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Human Characteristics Impact on Strategic Decisions in a Human-in-the-Loop Simulation

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Abstract

In this paper, a hybrid simulation model of the agent-based model and cooperative game theory is used in a human-in-the-loop experiment to study the effect of human demographic characteristics in situations where they make strategic coalition decisions. Agent-based modeling (ABM) is a computational method that can reveal emergent phenomenon from interactions between agents in an environment. It has been suggested in organizational psychology that ABM could model human behavior more holistically than other modeling methods. Cooperative game theory is a method that models strategic coalitions formation. Three characteristics (age, education, and gender) were considered in the experiment to see if there is a difference between decisions made by humans with different characteristics. The final coalition, in which the human is a member, was compared to an ideal coalition known as a core coalition. The experimental results show that there is no significant difference in strategic decisions due to their characteristics. In other words, none of the considered demographic information has an impact on human strategic choices.

Keywords
Human subject experiment, strategic behavior, agent-based model, cooperative game theory, hybrid simulation

1. Introduction

There is a challenge in agent-based modeling and simulation (ABMS) to model human behavior [1]. Human decision-making is one part of human behavior. Using ABMS to model human decisions is of interest in various fields such as psychology and management [2, 3]. As Hughes, et al. [2] believed, ABMS could model human behavior more holistically than other modeling methods in organizational psychology. Human decision-making is a broad field of study; it includes a variety of different types of decisions and how those decisions are affected by different circumstances. In this paper, our focus is only on one type of human decision, which are decisions in the context of strategic coalition formation. A hybrid simulation model of the agent-based model and cooperative game theory is used in our human-in-the-loop experiment to study strategic coalition formation decisions, which is presented in this paper.

To model human behavior with ABMS precisely, the agents are required to behave similarly to how a human behaves in the same scenario. So, it is necessary to understand factors that may affect human behavior. In this paper, we try to understand which human demographic characteristics; such as age, education, and gender; influence the strategic decisions that a human would make in the context of strategic coalition formation. A human-in-the-loop experiment was used to collect data to help answer this question.

In our experiment, a type of game in cooperative game theory, known as the glove game, was incorporated within an ABMS to provide a strategic coalition formation context. Also, core stability, which is a major solution concept in cooperative game theory, was considered as the solution concept in our experiment. The resultant stable partition of agents in coalitions is known as core partition.

The glove game, also known as the shoe game, is a standard cooperative game, along with exchange economies or voting games, that is used in experimental game theory [4, 5]. In the glove game, players have a different number of left-hand and/or right-hand gloves. Players make coalitions based on the profit which they can gain by pooling their gloves together. Each pair of gloves provides a reward of one, and the total reward of a coalition is divided equally among the players participating in that coalition regardless of how many gloves a player adds to the coalition. Players join, or defect from, a coalition in a way that increases the reward which they can earn. The outcome of the game is a coalition structure. A coalition structure is a covering collection of all disjoint coalitions. This coalition structure is a core partition if there exists no coalition that all members of that coalition prefer that coalition to their current coalition [6]. In other words, there is no incentive for members to leave their current coalition in the partition and form a new coalition. The set of core partitions form the core of the game. We refer to any coalition in this core partition as a core coalition.

In this experiment, a hybrid human-in-the-loop agent-based simulation was used, which means that we used only one human in each game and the rest are computerized agents. Seven different glove games are considered for a human to play, ranging from easy to hard. Games become more sophisticated by increasing the number of computerized agents in the game. For instance, the initial game starts with one computerized agent and one human, but the last game includes six computerized agents and one human. Participants were asked to answer a questionnaire with demographic information such as age, education, and gender before the experiment starts. We should note that the consistency of computerized agents' behavior to human behavior in the context of strategic coalition formation in our model was ascertained in our previous study [7].

In the literature, there exists a variety of papers that applied game theory, ABMS, and human subject experiments in one study to investigate human behavior in different contexts [8-13]. In all these studies, game theory is used to conduct human subject experimentation with supporting results outputted from ABMS or revealing rules that can be used as input data to develop ABMS. We will next discuss studies from both scenarios.

For the case in which human subject experimentation plays a supporter role and validates results outputted from ABMS, Sohn [8] studied human decisions in the context of market exchange by applying the coordination game model in ABMS. Also, Li, et al. [9] incorporated Janus game rules to ABMS to simultaneously study cooperation and competition behavior. In all papers, a human experiment was conducted at the end to validate results gained from ABMS.

