

Consensus and single leader decision-making in teams using structured design methods

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Decision-making in teams can be accomplished by including varying levels of team member opinion. This study considers two styles of group decision-making, consensus building and single leader decision-making with input from the team, in structured design selection tasks. The role of decision-making style in the speed of decision-making, team member satisfaction, and decision quality are examined. In this study, single leader was found to be faster than consensus. However, single leader was not rated by teams as faster, suggesting that perception of speed may be more important than actual speed. It was also found that when there was more ambiguity in a decision, as represented by a smaller point spread between choices, teams tended to rate speed and process quality lower.

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Team decision-making is a pervasive and critical activity in product design and development. Research in social psychology on team performance suggests that groups tend to be more effective than direct aggregation of individual team members' choices (Stasser & Dietz-Uhler, 2001) and make better decisions than the most highly skilled individual in a group (Michaelsen, Watson, & Black, 1989; Shaw, 1971). There are a number of strategies for team decision-making, and one way to categorize them is by the balance of participation between the leader of a team and individual team members, from no team member participation (autocratic) to no leader participation (delegation) (Vroom & Jago, 1988). Management experts argue that, in many cases, team function will improve when decision-making moves away from traditional command decision-making to give individual team members more of a voice or buy-in to decisions (Fisher, 2000; Katzenbach & Smith, 1993). However, team-centered decision-making can have caveats. Fisher points out that managers accustomed to traditional "bossing" are often uncomfortable ceding decision-making power to the greater team. Likewise, team members are sometimes reluctant to take the responsibility that comes with playing a role in decision-making.

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While decision-making style appears to play an important role in team effectiveness, there is little research on its value specifically for design teams. Research on decision-making in design has focused on strategies for modeling design choices themselves, but less attention has been paid to the social aspects of how decisions are made during design. This paper seeks to bridge this research gap by comparing two team-centered decision-making styles applied to design tasks: consensus building and single leader decision-making with team input (Arnold, 2001). In consensus, all team members discuss their rationale for making decisions in order to arrive at a mutual agreement that is acceptable to all. Consensus tends to increase buy-in from individual team members, but decisions may be “watered down” through compromise in order to reach a conclusion that all can agree on. As a result, the process of building consensus can take additional time compared to other approaches. In single leader decision-making with team input, a leader makes a final decision after conferring with team members as a group. Individual team members may take less ownership of a decision than in consensus, but a decision may be reached with less compromise and in potentially less time. These two methods are similar in that they take into consideration the comments of the team, but they differ in the way authority is applied to a final decision. The research question considered in this paper is: What differences in decision-making outcome, if any, are there between design teams using consensus and those using single leader decision-making with group input? The overall intent of this work is to contribute to understanding of design team behavior that will help improve how designers make decisions in a group context.

This study looks at these two decision-making styles specifically in the context of structured engineering design methods. Some of the more well known of these methods are Quality Function Deployment (House of Quality) (Akao, 1990), Axiomatic Design (Suh, 1990), and Pugh Concept Selection (Pugh, 1991). Such methods provide formal guidelines for design decision-making and offer a shared visual representation around which teams can discuss issues concerning a design. This study uses structured design methods as a tool to engage teams in qualitative debate and discussion regarding design tasks. Structured design methods impose order on the process of decision-making and encourage the elicitation of design rationale and negotiation among team members.

In this paper, three common criteria for group decision-making are used to assess design decision-making tasks. First, the *speed* of reaching a decision is considered. Speed is a critical quantity particularly in environments where decisions must be made under time pressure (Eisenhardt & Zbaracki, 1992). Second, this study examines how satisfied individual team members are with the final choice (De Dreu & Weingart, 2003). Team member satisfaction with a decision may have implications for how well team members will support the final decision in the future and may reflect how well members believe they

are heard by their leaders (Miller & Monge, 1986). Finally, the quality of the final decision is addressed (Laughlin, Zander, Knievel, & Tan, 2003).

