ELSEVIER

Impact of Argumentative Negotiation on Collaborative Engineering

Y. Jin, M. Geslin, S.C-Y. Lu (1)
IMPACT Laboratory, Department of Aerospace and Mechanical Engineering
University of Southern California, Los Angeles, USA

Abstract
Engineering of complex systems involves multiple disciplinary design teams with diversified skills. The team members must work together to make joint decisions, but are often faced with difficulties when trying to reach agreements. Negotiation has been studied as a method for facilitating information exchange, mutual understanding, and joint decision-making. In our previous work, we introduced an argumentative negotiation model to support collaborative engineering. In this paper, we present an experiment study that was conducted to assess the impact of this negotiation support system on the process and the outcome of collaborative design. The results of the experiment have demonstrated the positive effects of the approach.

Keywords:
Design, Decision Making, Negotiation

1 INTRODUCTION

Engineering design is a multi-faceted activity whose goal is to achieve tradeoffs between competing criteria in order to deliver quality products to a demanding market. To keep up with such a fast-paced market, effective teamwork is essential. Engineering teams composed of experts in different technical areas are working together to identify requirements, make joint decisions, and eventually arrive at a final design [1]. This process requires not only flawless communications but also proper means to facilitate mutual understanding and collaborative generation of new ideas.

The primary goal of the current collaborative engineering support systems is to achieve a seamless information flow among engineering systems. Database systems, various communication and workflow tools have been developed to support information sharing, design change propagation, and process management. Few systems provide means for engineers to negotiate their decisions for the benefit of the overall design and little work has been done to quantitatively assess how different negotiation methods may impact on the engineering process and results.

In our research, an *argumentation-based negotiation* [2] approach is taken to support collaborative design. Our intention is to develop a negotiation framework that links designers and engineering systems together at decision-level, facilitates understandings among them, and helps designers expand their search space and generate better alternatives. In our previous work [3], we developed an *Argumentative Negotiation framework for Engineering Design*, called ANED. As the second step of this research, we conducted an experiment study to assess the impact of the ANED approach on the process and results of collaborative design.

Negotiation is a process in which a joint decision is made by two or more parties [4]. The parties first verbalize contradictory demands and then move towards an agreement through tradeoffs and searching for new alternatives. For collaborative design, negotiation is a way for multiple designers to exchange information, learn about other designers' perspectives and intents, and identify new opportunities based on the learned information and knowledge. Design negotiation is not only a way to reach mutually acceptable solutions, but also a method to generate new solutions. In the following, we first briefly review the key concepts of ANED and then describe the design and measures of the experiment study. After that, the experiment results are presented and discussed, and concluding remarks drawn.

2 ARGUMENTATIVE NEGOTIATION

ANED was developed based on an argumentation-based approach to negotiation [2]. The basic idea is that negotiation should not be reduced to a mere give-and-take/reject process. Instead it should be viewed as an opportunity for the participants to argue about their respective positions and expectations and achieve mutually beneficial agreements. To ensure that negotiation is efficient and moving toward a right direction, designers should do more than simply "agree" or "reject" a proposal. They must provide "arguments" for others to understand "what do you want" and "why." Following Toulmin [5], we model argument as a structure depicted in Figure 1.

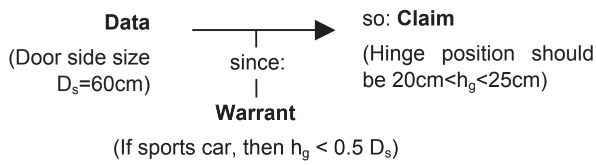
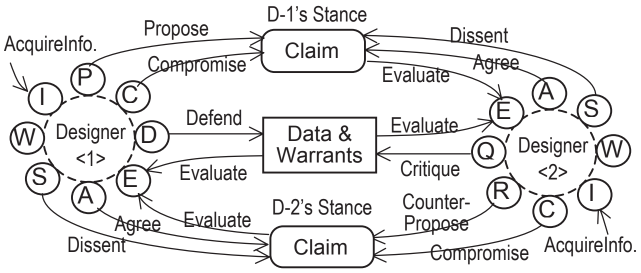


Figure 1: ANED Argument Model (after [5])

In this model, negotiation starts when a designer makes a "Claim", e.g., "Hinge position h_g should be 20cm < h_g < 25cm." If the claim is challenged by another designer, then the designer is required to provide "Data", e.g., "Door size D_s=60cm", to defend it. If the challenger is still not satisfied with the data, then a "Warrant", e.g., "If sports car, then h_g < 0.5 D_s", can be supplied by the designer, either voluntarily or at the request of the challenger.