On the other hand, in a situation where the output from a human subject experiment is used as an input to develop ABMS, Takko [11] modeled risk perception and rationality behind human decisions in agent-based model with data received from human experiments so that the model can replicate human behavior precisely. In the competitive environment, Coen [12] extracting rules from social dilemma human experiment on how people behave in the context and used the rules to construct ABMS that discover effective decisions in the competitive environment. Dal Forno and Merlone [13] used ground theory to reveal human behavior rules from social dilemma human experiment in an incentive situation; so that the rules can be used as an input to the agent-based model to check the validity of results from ground theory.

In this section, although all works used an agent-based model and/or human subject experiment with the application of game theory interchangeably to address research problems, none of them used cooperative game theory and human-in-loop simulation in the same experiment. Our hybrid human-in-loop simulation was used within the human subject experiment to study effect of demographic information on human strategic decisions, as opposed to being used separately to validate it.

The reason behind using simulation in this research is that; at any game state, the human player has 64 possible coalitions that they can suggest. For each suggested coalition, the effected computerized players will need to determine whether they will join the suggested coalition or not. Their decision is affected by the current game state (coalition structure) and there are literally thousands of game states. As such, scripting what each computerized agent does in every game state would require thousands of lines of code; far more than the code needed to create a simulation of the game. This, along with the need for stochastic play by the computerized agent, is why a simulation is used in this experiment.

2. Experiment

A human-in-the-loop experiment was conducted to investigate which human demographic characteristics affect human decision-making in the context of strategic coalition formation. We recruited 31 participants with various demographic characteristics, mostly from the Old Dominion University community, by word of mouth. Each experimental trial consisted of several glove games being played. Each game involved only one participant, and the rest of the players were computerized agents; this was to remove the complex inter-personal behavior that may appear if multiple human participants interact in the game. Computerize agent behavior was driven by the ABMSCORE algorithm [14]. The details of how the algorithm was adapted for the experiment can be found in [15]. We were able to show that the agent behavior generated by the algorithm was consistent with actual human behavior in the context of our strategic coalition formation game [7].

A summary of the experimental protocol is as follows. Each participant was first asked to complete a questionnaire to collect demographic information and then shown a disclaimer about their rights in the experiment. An instructor then starts to play two test glove games conducted with cards to help the human understand the game's rules. After that, the human is required to play five computerized games on the Graphical User Interface (GUI) used in the simulation. The GUI of a particular game is shown in Figure 1 with 3 players having different number of right (blue) and left (red) gloves that they would use to form a coalition and the coalition will get rewarded for each pair of gloves.

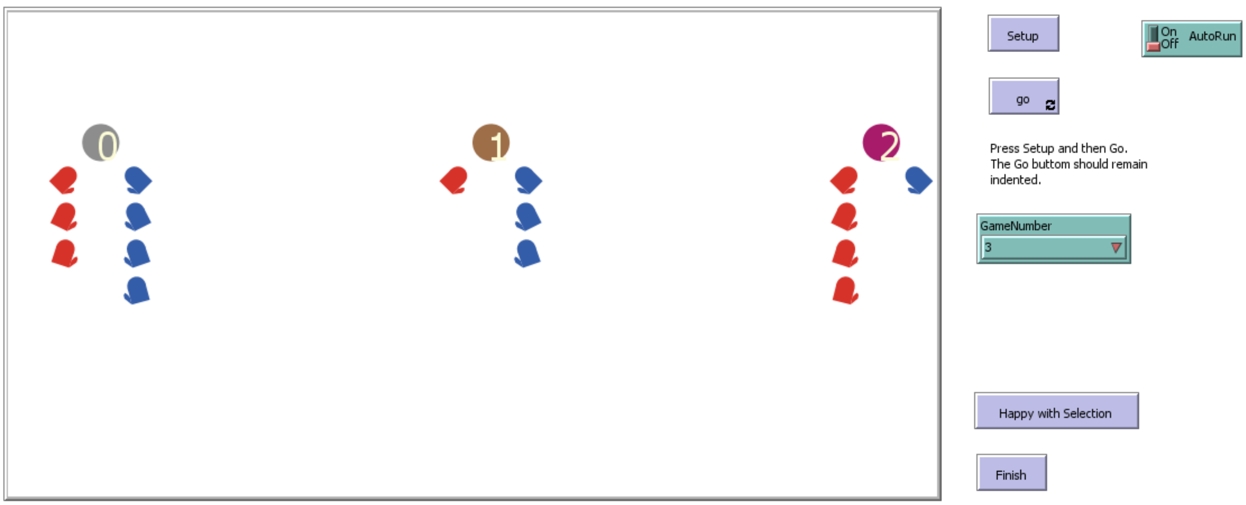

Figure 1: Graphical User Interface (GUI) used in the simulation for the third test game (Human is player zero in all games)

After the card games, the human is required to play three computerized test games on the GUI to make sure that a complete understanding of the game's processes and rules was achieved. After understanding the glove game is achieved by the human player, the last two trial games were played. These trial games' results were used for the analysis. An overview of the experimental protocol is provided in Figure 2.