This study posits the following:

1. *Hypothesis 1: Using a structured engineering design method, consensus building takes longer than single leader decision-making with team input.* Consensus often requires individual team members to make compromises in order to reach mutual agreement, and this process can extend the time needed to reach a decision.
2. *Hypothesis 2: Team members perceive the quality of design choice and decision-making process through consensus as better, but rate single leader as more efficient (faster).* Team member satisfaction with decision-making is important because it plays a role in overall team cohesion and how well a team might work together on future projects (Thompson, 2004). Including opinions of individual team members tends to improve member satisfaction with choices and promote “buy-in” by the individual on decisions. Consensus, in particular, includes the comments of all group members and does not summarily dismiss minority opinions (Tjosvold & Field, 1983), and has been found to generally aid team members in accepting a decision. In addition, if Hypothesis 1 regarding the relative speed of single leader decision-making is true, team members will also perceive it as more efficient.
3. *Hypothesis 3: The decision outcomes of consensus and single leader are comparable.* A broad range of research from the social sciences suggests that the quality of process used in decision-making is linked to better results, and that emphasizing decision-making process may be more effective than emphasizing decision outcomes (Peterson, 1997). An implicit assumption in the study described in this paper is that *team processes*, such as decision-making strategy, play some role in *project success*. Are the design results of structured design methods from consensus any different from those of single leader? Consensus brings to bear the opinions and expertise of all team members which suggests that it could improve decision quality. However, a dichotomy has been found between group harmony and quality of decisions (Schweiger, Sandberg, & Rechner, 1989) as some degree of conflict is thought to bring about opposing views that foster a higher level of decision-making. This is not to say that consensus is always a harmonious process. Indeed, consensus building often entails frank discussion of opposing opinions. However, the end goal of consensus is always a mutual agreement by the team.
4. *Hypothesis 4: In structured design approaches, choices that are rated much higher than others tend to be associated with higher ratings for design choice quality, efficiency, and process quality, than for ambiguous choices.* If the gap between a team’s top two design choices is large, then it is believed that a team is much more positive about the choice and is likely that

the design teams will rate the quality, speed, and process more positively than average. By the same token, when there is a smaller difference between design choices, there is likely more ambiguity and lower perceived quality, efficiency, and process than average.

1 Related work

1.1 Decision-making styles in engineering design

Research in decision-making has focused on a variety of problem types, from business case studies (Schweiger, Sandberg, & Rechner, 1989), to marketing problems (Nel, Pitt, Berthon, & Prendergast, 1996), to fictional “what if” scenarios with a known “right” answer (Tjosvold & Field, 1983). Engineering design problems tend to differ because they are often ill-defined, require a variety of trade-offs to arrive at an answer, and may have multiple acceptable solutions. Design team communication is an active area of research in the field. Stempfle and Badke-Schaub (2002) have closely examined the thinking process in design teams. Dong, Hill, and Agogino (2004) investigated the assessment of the shared “thought worlds” of teams, and further linked this team coherence to better design outcomes. Yang and Jin (2008) considered team coherence from the perspective of team members’ satisfaction, and also examined the role of decision-making quality in those perspectives. Olson, Olson, Carter, and Storrosten (1992) conducted protocol studies to understand what design teams talk about, and found that 40% of time was spent discussing design, with several “swift transitions between alternative ideas and their evaluation.” Ostergaard, Wetmore, Divekar, Vitali, and Summers (2005) looked specifically at design review meetings and found that those conducted by groups were more effective than those conducted by individuals. The role of experiential learning in design teams is considered by Stumpf and McDonnell (2002). However, research specifically into the nature of decision-making styles that can be used by design teams is quite limited.

1.2 Decision-making style in small groups

In social science research, decision-making in small groups has been very widely studied (Ellis & Fisher, 1974; Frey, Gouran, & Poole, 1999). Several studies have compared consensus with other decision-making strategies, although none have compared it directly to single leader decision-making with team input. This section provides some background on both consensus and single leader decision-making to illustrate gaps in previous work that can be applied to design teams.

