heuristics, thus there are $2^6 = 64$ total heuristic combinations), we simulate the wargame 1,000 times and record the winning frequencies for each player (see Figure 3), and the average (over 1,000 simulations) of the ending periods (the number of periods before game ends, when one player fulfills his Victory Conditions; see the "P1's 1.A & 1.B" line in Figure 4). In particular, Figure 3 provides the simulation results of winning frequencies from 1000 times for each of 64 heuristic combinations. We observe that Player 6 might hold more winning times than Player 1 in some heuristic combinations, especially when Player 1 chooses heuristic 1.B, Player 5 chooses heuristic 2.A, and Player 4 chooses heuristic 4.B.

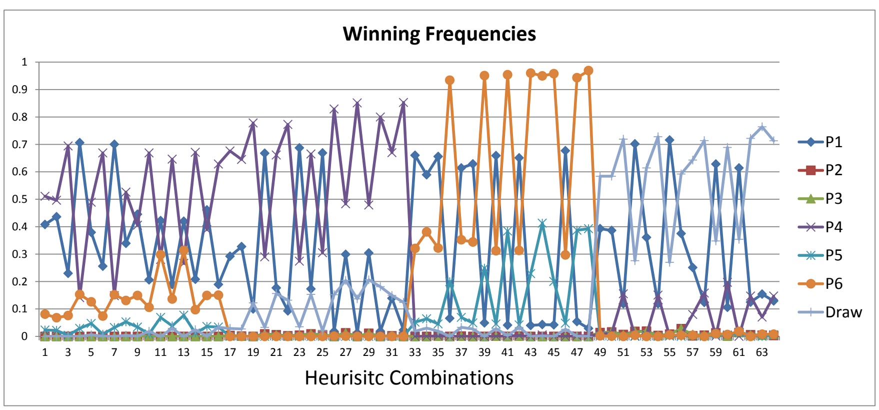

Figure 3: Six Players' Winning Frequencies for Each of the 64 Heuristic Combinations

3.4 Equilibrium Analysis based on Winning Frequencies

Note that in Figure 3, the players' winning frequencies depend on all players choice of heuristics. We assume that the players want to maximize their own winning frequencies by choosing one of the two heuristics. We calculate the Nash equilibrium using the data provided in Figure 3 for the game with six players. To reduce dimensions in the equilibrium solving process, we repeatedly delete the strictly dominated strategies [3] by comparing the players' payoffs for each combinations of other players' choices. For example, Table 4 illustrates that Player 2's Heuristic 2.A is strictly worse than Heuristic 2.B in 29 out of 32 cases, except the following three heuristic combinations (1.A, 3.A, 4.A, 5.B, 6.A), (1.A, 3.A, 4.B, 5.B, 6.A), and (1.A, 3.B, 4.A, 5.B, 6.B). In these three cases, Player 2's winning frequencies are all zero regardless of choosing 2.A or 2.B and we will further investigate those cases. However, we could remove 29 other combinations where Heuristic 2.A is strictly worse than Heuristic 2.B.

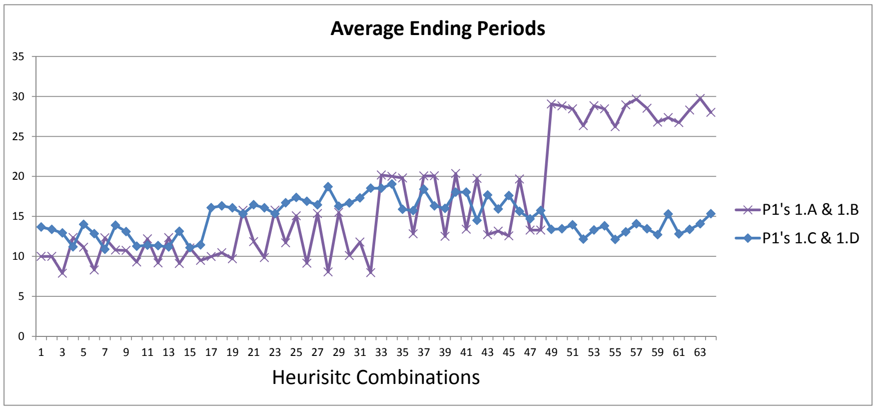

Figure 4: Comparison of Ending Periods in 64 Heuristic Combinations between the Original (P1's 1.A & 1.B) and the Improved (P1's 1.C & 1.D) Heuristics

