Preliminary Validation of Scenario-based Design for Amorphous Systems

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Abstract. Designing amorphous systems is challenging because of the broad scope of the task. The design team must integrate various solution elements, such as hardware, software, service, and infrastructure, while resolving the communication challenges among different domain-experts. *Scenario-based Design for Amorphous Systems* enables design teams to effectively deal with ambiguity and to communicate their ideas among team members and managers, as well as with customers through a common language. We validated its effectiveness in both academia and industry. This paper describes the process and the preliminary results of the validation based on three approaches: Statistical, voting and interviews.

1. Introduction

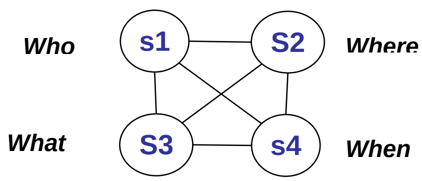
Today's products and processes invariably involve not only hardware and software, but also services, infrastructure, and policy. Decision makers must address the system requirements at a higher level than functions or components. They need to capture the interaction between the system elements and every "player" in the value chain. Our previous paper proposed a framework of *Scenario-based Design for Amorphous Systems* and has shown how this framework has helped a design team transform their device-based project into a system-based one. The paper focused on constructing scenarios characterized by *Who, Where, When and What* (4 *W*'s). The 4 *W*'s provide the grammar for Scenario Graphs or Scenario Menus. To describe the workings of the amorphous system, Dynamic Customer Value Chain Analysis simulates the flow of materials, products, information, and funds, thus simulating the business models for each scenario. The scenario-based characterization of amorphous systems aids in life-cycle considerations such as service innovations and upgradeability, as well as creative concept development. By applying the proposed scenario-based methods, design teams have effectively transitioned from themes to functions and requirements for amorphous-systems projects.

Our original research question was: "How can we methodically design systems that are under-defined?" We addressed this question by investigating the source of ambiguity in designing systems-oriented products that are under-defined and then suggesting a framework and methods for clarifying and managing ambiguity to create an innovative product.

First, we introduced the 6W framework to analyze the information that design teams are given at the onset of a project. Using the 6W framework, we analyzed 32 projects from the graduate level course ME317: Design for Manufacturability. We then categorized the projects with three or fewer constrained W's as under-defined. Two common attributes of these projects were that they were under-defined and systems-oriented (meaning, they consist of multiple constituents). We defined these two attributes as "amorphous."

Of the six W's, four provide insight: Who, What, Where and When. These four W's led us to the observation that the missing element in most of the under-defined projects was contextual information. We defined this missing contextual information as the scenario and developed methods such as Scenario Graph, Scenario Menu, Voice of X (VOX), and Scenario Prototyping Rapidly to help design teams envision customer needs, organize information, and communicate their ideas to other stakeholders.

Scenario-based Design for Amorphous Systems (Kim, 2007) is a framework that helps design teams visualize, organize, and communicate potential scenarios in which the system will provide value. Here we define scenario as an account or synopsis of a series of events in a setting which contains the answers to *Where, What, When and Who*: *Where* refers to a place or a location, *What* refers to activities or events, *When* refers to circumstances, and *Who* refers to people or parties associated with the activities or situations. Figure 1 shows the four elements, *Where, What, When, and Who,* that complete a scenario. Using set theory, the four elements can be coupled with each other.



s1=Who, s2=Where, s3=What, s4=When
Si= {s1, s2, s3, s4},
Ri = {{s1,s2},{s1,s3},{s1,s4},{s2,s3},{s2,s4},{s3,s4}}

Figure 1: 4W's make a scenario.

The Scenario Graph and the Scenario Menu are the main methods that guide the design teams in scenario-based thinking. In the early product-definition stage, they enable design teams to generate potential scenarios and organize them. By further exploring these scenarios, the design teams can identify the needs, the functions and the requirements of the system. Once this information has been acquired, they can apply existing design methods in the current dfX framework. Since early product definition is about identifying the right problem to solve, it essentially means specifying the 6 W's of the problem.

In a traditional product-design project, design teams typically start by extracting functions and requirements from the voice of their customers because they already know who these customers are. However, for an amorphous-system project, the initial scope is so broad in the beginning that it has no boundaries and usually seems overwhelming for design teams. only do such projects require initial guidance to allow visualization of the potential needs, but they also require effective communication between the various domain experts.

Looking at amorphous projects undertaken at Stanford University, we observed that using scenarios in a particular way helped design teams extract functions and requirements from vague project goals such as “creating value for new markets.” Scenario-based Amorphous Design (Scenario-based Design for Amorphous Systems) proposed a framework which consists of 1) trend analysis, 2) scenario generation, selection and evolution, 3) function and requirements extraction, 4) solution generation, selection and evolution, 5) business model and roadmap planning, and 6) validation. The approach is based on the Design for X (DFX) methodology but is tailored to address the specific needs of the amorphous systems' product development process. Figure 2 presents the framework of Scenario-based Design for Amorphous Systems on the v-model and the methods deployed along the requirements flowdown and quality roll-up.