1.2.1 Consensus

Consensus has been compared with Devil’s Advocacy and dialectical inquiry (Schweiger *et al.*, 1989) and was linked to higher satisfaction within a group, higher interest in working with that group on future tasks, shorter decision-making duration, and greater acceptance of decisions.

At the same time, minority opinions (dissent) have been found to encourage creativity in decision-making when there is high individual participation (De Dreu & West, 2001). Nel *et al.* (1996) observed that “negative socio-emotional behavior and solution satisfaction” are associated with increased decision quality. A risk of all group decision-making is the possibility that teams will fall into groupthink, in which individuals go along with decisions in the interest of keeping team cohesion, even if they privately disagree with the choices (Janis, 1982).

Tjosvold and Field (1983) compared consensus with majority vote and suggest that “decision acceptance, understanding, decision time, and affective reactions” are elements of decision-making that can be linked to decision strategy and social context. They found no difference in decision quality using consensus and majority vote, but observed more team commitment using consensus. They also argue that cooperative social contexts make for faster decision-making than competitive environments.

1.2.2 Single leader with team input

This style of decision-making has similarities to “consensus with qualification” (Eisenhardt, 1990) in which interested parties are encouraged to voice their opinions, but the leader will rely more heavily on the opinions of one or two trusted consultants. However, in the end, the individual leader makes the final decision. This approach is associated with “fast” decision-making, while consensus is associated with “slow” decision-making.

On the surface, these decision-making styles are very similar because they both take into consideration team member opinions, but the “final call” authority that a single leader has can present a subtle but important difference. Stoner (1961) describes the “risky shift phenomenon” in which individual decision makers tend to make decisions that are lower risk than decisions made by groups, in part because the responsibility for decisions is diffused among all team members rather than attributable to one person. Harvey (1988) defined the “Abilene paradox” in which individual members behave in ways contrary to their own preferences when they operate in certain group situations.

2 Methods

This study evaluated the design decisions made via consensus and single leader with team input using groups of graduate engineering students in two design selection tasks. A total of 59 participants were randomly assigned into one team of six, nine teams of five, and two teams of four members composed of masters level students enrolled in a graduate elective engineering management course at a university in the Western US. Team size was chosen to fit within the constraints set forth by Katzenbach and Smith (1993) who argue that high performing teams are characterized by memberships of between three to seven individuals. All students had bachelor’s degrees in engineering

or science and had varying levels of professional working experience. The teams were given a brief introduction to consensus and single leader decision-making. These teams had no history of working together, nor had they any stake in working together in the future as a team. In the single-leader scenario, leaders were chosen by the group. Individual team members were surveyed to assess decision-making process quality. Participants were informed that the task was an in-class exercise and would not be graded. To encourage teams to thoughtfully engage in the decision-making process, they were asked to present and explain their final choices to the other teams at the end of the session.

2.1 Decision-making task

Each team was asked to complete one of the two design tasks (Tasks A and B) following either a consensus or single leader with team input decision-making strategy. Next, each completed the other design task using the other decision-making strategy. Six teams completed each task under each decision-making style for a total of 24 runs. Once given instructions, teams were left to operate on their own. Teams were permitted to take as much time as they needed to complete the tasks.

The design decision matrix for concept selection used in this study was a variation on Pugh Concept Selection (Pugh, 1991) and the House of Quality (Akao, 1990), chosen because of its simplicity and because students would be equally unfamiliar with the technique. Teams were asked to complete a design decision matrix by selecting among four design alternatives based on a set of five criteria. Each team assigned numerical weights (1, lowest, to 5, highest) to each criterion according to their importance, and then rated (1 to 5 scale) how well each criterion was met by each design alternative. Team members were each given a handout that detailed the features of each alternative. The teams then multiplied the weights and cell values, and summed the column values for each alternative. The summed values become a ranking of the four alternatives. All teams were permitted to iterate on their ratings until the team or leader was satisfied with the resulting ranking. There were no pre-determined “best” answers for the matrix.