Table 4: Illustration that Player 2's Heuristic 2.A is Dominated by Heuristic 2.B, based on Player 2's Winning Frequencies

(P1,P3,P4,P5,P6)	**2.A**		**2.B**	**(P1,P3,P4,P5,P6)**	**2.A**		**2.B**
(1.A,3.A,4.A,5.A,6.A)	0.0%	<	0.3%	(1.B,3.A,4.A,5.A,6.A)	0.0%	<	1.4%
(1.A,3.A,4.A,5.A,6.B)	0.0%	<	0.1%	(1.B,3.A,4.A,5.A,6.B)	0.0%	<	1.6%
(1.A,3.A,4.A,5.B,6.A)	0.0%	<	0.1%	(1.B,3.A,4.A,5.B,6.A)	0.1%	<	0.7%
(1.A,3.A,4.B,5.A,6.A)	0.0%	<	0.9%	(1.B,3.A,4.B,5.A,6.A)	0.0%	<	1.8%
(1.A,3.B,4.A,5.A,6.A)	0.0%	<	0.6%	(1.B,3.B,4.A,5.A,6.A)	0.1%	<	1.9%
(1.A,3.A,4.A,5.B,6.B)	0.0%	<	0.2%	(1.B,3.A,4.A,5.B,6.B)	0.0%	<	0.3%
(1.A,3.A,4.B,5.A,6.B)	0.0%	<	0.4%	(1.B,3.A,4.B,5.A,6.B)	0.0%	<	0.8%
(1.A,3.B,4.A,5.A,6.B)	0.0%	<	0.9%	(1.B,3.B,4.A,5.A,6.B)	0.1%	<	2.8%
(1.A,3.B,4.A,5.B,6.A)	0.0%	<	0.6%	(1.B,3.B,4.A,5.B,6.A)	0.0%	<	0.2%
(1.A,3.A,4.B,5.B,6.A)	0.0%	=	0	(1.B,3.A,4.B,5.B,6.A)	0.1%	<	0.4%
(1.A,3.B,4.B,5.A,6.A)	0.0%	<	1.3%	(1.B,3.B,4.B,5.A,6.A)	0.0%	<	1.3%
(1.A,3.B,4.B,5.B,6.A)	0.0%	=	0.0%	(1.B,3.B,4.B,5.B,6.A)	0.0%	<	0.1%
(1.A,3.B,4.B,5.A,6.B)	0.0%	<	1.1%	(1.B,3.B,4.B,5.A,6.B)	0.0%	<	1.4%
(1.A,3.B,4.A,5.B,6.B)	0.0%	=	0.0%	(1.B,3.B,4.A,5.B,6.B)	0.0%	<	0.6%
(1.A,3.A,4.B,5.B,6.B)	0.0%	<	0.2%	(1.B,3.A,4.B,5.B,6.B)	0.0%	<	0.4%
(1.A,3.B,4.B,5.B,6.B)	0.0%	<	0.1%	(1.B,3.B,4.B,5.B,6.B)	0.0%	<	0.3%

Similarly, by repeatedly removing the strictly dominated heuristics for Player 1, Player 4, Player 3, Player 5, and Player 6, and individually investigating those weakly dominated cases, we find a unique equilibrium solution (1.B, 2.B, 3.B, 4.A, 5.B, 6.A) with the corresponding equilibrium winning frequencies $(25.1\%, 0.2\%, 0.7\%, 8\%, 0.2\%, 0.4\%)$. The detailed solution process is available upon request.