A "Warrant" can be a rule that states the relation between the "claim" and "data", as shown in Figure 1, or a related higher-level concept, such as a function requirement. In this case, if the challenger starts to challenge the "warrant", i.e., the higher-level concept, the negotiation moves to a higher-level in which the "warrant" becomes a "claim" and negotiation continues. Figure 2 briefly illustrates the ANED protocol. The details can be found in [3].

This protocol benefits the parties by providing them with a common negotiation process with which they can unambiguously exchange information of their negotiation stance, argue about them and resolve their differences in a systematic and rational way.



Speech-Acts: Propose, Agree, Dissent, Defend, Compromise, Critique, CounterPropose

Negotiation States: (P)=Proposing, (D)=Defending, (C)=Compromising, (E)=Evaluate, (A)=In-Agreement, (S)=In-Disagreement, (Q)=Critiquing, (R)=CounterProposing, (I)=AcquiringInfo, (W)=Waiting

Strategic Actions: Propose, Defend, Compromise, Agree, Dissent, Critique, Counterpropose, Wait, AcquireInfo.

Figure 2: ANED Negotiation Protocol

3 EXPERIMENT DESIGN

The objective of this experiment study is to evaluate the effectiveness of ANED negotiation protocol and investigate how the protocol influences the negotiation process and design results. Prior to this experiment, we formulated the following hypotheses:

Hypothesis 1: *The ANED negotiation protocol can help designers generate more alternatives,* because the better understanding of others through argumentation and the attempt to maintaining one's own stance may lead to searching for more alternatives.

Hypothesis 2: T*he ANED protocol can improve the performance of collaborative design,* since more design alternatives lead to better design results.

Hypothesis 3: The restrictive ANED protocol can impact on the collaboration process in two ways: (1) *collaboration is more efficient,* due to more focused exchange of information, and *(2) more exchanges are needed for a solution,* since each party tries to argue about and maintain its positions.

The subjects include 16 senior students of mechanical engineering, who are divided into 2 treatment groups, a Control Group (CG) and a Protocol Group (PG). Each group has 4 teams, and each team has 2 participants working together to solve a common design problem. All teams worked on the same design problem.

To make sure that all communications between the two subjects of a team are correctly monitored, we divide the two subjects into two rooms, and they can communicate only through a keyboard-based computer connection that we provide. The CG teams are given an ordinary *chat tool* so that they can chat freely as they collaborate on solving the common design problem. The PG teams are asked to use an *ANED tool* so that they are forced to communicate using the ANED speed-acts shown in Figure 2 and the process defined by the ANED protocol. All communication logs are saved and used for analysis.

Each design team in both CG and PG groups is asked to design a manufacturing line for producing a *water filter* composed of a *grid* and a *filter body*, as shown in Figure 3. One designer (Designer 1) is in charge of the fabrication of the filter body, and the other (Designer 2) is in charge of the grid production and the assembly process.

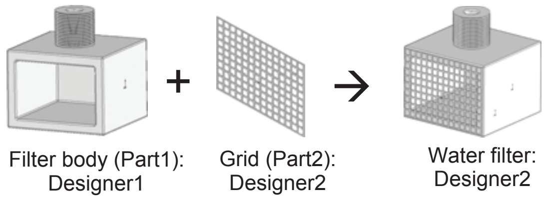


Figure 3: Water filter to be manufactured

The task of each subject is to select (1) a set of operations needed for fabricate the water filter and (2) a set of machines to carry out the selected operations. The operations for producing Part1 and Part2 and assembling them are predefined. Each operation has 3 alternative corresponding machines. Each machine as two attributes: the *cost ($)* of using the machine and the *space (m^2)* the machine occupies. Table 1 summarizes the design objectives, tasks, and the design information for each designer.

	Design Objectives	Design Tasks	Information Provided
Designer 1	- Ensure full compatibility of machines selected - Minimize the cost of use of machines - Minimize the space occupied by machines	- Select operations and machines to produce Part 1 - Lay out machines according to the rules	- Drawing of Part 1 - Table of operations for Part 1 - Partial table operations for Part 2 (no cost & space info) - Compatibility, issue, option list - A list of rules
Designer 2		- Select machines to produce Part 2 & assemble it with Part 1 - Lay out machines according to the rules	- Drawing of the Part 2 - A table of operations for Part 2 - A partial table of operations for Part 1 (no cost & space info) - Compatibility, issue, option list - A list of rules

Table 1: Design tasks, objectives and information

To add needed complexity to the manufacturing line design problem, we framed the following concepts as part of the problem definition.

Local incompatibility: Two machines may be locally incompatible so that they cannot be applied simultaneously by one designer in one manufacturing process.