Each of the two tasks focused on a simple consumer product and presented four alternatives along with four criteria on which to base decision-making. The cases were intended to be products that teams would be familiar enough with that they would be comfortable discussing them. Furthermore, these cases were intended to be sufficiently general that results could be extended to design tasks involving other similar consumer products. The description of each alternative included photographs of the design alternatives, a brief overview of their features, and retail prices.

- *Task A:* An iPod case for bicyclists. Your team’s task is to select a design for a case for an iPod player for a college student who listens while on their daily bicycle commute.
Criteria: Cost, Holds iPod securely while biking, Attractive, Easy to access controls, Compact.
Design Alternatives: Armband, Belt, Plastic case, Clear case
- *Task B:* Private reading light. Select a design for a light for someone who wants to read at night without disturbing a sleeping roommate. Occasionally, this light may also be used for travel.
Criteria: Cost, Sufficient light for reading, Battery life, Compact for travel, Attractive
Design Alternatives: Arm, Bracket, Gooseneck, Page
- *Instructions for Consensus:* Your team will make decisions based on consensus. This means that everyone must generally agree on decisions in [the steps of the process], although it is not necessary that these decisions be unanimous. However, if someone does not agree with the others, the team must make the effort to listen and discuss the point of disagreement.
- *Instructions for Single Leader with input from the team:* One person on each team should volunteer to serve as team leader. The leader will have the final call on all the team decisions in [the steps of the process], but should take into consideration input from all team members.

2.2 Time to reach a decision

Each team was timed to see how long it took to complete each task. Teams would signal completion of a task by raising their hands. Teams were not told they were being timed so as not to introduce an undue sense of external time pressure.

2.3 Individual assessment of decision-making outcome and process

After each task, every team member completed the following survey to determine their individual, self-reported perceptions of outcome (quality of final choice), efficiency (speed), and process quality on a scale of 1 (lowest) to 5 (highest). These questions were meant to assess each team member’s perception of the decision-making style. In a sense, how a team member perceives the decision-making process is more important than the objective, measured values of decision outcome and time to reach a decision because perception can influence their trust in a style and the likelihood they will use a style in the future.

1. *How would you rate the quality of your team’s final design choice (project outcome)? That is, how well did you satisfy [the Task]?*

The quality of outcome was individually reported, without input from other team members. There was no pre-determined “right” solution to either of the design tasks.

2. *How would you rate the efficiency (speed) of your team's decision process?*

This question was meant to assess each individual's perception of time spent making the decisions, as perceptions can play an important role in what methods design teams choose to use.

3. *How would you rate the quality of your team's decision process? Do you think your team discussed things thoroughly, and your opinions were well-represented?*

The second part of this question specifically compares two aspects of single leader and consensus that typically distinguish the two decision-making styles.

2.4 Decision quality

In this study, decision quality was assessed by its consistency with other teams and a panel of independent experts. This panel was composed of eight practicing product development designers and engineers in industry. Each reviewer was asked to independently rank the alternatives for Tasks A and B using the same criteria as given to the teams.

The Spearman Ranking Correlation for nonparametric populations was employed to test for correlations between design data and design outcome. The Spearman correlation coefficient R_s (Spearman, 1904) is expressed in Equation 1:

$$R_s = 1 - \frac{6 \cdot \sum_{i=1}^N d_i^2}{N^3 - N} \quad (1)$$

where N is the number of individuals in a sample population and $d_i = X_i - Y_i$. X and Y are the ordinal rank of the variables being correlated, in this case design data and design outcome. R_s can take on a value between -1 and 1 . If $-1 < R_s < 0$, there is a negative correlation between the two data sets. If $0 < R_s < 1$, there is a positive correlation.

3 Results and discussion

3.1 Speed of decision-making

Hypothesis 1: Using a structured engineering design method, consensus building takes longer than single leader decision-making with team input.

Table 1 shows the average time to complete Tasks A and B. For both tasks, the average time for single leader was 4–6 min (16–36%) faster than for consensus decision-making. Observations of the teams suggested that structured methods forced teams to decide on weightings and cell values one at a time, possibly extending the decision-making time beyond what it might have been without structure. It was also noted that teams generally took their tasks seriously, engaging in debate and discussion throughout, perhaps because they knew their answers would be shared with their peers in the end.