4. The Improved Heuristics after Human Observations, and Simulation Results

4.1 Using Human Observations to Develop Player 1's Improved Heuristics 1.C and 1.D

Three human observers separately played the wargame as Player 1, using the manual user inputs, for about two hundred times in about 30 hours. After learning and discussing with each other, the human observers note that (a) engaging Population Cards in the order of population types would lead to a higher payoffs than engaging Population Cards in the order of the Locations; and (b) using P, M, and I_1 missions are favorable since Player 1's Faction Cards have relatively high P, M, and I_1 values (as shown in Table 2). With these two observations, we upgrade Heuristic 1.B to Heuristic 1.C as follows:

- Heuristic 1.C: Player 1 only chooses Political, Military, and Information as his Nature of Mission. He chooses Political twice in a row first, Military twice in a row after, Information once, and repeat the sequence. We assume that when Player 1 chooses "Political," "Military," and "Information" as the Nature of Mission, he will engage the Population Cards in the opposite orders of the Population Card's PMESII values; i.e., in the order of (Bandit, Farmer, Church, Government), (Government, Farmer, Church, Bandit), and (Bandit, Farmer, Government, Church), respectively. For each type of Population Cards, he engages Population Cards in the order of Location from 1 to 7.

Another important observation that human observers agree is that the Player 1 should not only focus on his short-term payoffs by assigning faction to Population Cards, but also prevent other players (Player 6 in this particular case, who takes the advantage of Player 1 and wins in many simulations) from winning by destroying their resources, especially when the other players are close to their victory conditions. In particular, since Player 6 needs to engage every Location 5's Population Cards to his home cell, Player 1 would like to engage those Population Cards that are in Player 6's home cell. Based on this observation, we upgrade Heuristic 1.C to 1.D with the consideration of preventing Player 6 from winning the game:

- Heuristic 1.D: If there is no Population Card from Location 5 (which is mentioned in Player 6's Victory Conditions) on the Player 6's home cell, follow Heuristic 1.C; otherwise, engage Population Card on the Player 6's home cell.

4.2 Simulation Results Using the Improved Heuristics

Using the improved Player 1's Heuristics 1.C and 1.D, and other five players' original heuristics, we conduct 1,000 simulations in 64 heuristics combinations. The line "P1's 1.C & 1.D" in Figure 5 shows the new winning frequencies of Player 1 using the improved Heuristics 1.C and 1.D. (We do not show the new winning frequencies of other five players since those values are almost zero and thus hard to observe.) By contrast, the line "P1's 1.A & 1.B" in Figure 5 re-plots the original winning frequencies of Player 1 as shown in the line "P1" in Figure 3. By comparing the two lines in Figure 5, we observe that the Player 1's winning frequencies have been significantly improved by using the new Heuristics 1.C and 1.D. Figure 4, which was introduced in Section 3.3, compares the ending periods between the original and improved heuristics. In most cases we observe that the ending periods using Heuristics 1.C &1.D are lower than the ending periods using Heuristics 1.A &1.B.

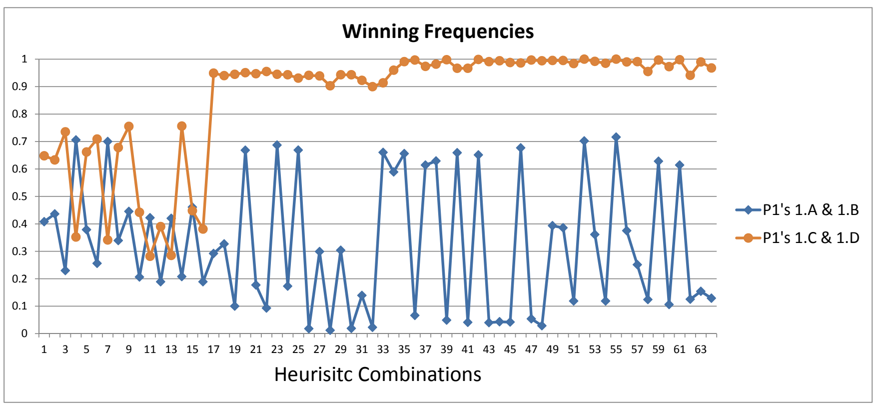

Figure 5: Comparison of Player 1's Winning Times out of 1,000 Simulations in 64 Heuristic Combinations between the Original and the Improved Heuristics

4.3 Equilibrium Analysis based on Winning Frequencies using the Improved Heuristics

Using the same approach discussed in Section 3.4, we calculate the equilibrium using the improved Heuristics 1.C and 1.D. First, Table 5 shows that Player 1's Heuristic 1.C is strictly dominated by Heuristic 1.D; so that we could remove all 32 combinations that involve Heuristic 1.C.