Global incompatibility: Two machines may be globally incompatible so that they cannot be applied by the two designers in a team simultaneously in the overall process.

Issue: Two machines may have a shared *issue*. In this case, they can be simultaneously applied only if the issue is addressed by selecting an option.

Option: An option is an item that can be selected from the option list to resolve an issue encountered by the subjects during their machine selection task.

A machine layout tool, shown in Figure 4, is given to each subject during the design session. Each subject can see the other team member's machine layout screen.

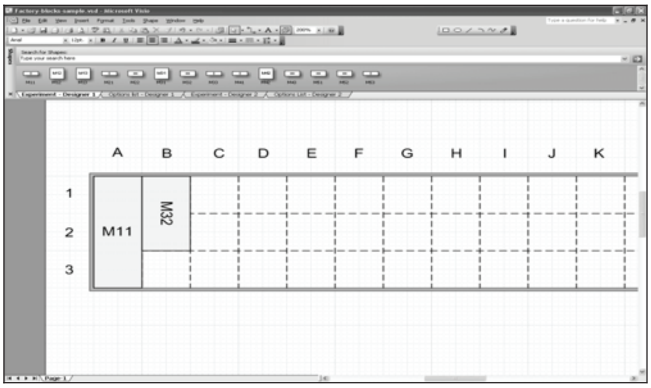


Figure 4: The main Window of the machine layout tool

The following guidelines were given to the subject:

- The space is shared between the two sets of machines selected by each designer and machines cannot overlap.
- Machines must be laid out from left to right following the order of operations.
- Designer 1 must position machines in the top half of the factory, and Designer 2 in the bottom half.

4 PERFORMANCE MEASURES

One major task of this research is to develop meaningful performance measures to assess the effectiveness and efficiency of the collaborative design process. Following indices are introduced as design performance measures.

Score-based Design Performance Index (SDP): This index is computed using two metrics: cost performance S_c and space performance S_s. The maximal score S_c=100% was assigned to the cheapest design observed (m_c), while the score of S_c=0% was assigned to the design with the highest possible cost (M_c). A linear grading scheme was used. The score S_c can be represented as:

$$S_c = 1 - [(m_c - A_c)/(M_c - m_c)]$$

where A_c is cost of the machine set selected by the team.

The space is measured along the horizontal direction. The space score is computed as:

$$S_s = 1 - [(m_s - A_s)/(M_s - m_s)]$$

where M_s: maximum number of cells used; m_s: minimum number of cells used; A_s: number of cells used in the experiment evaluated.

The SPD index is computed using weighting factors:

$$SPD = 0.8 \times S_c + 0.2 \times S_s$$

Design Space Exploration Index (DSE): When there is an issue associated with an incompatibility, resolving the issue may need new solutions or options. DSE index measures the "exploration" quality of the design process and is computed by counting the number of issues discussed (A_I) and the number of options considered (A_O) to resolve these issues. For each of these two measures the highest number recorded throughout the experiment (M_I and M_O, respectively) are considered as full scores and scaled to 100%. The lowest values for each were both 0. We have:

$DSE = (I + O)/2$; where $I = A_I / M_I$ and $O = A_O / M_O$

Negotiation Content Distribution (NCD): This term refers to the occurrence of each *speech-act* (Figure 2) in a given experiment. For each team, the numbers of occurrence of the following utterances are collected: (1) plan proposals (propose/counter-propose), (2) solution proposals (propose /counter-propose), (3) arguments (critique, defend, dissent) and (4) information requests (acquire-info).

Tracking the speech-acts used provides an overview of the negotiation contents that can be used to assess dominant communication activities in each team.

Negotiation Process Distribution (NPD): In this study, we divide a negotiation process into 3 consecutive phases, i.e., *planning* (decide on strategy), *resolution* (develop solution), and *optimization* (improve solution). For each team sample, the NPD index measures the ratio of the number of utterances devoted to each of the phases. For example, for the planning phase, we have:

$$NPD_{Planning} = \sum Utterances_{Planning} \Big/ \sum Utterances_{Total}$$

Similarly, we can calculate $NPD_{Resolution}$ and $NPD_{Optimization}$.

5 EXPERIMENT RESULTS AND DISCUSSION

The one-way analysis of variance (ANOVA), equivalent to a t-test in this case, was performed with the negotiation type (two levels: ad-hoc (-1) and ANED-protocol (+1)) as the independent variable and the performance measures as dependent variables. The level of significance was chosen at p = 0.05 as a matter of convention. Pearson's correlation coefficient was also used to support a number of observations. Table 2 summarizes the experiment results, which are discussed in the following subsections.