Table 1 Average time, in minutes, to achieve decisions for Tasks A and B under consensus and single leader with team input decision-making

	Average time, min			p-Values
	Consensus	Single	%Diff.	
A	25.3	18.5	-36.9%	0.02
B	30.8	26.5	-16.4%	0.46
Both	28.1	22.5	-24.8%	0.10

3.2 Perception of quality, efficiency, and process

Hypothesis 2: Team members will perceive the quality of design choice and decision-making process through consensus as better, but will rate single leader as more efficient (faster).

Table 2 summarizes the average ratings from the surveys given by each participant for decision-making efficiency, process quality, and decision quality. The Student *t*-test was applied to each pair of comparisons to estimate their validity.

3.2.1 Quality of design choice

Single leader was rated lower (8.7%) than consensus for the quality of design choice for Task A, but somewhat higher (10.7%) than consensus for Task B. The Student *t*-test *p*-values were less than 5% for both, suggesting that these results are valid.

3.2.2 Efficiency of decision process

The perceived differences in efficiency between consensus and single leader were less pronounced. For both tasks, single leader was rated slightly higher for efficiency (1.7–4.5%), even though the average measured time to perform single leader decision-making was noticeably faster (~24%). This suggests that the *perception* of efficiency (speed) is not consistent with the *actual* efficiency (speed) of decision-making, and in fact there is a statistically significant negative correlation (-0.66 where $N = 24$ and $R_s = 0.406$ for $\alpha = 0.05$) between the actual time that a decision took and the perceived time. The student

Table 2 Average ratings (1—lowest to 5—highest) for decision-making efficiency, quality of decision-making process, and decision quality by task and decision-making strategy

	Quality of final design choice				Efficiency of decision process				Quality of process			
	Consensus	Single	%Diff.	p-Val.	Consensus	Single	%Diff.	p-Val.	Consensus	Single	%Diff.	p-Val.
A	4.68	4.31	-8.7%	0.02	4.29	4.37	1.7%	0.87	4.45	4.24	-4.9%	0.36
B	3.90	4.37	10.7%	0.00	3.77	3.94	4.5%	0.49	4.29	4.37	1.7%	0.56
Both	4.29	4.34	1.1%	0.89	4.03	4.16	3.0%	0.61	4.37	4.30	-1.5%	0.79

t-test *p*-values for both are high, suggesting that the calculated differences are not significant.

3.2.3 Decision process

Question 3 of the survey was concerned with participant's perception of the quality of the decision-making process. For Task A, consensus was rated somewhat higher as a decision-making process than single leader (4.9%). For Task B, however, single leader was rated slightly higher (1.7%). Calculated *p*-values were again high, suggesting low confidence in these differences. Taken together, these ratings of quality of final design choice, efficiency of decision process, and quality of decision process suggest that the differences between consensus and single leader with team input are small. Consensus is not perceived as producing significantly better design choices or providing a higher quality decision-making process. At the same time, consensus was rated as a more efficient process.

The expected effect of buy-in during consensus decision-making was not observed, and one reason might be that buy-in plays a less critical role in short term tasks such as the ones in this study.

To further understand the interaction between efficiency, process, and outcome was examined. Table 3 summarizes the Spearman correlations between survey ratings for both tasks for consensus and single leader decision-making. Values in bold indicate statistically significant correlations. For both consensus and single leader, efficiency and design choice, and efficiency (speed) and decision-making process were correlated in a statistically significant way. This suggests that the speed of a decision process is an important factor overall in the way team members perceive decision-making, and that an efficient process is linked to a "good" design decision-process and also with a quality final design choice.

3.3 Decision outcomes

Hypothesis 3: The decision outcomes of consensus and single leader are comparable.