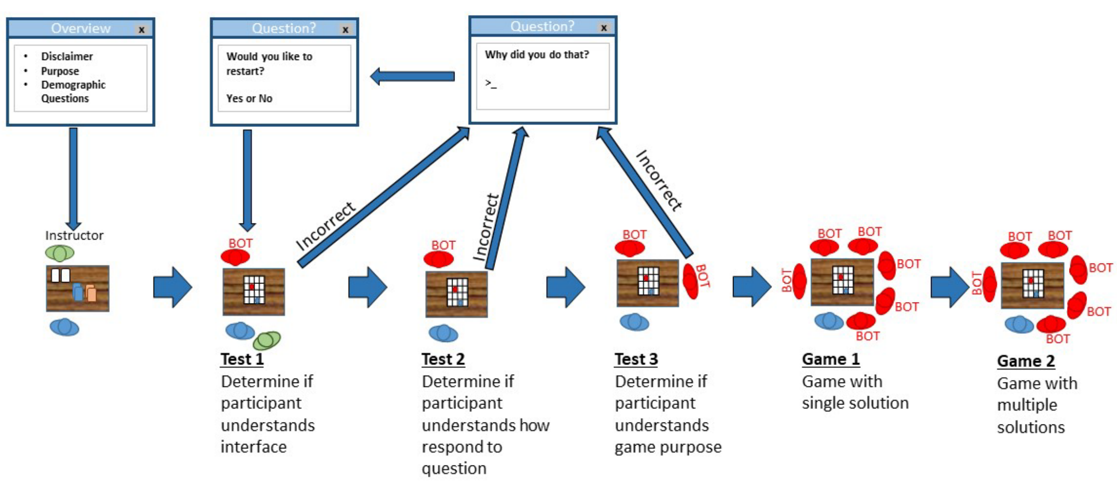

Figure 2: Flow diagram of a trial's protocol involving a human subject with computer interaction. (Extracted from [15])

Demographic information and glove game outputs are two major data that were collected from the experiment. Demographic information; such as age, education, and gender; was collected before the trial started. Below are the questions and possible choices for each participant to choose from:

- Select your age "18-20", "21-29", "30-39", "40-49", "50-59", "60 or older", "Prefer not to answer."
- Select your gender "Female," "Male," "Other," "Prefer not to answer."
- Your highest level of education "Less than a high school degree," "High school degree," "Some college credit, no degree," "Associate degree," "Bachelor's degree," "Master's degree," "Doctoral degree," "Prefer not to answer."

The distributions of demographic information from participants are shown in Figure 3.

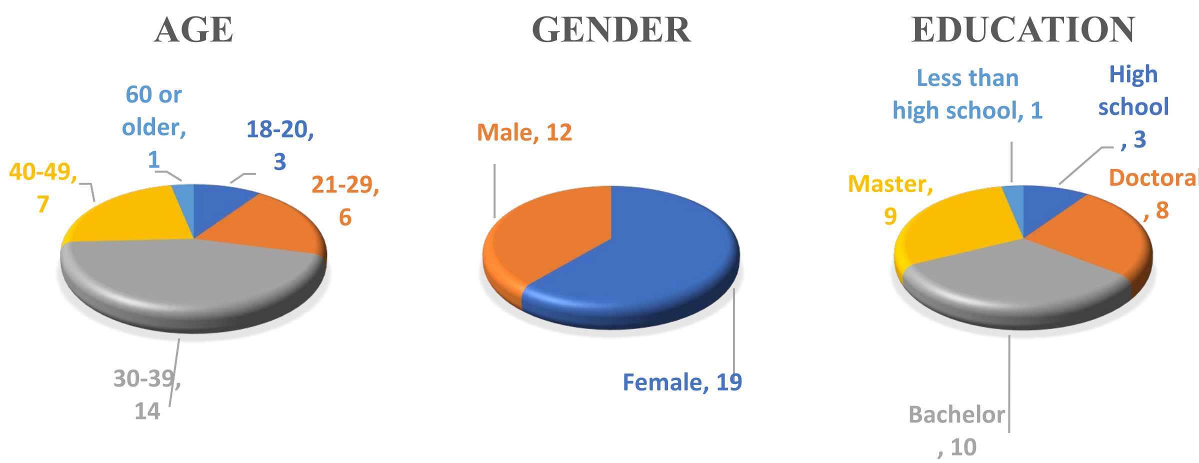

Figure 3: Distribution of demographic information from participants

As we can see in Figure 3, the population of participants in the game was very diverse. Also, we should note that no identifiable information was collected from participants as our commitment to our Internal Review Board (IRB) requirements. In the following section, we are going to discuss the results of the experiment.