	Control Group (CG)				*Protocol Group (PG)*			
	T1	*T2*	*T2*	*T4*	*T1*	*T2*	*T3*	*T4*
SDP (%):	*73.9*	*83.4*	*79.3*	*89.0*	*87.6*	*86.6*	*90.4*	*78.0*
Score-cost (%)	77.9	79.3	77.6	86.2	84.5	100	96.5	81.0
Score-space(%)	66	100	66	100	100	33	66	66
DSE (%):	*37.5*	*0*	*0*	*0*	*87.5*	*87.5*	*75*	*62.5*
Issue-discussed	1	0	0	0	4	3	4	3
Option-discussed	2	0	0	0	3	4	2	2
NCD:								
Proposals-plan	*8*	*4*	*15*	*11*	*6*	*0*	*0*	*2*
Proposals-other	*6*	*2*	*10*	*9*	*14*	*12*	*21*	*12*
Arguments	*14*	*3*	*15*	*13*	*25*	*14*	*19*	*9*
Info-request	*21*	*5*	*37*	*29*	*6*	*5*	*9*	*5*
Issue-discussed	*1*	*0*	*0*	*0*	*4*	*3*	*4*	*3*
NPD:								
Planning	*0.56*	*0.20*	*0.09*	*0.09*	*0.02*	*0.00*	*0.00*	*0.00*
Resolution	*0.21*	*0.20*	*0.64*	*0.62*	*0.91*	*0.83*	*0.86*	*0.88*
Optimization	*0.23*	*0.60*	*0.27*	*0.29*	*0.07*	*0.17*	*0.14*	*0.12*

Table 2: Summary of experiment results

5.1 Impact on Design Performance

From the data shown in Table 2, the average SDP of the Control Group is 81.38% versus 85.66% for the Protocol Group. While the difference is subtle, the tendency of improvement from using Protocol can be seen. Because the standard deviation is relatively large in both groups, the one-way ANOVA with the experiment type (CG vs. PG) as factor and the SDP as response did not yield a significant result ($F_{1,6}$ = 1.05, p = 0.344), hence could not conclusively validate our *Hypothesis #2*.

The insignificance might be due to the definition of the design problem. Further analysis of the design problem revealed that the problem was created such that the score differences between the good solutions and the bad ones are small comparing with the total scores. Therefore the chance for the subjects to achieve significantly better scores by uncovering win-win situations was relatively low. To verify this measurement shortcoming, we examined the design space exploration aspect of the design process.

5.2 Impact on Design Space Exploration

An effective negotiation process should lead to exploration of a larger design space, since the final agreement is only as good as the best of the agreements explored during the negotiation. Using DSE as the response and the CG/PG as the factor, the ANOVA result shows that the ANED protocol *has a significant effect on design space exploration* ($F_{1,6}$ = 38.21, p = 0.001), supporting our *Hypothesis #1*. Another interesting analysis can be done by looking at the correlation between the experiment type (with or without protocol) and the number of issues discussed. Pearson's coefficient value computed is r = 0.961 (p = 0.000), indicating a very strong correlation.

When ANED was developed, one of the initial postulates was that negotiation is not merely a communicative process but also a stimulating and hence creative one, during which the parties not only exchange information but also argue with, and attempt to influence, each other. Conflicts between two parties are not only problems to deal with but also opportunities to explore new solutions. This basic principle is adopted by TRIZ. Our results indicated the potential to apply the principle to collaborative design.

5.3 Impact on Negotiation Content Distribution

One objective of this experiment was to observe the impact of ANED protocol on the collaboration process in engineering design. By analysing the *negotiation content distribution* (NCD) data shown in Table 2, we notice a significant difference between the two treatment groups in the type of activities dominating the negotiation process.

The one-way ANOVA for the total number of non-planning proposals ("Proposal-other" in Table 2) shows that the protocol *has a significant impact on subjects' proposal making behaviour* ($F_{1,6}$ = 8.21, p = 0.029). Using ANED protocol leads the subjects to generating more *resolution* and *optimization* related proposals. This result was expected because proposals and counter-proposals are the locutions introducing possible agreement points: generating more proposals expands the range of the possible agreements. This supports our *Hypothesis #1*.

The analysis of the number of information request utterances indicates that the protocol *reduces the need for information request* ($F_{1,\ 6}$ = 5.90, p = 0.051). This can be explained as the result of two combined effects. First, the higher number of proposals is balanced by a lower number of information request/passing loops since proposing and arguing assume the information passing function in the form of *data* and *warrants* (Figure 1). Second, the efficiency of argumentative negotiation enhances mutual understanding of their stances and reduces the need for information requests.