Table 3 Spearman correlations between team members perceived decision-making efficiency, decision process, and decision quality. For N = 59, $R_s = 0.259$ for $\alpha = 0.05$

	<i>Choice</i>	<i>Speed</i>	<i>Process</i>
Consensus, both tasks			
Choice	—	0.33	0.09
Speed	—	—	0.28
Process	—	—	—
Single leader with team input, both tasks			
Choice	—	0.44	0.20
Speed	—	—	0.29
Process	—	—	—

To evaluate the relative outcomes for the two decision-making styles, the resulting rankings of the alternatives of each were compared for Task A (Table 4) and for Task B (Table 5). These rankings were also compared with the average rankings given by the external panel of design reviewers.

In Table 4, the “Avg. rating” column under “Consensus” shows the average rated values (on a scale of 1–5, where 5 is best) over the 6 teams that were tested under this condition. The standard deviation of these ratings appears at the bottom of the table. The ranking that results from these ratings appears in the “Rank” column, with the highest rating, 70.33, assigned a 1 and the lowest rating, 47.67, assigned a 4. The same results are shown for the “Single leader” style. Experts were asked to give rankings rather than ratings to make comparisons more consistent. These rankings were averaged and ranked again. The resulting “Norm. rank” provides a sense of the overall rankings of the experts. In this case, the lower the average expert ranking, the higher the overall expert ranking, so a 1.25 average ranking was translated to a number 1 ranking overall.

Table 4 shows that, for Task A, there is perfect agreement in terms of rankings between the two decision-making styles, as well as with the rankings offered by the reviewers, with the Armband ranked first, the Clear case ranked second, the Belt ranked third, and the Plastic case ranked last.

Furthermore, analysis of the choices of the individual teams showed that 5 of 6 of the teams under the consensus condition, 4 of 6 teams under the single leader condition, and 6 of 8 experts all ranked the Armband (alternative 1) as their top choice.

The results from Task A suggest that there really is no difference in the decision outcomes between the two decision-making styles. However, the results shown in Table 5 paint a slightly different picture.

Table 5 shows the average rating and ranking for Task B for consensus, single leader, and experts. In this case, the consensus and single leader rankings are

Table 4 Rankings of Task A alternatives under consensus decision-making, single leader decision-making, and individual expert opinion

	<i>Consensus</i>		<i>Single leader</i>		<i>Experts</i>	
	<i>Avg. rating</i>	<i>Rank</i>	<i>Avg. rating</i>	<i>Rank</i>	<i>Avg. rank</i>	<i>Norm. rank</i>
Armband	70.33	1	72.50	1	1.25	1
Belt	47.67	3	52.33	3	3.00	3
Plastic case	51.00	4	52.50	4	3.13	4
Clear case	65.83	2	68.50	2	2.63	2
Std. dev.	11.06	NA	10.57	NA	NA	NA

Table 5 Rankings of Task B alternatives under consensus decision-making, single leader decision-making, and individual expert opinion

	<i>Consensus</i>		<i>Single leader</i>		<i>Experts</i>	
	<i>Avg. rating</i>	<i>Rank</i>	<i>Avg. rating</i>	<i>Rank</i>	<i>Avg. rank</i>	<i>Norm. rank</i>
Arm	50.17	4	54.17	4	2.00	1
Bracket	54.17	3	57.67	3	2.38	2
Gooseneck	55.83	2	57.92	2	2.75	3
Page	68.83	1	66.50	1	2.88	4
Std. dev.	8.08	NA	5.25	NA	NA	NA

identical, with the Page light ranked first for both cases. However, the last two columns show that the experts' rankings were the inverse of those of the teams.

For Task B, analysis of the team choices shows that 4 of 6 ranked the last option, the Page light, as the number 1 choice for both decision-making styles. However, the experts were uniformly divided with each of the 4 options receiving 2 first place rankings.