3. Results and Discussions

In this section, we show the outcomes of our statistical analysis, i.e., chi-square tests of independence, on the results generated from the last two games in the experimental trials to investigate the impact of demographic information on the strategic decisions made by humans. This means that we had (2 x 31) 62 data points to use for each test.

To understand the difference, we will compare the final coalition, which a human is a member after the experiment completed by a human participant, to the ideal coalition known as the core coalition, in which a human should be a member but is not. So, the research question is "Does the characteristic affect the outcome of being a core coalition?" As we discussed in the introduction section, core coalition refers to any coalition in the core partition.

All null hypotheses were that there is no difference between each population group. Also, we should note that all tests were conducted at the 95% confidence level or alpha equal to 0.05.

For analyzing the education level, we grouped humans into two categories as a graduate who has a master's or doctoral degree and an undergraduate level, anything lower than a master's degree. The population at the graduate level is 17, and it is 14 for the undergraduate level. The first alternative hypothesis is "there is a difference between players with graduate/undergraduate degree in the final coalition which they are a member." As we mentioned before, all data compare to the ideal coalition named the core coalition. The result from the chi-square test is available in Table 1.

Table 1: Chi-squared test for education level and final coalition.

Chi-squared	Member a coalition in the core	Not a member of a coalition in the core
Graduate	15	19
Undergraduate	11	17
p-value=0.70		

The chi-square test with p-value=0.70 in Table 1 tells us that we cannot reject the null hypothesis. So, there is no difference between the final coalition in which a graduate or undergraduate human is a member.

For the gender analysis, the alternative hypothesis is "there is a difference between female/male players' final coalition in which they are a member." As shown in Figure 3, the female and male population is 19 and 12, respectively. So, the result from chi-square is shown in Table 2.

Table 2: Chi-squared test for gender and final coalition.

Chi-squared	Member a coalition in the core	Not a member of a coalition in the core
Female	14	24
Male	12	12
p-value=0.31		

Because the p-value is equal to 0.31, which is greater than the alpha=0.05, we cannot reject the null hypothesis. In other words, there is no difference between the final coalition in which a male or female is a member.

As we interpreted from Figure 3 distribution of player's age is vast such because the most populated interval is 30-39, we divide the population into two groups: "30-39" and "others." The alternative hypothesis is "there exists a relationship between player's age and the final coalition." The result from the chi-square test is shown in Table 3.

Table 3: Chi-squared test for age and final coalition.

Chi-squared	Member a coalition in the core	Not a member of a coalition in the core
30-39	11	17
others	15	19
p-value=0.70		

The result is not significant because the p-value is large, and it is greater than the alpha value. Therefore, there is no evidence for a relationship between a player's age and be/not a member of a coalition in the core.

To make sure that our sample size is sufficient in this study, we did a power calculation based on the chi-squared test results and our dataset with 62 records [16]. Assuming a large effective size (0.5), the power of research was shown to be 0.97. This number was greatly reduced for smaller effect sizes, as expected from a small sample like ours, but we can generally conclude that our sample size was sufficient to provide some evidence of our conclusions. Our sample contains two different game outcomes and independence between a participant in two data points, the assumptions make it inappropriate to make a stronger conclusion.

Results from chi-square tests on demographic information tell us that none of the demographic information impacts the strategic decision that the humans' made in the context of coalition formation. In other words, humans with different characteristics make similar strategic decisions in strategic coalition formation. Further analysis using a combination of demographic information or considering different demographic information could be conducted to strengthen our findings.

4. Conclusion

A human-in-the-loop experiment was conducted to understand which human characteristics as age, education, and gender might affect the strategic coalition formation decisions made by human participants. To analyze the situation, the final coalition, in which a participant is a member at the end of each game trial, was compared to the ideal coalitions known as the core coalition for the same game. Our results showed that none of the demographic information seems to affect the strategic decision which the participants made. The eagerness toward understanding the impact of human characteristics on decision-making in the strategic environment was to find out factors that may cause differences in the outcome of human strategic decisions. This understanding may help researchers and business owners to deal with the practical decision-making environment in the strategic context. Further analysis, such as considering more demographic information, a combination of demographic information, or making changes to the questionnaire questions' choices, could be conducted.