The analysis of the number of *planning* related proposals shows a conclusive result ($F_{1,\ 6}$ = 7.58, p = 0.033): the *ad-hoc group* does more planning related exchanges than the *protocol supported group*. We will discuss this interesting result in the following subsection.

The average amount of utterances used by each group validates our *Hypothesis #3(1)*, i.e., the protocol improves collaboration efficiency, as the teams in Protocol Group used an average of only 69 utterances to complete the design task whereas the Control Group teams needed an average of 118.

5.4 Impact on Negotiation Process Distribution

Besides negotiation content distribution, we assessed the impact of the protocol on negotiation process distribution (NPD) by counting the numbers of utterances used in each of the three phases, *planning*, *resolution*, and *optimization*. The experiment results are shown in Table 2. We have:

- For the *planning* phase, the Control Group used 23% of the utterances, whereas the Protocol Group used 0%.
- For the *resolution* phase, 42% are used by the Control Group versus 87% by the Protocol Group.
- For the *optimization* phase, the Control Group had 35% while the Protocol Group had 12%.

A statistical analysis supports the observations. Although the significance is not as strong for the resolution phase ($F_{1,6}$ = 4.25, p = 0.085), the data leads to significant results for planning ($F_{1,6}$ = 13.33, p = 0.011) and optimization ($F_{1,6}$ = 6.45, p = 0.044).

The data and analysis revealed two interesting results. First, the teams in the Protocol Group spend little effort of their communication on *planning,* while the Control Group teams devote almost a quarter of their effort in *planning*. Planning related communications are needed when two designers try to decide on the strategy and process to solve a problem. The ANED protocol was designed with a focus on the argument exchange, and the exchange process is predefined. This restriction to some extent relegates the need for planning. Using the protocol, the subjects first identify their stances and go directly into the argumentation process. In the ad-hoc Control Group teams, however, after the subjects get together, they spend a long time on deciding what needs to be done and how to do it. In other words, they try to "optimize" the way to solve the problem. This planning "optimization" often leads to an "easy way out" to solve the problem. As a result, the solutions found from the "easy ways" are considered as *the* solutions. Few more explorations are pursued. The discussion in the following paragraph further supports this observation.

The second interesting result is that the Protocol Group had twice the *resolution* related communications than the Control Group, supporting our *Hypothesis #3(1)*. Without the guidance and restriction of the protocol, the ad-hoc teams tend to find solutions and then stick to the found solutions, rather than try to argue for and maintain their own stances. As a result "any solutions are good solutions", leading to less effort in resolution phase. On the other hand, The Protocol Group dedicated most of their communication exchange to problem resolution. The argumentative negotiation protocol contributes to a richer communication contents amongst the subjects and let them spend more time arguing about their positions, exploring new alternatives, and proposing compromises during the problem resolution phase. This more thorough design space exploration often results in a convergence to desirable solutions, reducing the need for post-resolution *optimization*, as visible in the data shown in Table 2.

6 CONCLUDING REMARKS

This experiment study yielded several results backing up our initial hypotheses and showed that negotiation outcomes in a collaborative design process can be positively affected by a negotiation support system. The use of the ANED protocol denoting clear argumentative positions and promoting mutual challenge of arguments proved to have a positive effect on the dynamics of the negotiation process and have the potential of improving collaborative design results. By imposing argumentative interaction, the protocol leads the subjects to making more efforts on design space exploration and alternative generation, avoiding general human tendency of "planning, quick solution, and finish." Furthermore, the restrictive exchange of information makes the overall collaboration process more efficient.

It should be mentioned that the results obtained thus far are limited to the types of the design problem tested. Future experiment research is needed to test various types of design problems and to include professional engineers as subjects. Another future research direction is to introduce design guidance, in addition to the protocol, to help designers manoeuvre more efficiently in the design space. Our current research addresses these two issues.

7 REFERENCES

[1] Tichkiewitch, S., Brissaud, D. 2000, "Coordination between product and process definitions in a concurrent engineering environment", *Annals of the CIRP* Vol.49/1:75-78

[2] Parsons, S. Sierra, C. Jennings, N.R. 1998. "Agents that reason and negotiate by arguing" *Journal of Logic and Computation*, 8/3:261-292

[3] Jin, Y., Lu, C-Y. S. 2004, "Agent based negotiation for engineering design", *Annals of the CIRP*, Vol.53/1: 122-125

[4] Pruitt, D.G., 1981, *Negotiation Behaviour*, Academic Press, New York

[5] Toulmin, S. 1969, *The Uses of Argument,* Cambridge University Press, Cambridge, UK.