The difference between the team and expert rankings suggests that the nature of the task plays a role in the choices that teams and individuals make. In particular, the range of alternatives may be critical. Both Task A and Task B were intended to be comparable. They were both consumer products that team members and experts would understand but not be so familiar with that they had pre-formed opinions. In the case of Task B, it can be inferred that the choices were less clear to both the teams and experts than for Task A. The standard deviations for Task A were 11.06 and 10.57 for both decision-making styles, while they were only 8.08 and 5.25 for Task B. Furthermore, the averaged ranking values for Task B, as shown in the second to last column of Table 4, were more tightly clustered between 2.00 and 2.88, while these same values ranged between 1.25 and 3.13 for Task A. In effect, the choices for Task B were less clear than for Task A, and may have made choices less clear for the teams and experts. This issue of clarity of choice is further examined in the following section.

3.4 Clarity of design choices

Hypothesis 4: In structured design approaches, choices that are rated much higher than others tend to be associated with higher ratings for design choice quality, efficiency, and process quality, than for ambiguous choices

Two scenarios of “design choice clarity” were examined. The first consists of the six cases in which the top ranked design alternative (of four) is at least 10 points higher than the next highest ranked choice. This larger point spread might suggest that the top choice is more clearly favored than the other choices and because of this clarity, the team members may experience a more effective

and efficient decision-making process. The second scenario consists of the twelve cases in which the top ranked choice is ranked higher than the next by five points or less. In this situation, it might be expected that the relatively small spread means that teams spent more effort in making their final choices and experienced a less efficient, lower quality decision-making process overall.

Spearman correlations were computed between the point spreads and the difference between the team's rating of choice, efficiency, and process, and the overall average rating for the task and decision-making style. Because the analysis presented earlier in this paper for Hypothesis 3 suggests there is not a significant perceived advantage to consensus over single leader decision-making, the following analysis did not distinguish between decision-making style.

Table 6 shows the case of large point spreads, or high clarity. In this case, the point spread ranged from 11 to 25 points. Values in bold indicate statistically significant correlations. The table illustrates no correlation between large point spreads and higher than average perception of design choice, process efficiency, and process. One possible explanation for this is the nature of weighted design matrices. Relatively modest (1 or 2 points) changes in only a few cell values can trigger dramatic changes in the final rankings, so that these larger point spreads do not actually represent clearer design choices.

Table 7 illustrates the case of small point spreads, or low clarity. In this case, the spread ranged from 0 to 4 points. Statistically significant negative correlations were found between small point spreads and difference between average perception of design choice, process efficiency, and process. This suggests when it is hard to distinguish between two design choices, there is a link to slower, more difficult decision-making processes.

3.5 Observations about structured design methods, team decision-making, and inconsistency

What does this work say about the role of structured design methods in team decision-making? Structured design methods offer a framework around which to conduct decision-making and discussion, including a shared, written representation in the form of a chart. At the same time, structured methods can produce inconsistent results. Efforts to analyze structured approaches to team decision-making suggest that these methods may produce irrational results

Table 6 Larger point spreads, high clarity. Spearman correlation between the point differences (>10 pts) and the ratings difference from average for design choice, decision-making efficiency, and quality of process. For $N = 6$, $R_s = 0.886$ for $\alpha = 0.05$

	<i>Choice diff. avg.</i>	<i>Efficiency diff. avg.</i>	<i>Process diff. avg.</i>
Diff. two top ranked	-0.10	-0.74	-0.64

Table 7 Small point spreads, low clarity. Spearman correlation between the point differences (<5 pts) and the ratings difference from average for design choice, decision-making efficiency, and quality of process. For $N = 12$, $R_s = 0.587$ for $\alpha = 0.05$

	<i>Choice diff. avg.</i>	<i>Efficiency diff. avg.</i>	<i>Process diff. avg.</i>
Diff. two top ranked	0.03	0.03	0.31

(Olewnik & Lewis 2003). In that study, when the same test subjects were asked to provide ratings for the same criteria on two separate occasions, they would often give different ratings each time. Scott and Antonsson (1999) investigated the formal aggregation of ratings provided by individual group members and noted that this process must be carefully and methodically conducted in order to maintain validity.