References

[1] R. Cheng *et al.*, "Simulation: the past 10 years and the next 10 years," presented at the Proceedings of the 2016 Winter Simulation Conference, Washington, DC, USA, 11-14 Dec. 2016, 2016.

[2] H. P. Hughes, C. W. Clegg, M. A. Robinson, and R. M. Crowder, "Agent-based modelling and simulation: The potential contribution to organizational psychology," *Journal of Occupational and Organizational Psychology,* vol. 85, no. 3, pp. 487-502, 2012, doi: https://doi.org/10.1111/j.2044-8325.2012.02053.x.

[3] G. Jie, "A Study of Organizational Knowledge Management with Agent-Based Modeling and Behavioral Experiments," University of Tokyo, 2016.

[4] S. Hart and M. Kurz, "Endogenous formation of coalitions," *Econometrica: Journal of the econometric society,* vol. 51, no. 4, pp. 1047-1064, 1983, doi: https://doi.org/10.2307/1912051.

[5] J. K. Murnighan and A. E. Roth, "Effects of group size and communication availability on coalition bargaining in a veto game," *Journal of Personality and Social Psychology,* vol. 39, no. 1, pp. 92-103, 1980, doi: https://doi.org/10.1037/0022-3514.39.1.92.

[6] G. Chalkiadakis, E. Elkind, and M. Wooldridge, *Computational aspects of cooperative game theory*, 1st ed. London, UK: Morgan & Claypool, 2011.

[7] A. J. Collins, S. Etemadidavan, and P. Pazos-Lago, "A Human Experiment Using a Hybrid Agent-based Model," in *2020 Winter Simulation Conference (WSC)*, Orlando, FL, USA, 14-18 Dec 2020: IEEE, pp. 1016-1026, doi: https://doi.org/10.1109/WSC48552.2020.9384113.

[8] J.-w. Sohn, "A study on how market policy affects human market selection decision," Doctoral Dissertation, Information Sciences and Technology, Pennsylvania State University, 2013. [Online]. Available: https://etda.libraries.psu.edu/catalog/19925

[9] X. Li, G. Yang, K. An, and J. Huang, "Human behavioral regularity, fractional Brownian motion, and exotic phase transition," *Physics Letters A,* vol. 380, no. 37, pp. 2912-2919, 2016, doi: https://doi.org/10.1016/j.physleta.2016.07.013.

[10] L. Tosselli, V. Bogado, and E. Martínez, "A repeated-negotiation game approach to distributed (re) scheduling of multiple projects using decoupled learning," *Simulation Modelling Practice and Theory,* vol. 98, p. 101980, 2020, doi: https://doi.org/10.1016/j.simpat.2019.101980.

[11] T. Takko, "Study on Modelling Human Behavior in Cooperative Games," Master Thesis, School of Science, Aalto University, 2019. [Online]. Available: http://urn.fi/URN:NBN:fi:aalto-201908255000

[12] C. Coen, "Mixing rules: When to cooperate in a multiple-team competition," *Simulation Modelling Practice and Theory,* vol. 14, no. 4, pp. 423-437, 2006, doi: https://doi.org/10.1016/j.simpat.2005.09.009.

[13] A. Dal Forno and U. Merlone, "Grounded theory based agents," in *Proceedings of the 2012 Winter Simulation Conference (WSC)*, Berlin, Germany, 9-12 Dec. 2012 2012: IEEE, pp. 1-11, doi: https://doi.org/10.1109/WSC.2012.6465064.

[14] D. Vernon-Bido and A. J. Collins, "Finding Core Members Of Cooperative Games Using Agent-Based Modeling," *Journal of Artificial Societies & Social Simulation,* vol. 24, no. 1, p. 6, 2021. [Online]. Available: http://jasss.soc.surrey.ac.uk/24/1/6.html.

[15] A. J. Collins and S. Etemadidavan, "Human Decision-making of Coalition Formation: An Experiment Using a Hybrid Agent-Based Model," *Available at SSRN 3765764,* 2020. [Online]. Available: http://ssrn.com/abstract=3765764.

[16] NCSS, "Chi-Square Tests," NCSS, LLC., PASS Sample Size Software. [Online]. Available: https://ncss-wpengine.netdna-ssl.com/wp-content/themes/ncss/pdf/Procedures/PASS/Chi-Square_Tests.pdf