After repeatedly removing the dominated heuristics for Players 1, 4, 2, and 3, we find the following 13 equilibrium heuristic combinations: (1.D, 2.A, 3.A, 4.A, 5.A, 6.B), (1.D, 2.A, 3.A, 4.A, 5.B, 6.A), (1.D, 2.A, 3.A, 4.A, 5.A, 6.B), (1.D, 2.A, 3.B, 4.A, 5.A, 6.A), (1.D, 2.A, 3.B, 4.A, 5.A, 6.B), (1.D, 2.A, 3.B, 4.A, 5.B, 6.B), (1.D, 2.B, 3.A, 4.A, 5.A, 6.B), (1.D, 2.B, 3.A, 4.A, 5.B, 6.A), (1.D, 2.B, 3.B, 4.A, 5.A, 6.A), (1.D, 2.B, 3.A, 4.A, 5.B, 6.B), (1.D, 2.B, 3.B, 4.A, 5.A, 6.B), (1.D, 2.B, 3.B, 4.A, 5.B, 6.A), and (1.D, 2.B, 3.B, 4.A, 5.B, 6.B). The equilibrium winning frequencies are: (96%, 0, 0, 0, 0, 0), (99.1%, 0, 0, 0, 0, 0), (97.4%, 0, 0, 0.1%, 0, 0), (99.8%, 0, 0, 0, 0, 0), (96.7%, 0, 0, 0.1%, 0), (98.6%, 0, 0, 0.2%, 0, 0), (99.5%, 0, 0, 0.5%, 0, 0), (98.4%, 0, 0, 1.4%, 0, 0), (99.2%, 0, 0.2%, 0.7%, 0, 0),

Table 5: Illustration that Player 1's Heuristic 1.C is Dominated by Heuristic 1.D, based on Player 1's Winning Frequencies

(P2,P3,P4,P5,P6)	1.C		1.D	(P2,P3,P4,P5,P6)	1.C		1.D
(2.A,3.A,4.A,5.A,6.A)	64.8%	<	95.5%	(2.B,3.A,4.A,5.A,6.A)	94.9%	<	99.5%
(2.A,3.A,4.A,5.A,6.B)	63.3%	<	96.0%	(2.B,3.A,4.A,5.A,6.B)	94.0%	<	99.5%
(2.A,3.A,4.A,5.B,6.A)	73.5%	<	99.1%	(2.B,3.A,4.A,5.B,6.A)	94.5%	<	98.4%
(2.A,3.A,4.B,5.A,6.A)	35.2%	<	99.7%	(2.B,3.A,4.B,5.A,6.A)	95.1%	<	100.0%
(2.A,3.B,4.A,5.A,6.A)	66.2%	<	97.4%	(2.B,3.B,4.A,5.A,6.A)	94.7%	<	99.2%
(2.A,3.A,4.A,5.B,6.B)	70.9%	<	98.2%	(2.B,3.A,4.A,5.B,6.B)	95.5%	<	98.5%
(2.A,3.A,4.B,5.A,6.B)	34.1%	<	99.8%	(2.B,3.A,4.B,5.A,6.B)	94.5%	<	100.0%
(2.A,3.B,4.A,5.A,6.B)	67.8%	<	96.7%	(2.B,3.B,4.A,5.A,6.B)	94.3%	<	99.0%
(2.A,3.B,4.A,5.B,6.A)	75.5%	<	96.7%	(2.B,3.B,4.A,5.B,6.A)	93.1%	<	99.1%
(2.A,3.A,4.B,5.B,6.A)	44.2%	<	99.9%	(2.B,3.A,4.B,5.B,6.A)	94.1%	<	95.5%
(2.A,3.B,4.B,5.A,6.A)	28.2%	<	99.1%	(2.B,3.B,4.B,5.A,6.A)	93.9%	<	99.7%
(2.A,3.B,4.B,5.B,6.A)	39.0%	<	99.4%	(2.B,3.B,4.B,5.B,6.A)	90.3%	<	97.3%
(2.A,3.B,4.B,5.A,6.B)	28.5%	<	98.8%	(2.B,3.B,4.B,5.A,6.B)	94.3%	<	99.8%
(2.A,3.B,4.A,5.B,6.B)	75.6%	<	98.6%	(2.B,3.B,4.A,5.B,6.B)	92.3%	<	94.1%
(2.A,3.A,4.B,5.B,6.B)	44.8%	<	99.7%	(2.B,3.A,4.B,5.B,6.B)	90.0%	<	99.0%
(2.A,3.B,4.B,5.B,6.B)	38.1%	<	99.4%	(2.B,3.B,4.B,5.B,6.B)	91.3%	<	96.8%