Would these results be similar if there was no structured framework? Research conducted in the social sciences tends to focus on non-design related problems, so it is difficult to compare structured design tasks with that body of work. Engineers may feel more comfortable basing decisions on quantitative ratings that are part of structured design methods such as the House of Quality. A tendency was observed in several teams to change ratings to suit their choices. If someone was not happy with a numerical value, the team would change the values iteratively until the desired number was reached. The goal thus became to fit the numbers to the desired outcome, rather than fixating on specific numerical values. A related phenomenon was observed by Bucciarelli (1994) as a team tried to agree on criteria for a Pugh Chart. The team could not agree on criteria even after extensive discussion. Bucciarelli notes that the team viewed this as a “disaster,” but he believed that the discussion itself, rather than completion of the chart, was a necessary step toward establishing a shared understanding of the design by the team.

4 Conclusions

This study compared consensus building and single leader decision-making with team input in the context of structured design decision-making, and resulted in the following findings:

1. *Speed of decision-making.* For the two design selection tasks studied, single leader decision-making was faster in measured time (minutes) than consensus.
2. *Perception of decision quality, efficiency, and process.* Consensus was rated higher for quality of design choice and decision-making process for Task B, but lower for these in Task A. Single leader decision-making was rated as slightly less efficient than consensus building, even though the measured time was faster though not validated by the Student *t*-test. This suggests that the perception of efficiency may be as important as the actual efficiency of decision-making. For both consensus and single leader,

significant correlations were found between efficiency and decision process, and efficiency and design choice, suggesting that a fast process is linked with better design decision outcomes and process. This last finding is consistent with observational studies of high performing managers who take a modified consultative approach (Eisenhardt, 1990).

3. *Decision outcomes.* Consensus is thought to lead to higher quality decisions because of its tendency to lead to individual buy-in. However, single leader with team input also provides some level of buy-in, and it is a faster decision process which this study suggests is a key factor in how team members perceive decision-making quality. There were no clear patterns of correlations between the final design alternative rankings for teams and experts which suggests that neither style was linked to better quality design choices than the other.
4. *Clarity of design choices.* This study suggests that higher point spreads between the top two design choices do not correlate to higher ratings of design choice quality, efficiency, or process, but smaller spreads do correlate with lower ratings. This may be in part due to the way changes in cell values are propagated in a weighted design matrix. Larger point spreads may not necessarily reflect stronger preference for a particular alternative, but smaller point spreads may more accurately represent ambiguous design choices.

The practical implications of this work are in how product development teams should go about making group decisions. The findings from this study suggest that the speed of decision-making is linked with individual team member's perceptions of decision quality. Since neither decision-making style was linked with better decision outcomes, the results of this study suggest that single leader decision-making might be a better choice because it was measured to be slightly faster on average than consensus building.

5 *Future work*

The findings of this study suggest some possible paths for future research in design team decision-making.

- *Role of team composition on decision-making style.* Teams in this study were formed at random, but in design practice, teams are generally brought together intentionally based on some set of individual team member skills. Katzenbach and Smith (1993) define the three key skills of a team as technical/functional skills, such as engineering or marketing expertise, interpersonal skills, such as the ability to communicate and manage conflict, and decision-making skills such as those that help in the evaluation of options in the design process. Because the setting for this study was a graduate level elective in engineering management class, it was assumed that the participants had technical expertise in engineering and some aptitude in management. However, no effort was made to engineer a complementary mix.

Wilde (1997) examined the use of Myers Briggs personality tests to construct engineering design teams, and found that certain distributions of personality type did correlate with better design outcomes.

- *Application of design decision-making processes for virtual product teams.* The teams in this study were co-located, but many product development teams are globally distributed, introducing a wide range of communication and interaction issues. Hammond, Koubek, and Harvey (2001) provide starting points to understand the factors “influencing distributed work group performance in both the theoretical and applied domains”. Consensus building in particular is difficult to conduct in virtual settings.
- *Engineering design education.* Teams are a widespread mode of work in industry, and students are often organized in teams in the classroom to gain skills in working on teams as they work on design projects. However, little curricula exist on how to help engineering students to formally develop decision-making skills.

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