(98.5%, 0.1%, 0, 1.4%, 0, 0), (99%, 0, 0, 1%, 0, 0), (99.1%, 0.1%, 0.1%, 0.4%, 0, 0), and (94.1%, 0, 0, 5.8%, 0, 0), respectively. Comparing Player 1's 13 equilibrium winning frequencies (96%, 99.1%, 97.4%, 99.8%, 96.7%, 98.6%, 99.5%, 98.4%, 99.2%, 98.5%, 99%, 99.1%, and 94.1%) with the one using original Heuristics (25.1% as calculated in Section 3.4), we observe that Player 1's equilibrium winning frequencies have been significantly improved by using the new heuristics.

5. Conclusion and Future Research Directions

Due to the complexity of the wargaming structure, it may be difficult to completely solve some wargames involving large number of players, player options, system states, mission types, and uncertainties of operation/campaign results. Thus it is important to develop and improve heuristics, which is studied in this paper. In particular, we transform a paper-based six-player wargame into a computer-based one using Matlab programming and its graphical user interface (GUI). We design 2-4 heuristics for each of the players, develop interfaces with user inputs and automation, and run the simulation 1,000 times for each possible combinations of different players' heuristics. In particular, based on the two original heuristics for Player 1 (prioritization based on location and population types), we use human experiences to improve his heuristics (e.g., not only maximizing his short-term payoffs by assigning faction to population cards, but also preventing other players from winning by destroying their resources, especially when the other players are close to their victory conditions). Our results show that the improved heuristics would: (a) increase Player 1's equilibrium winning frequencies from 25% to 90%; and (b) decrease the ending periods, leading Player 1 to win the game faster. Our research provides some novel insights for advancing automative wargaming.

Possible Future research directions include:

1. It would be interesting to invite more people to play with the user interface and provide them with surveys to evaluate their interactions with the program. It would also be interesting to record the player's actions and decisions, and analyze their experiences. Using the information these human interactions would provide, it would drastically improve the game by inputing such "knowledge" into the computer program. Placing the benefits from human inputs into the program, we could provide further smarter heuristics, from which people could learn and improve during the wargaming process.
2. In order to make a better program that can be used as a training tool, we will need to involve more people who are interested in wargames. This would lead to more improved heuristics due to more ideas of playing strategies and critiques in improving the physical automation.
3. It would also be interesting to make the game more complex and realistic. For example, we could set up multiple difficulty levels (e.g., Easy, Relatively Easy, Medium, Relatively Hard, and Hard). Easy versions could be similar to the one that we developed in this project. For the Medium versions, players might use Political Will to purchase Faction Cards from their Faction Deck. Players could also assign different Missions to different

Faction Cards, and use Political Wills to purchase Faction Cards. The Hard versions could have a complexity that is closer to the level of the SMITE project [6].

4. Finally, it would be interesting to consider all levels of difficulty for the wargame in one user interface. Such a system would provide more flexibility for the players since all different experience levels could play using the same interface and progress through the levels of difficulty as more experience is gained. Also, since they only have to use one interface, and they can learn from the lowest level (Easy) to the highest level (Hard) at a faster rate since the user would not have to re-learn the system to progress through the levels. The upgrades would make the wargaming system a useful experimental and training tool for Department of Defense decision makers and educators.

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