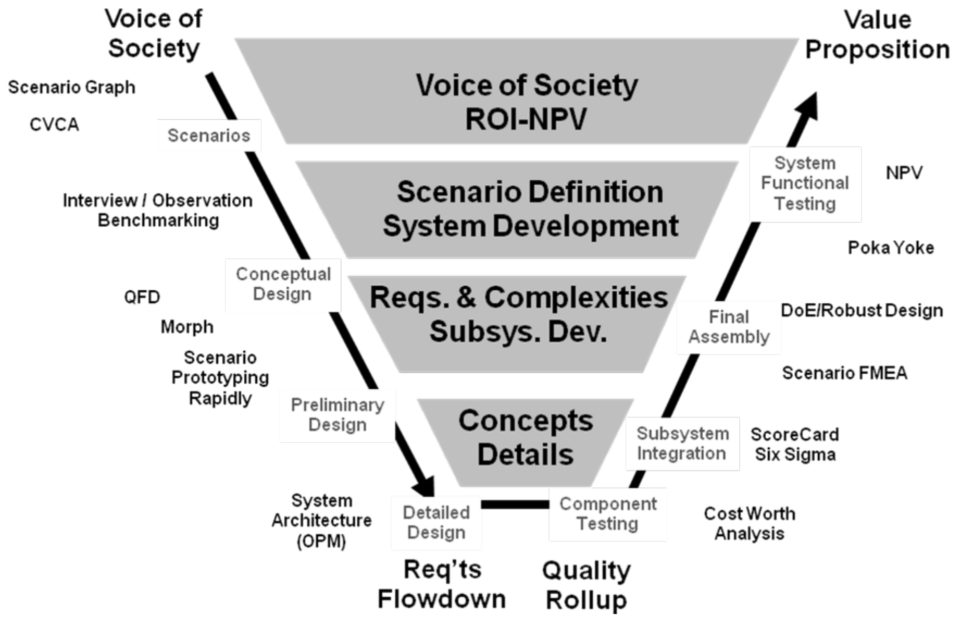


Figure 2: The V-framework of scenario-based design for amorphous system

2. Challenge of Validating Design Methods

Validating new design methodologies is important for the advancement of design theory and for helping the development of effective professional practices for industry (Frey, 2006). The common practice for validating design methods is to apply the method across diverse problems and to observe whether or not design teams continue to use the method. However, examples of formal or standardized validation of design theory used in the product definition phase are uncommon. The main reasons are that common metrics do not exist, gathering meaningful data is time consuming, and other factors— such as group dynamics, experience, and background—seem to have a greater influence on the design teams than the methods they use. We address these challenges by approaching the validation of Scenario-based Design for Amorphous Systems from both quantitative and qualitative viewpoints using three methods: statistics, voting and interviewing.

Methods for developing design theories that attempt to assist in the thinking and decision-making of design teams resemble those used in the fields of psychology or sociology. Both of these fields validate qualitative metrics, such as behavior, through statistical methods by collecting and analyzing indicators of human behavior. Similarly, in this chapter, our validation of Scenario-based Design for Amorphous Systems follows the principles and statistical protocols commonly used in the validation of new methods in these fields. Although we did not reach statistically significant results due to insufficient sample size, applying a common validation framework on a design methodology helped us determine how to formally approach the validation in the field of design research.

Jami et. Al (2000) have proposed a standardized test for product design skills. The test uses metrics such as novelty, variety, polity and quantity of the ideas generated by an engineer. This test may be useful for evaluating the quality of the ideas generated but not adequate for problem formulation at the early stage of design.

Olewnik and Lewis (2003) summarized three requirements for validating engineering design methods: 1. Be logical, 2. Use meaningful, reliable information, 3. Not bias the designer. These guidelines are sound and based on existing literature but difficult to use as a validation approach due to its generic nature.

3. Statistical Approach

3.1 Metrics of Effectiveness

To study the effectiveness of Scenario-based Design for Amorphous Systems, we designed an experiment that compared the level of understanding of design teams by measuring how many W's they constrained during the product definition phase. The premise is that, for amorphous projects, if a design team clearly understands and agrees on the objective, function, and requirements during the first half of product development, it is more likely that it will make informed decisions throughout the rest of the product development process.

The main outcome measure was the design team's level of understanding, which we obtained by measuring the 5W's (*Who, What, Where, When and Why*) through a survey, called the Edith Wilson Product Definition Checklist (Wilson, 2003). The Edith Wilson Product Definition Checklist (EW Checklist) is a checklist for gauging whether a design team understands the factors that are essential in defining the product. The Product Definition Checklist served as the survey method because its questions indirectly address the 5 W's: *Who, What, Where, When and Why*. In addition, five years' worth of data was available for the control group since the survey was conducted over more than five years. The five questions for the W's are as follows:

Who are the customers or the stakeholders involved with the product and the project?

What activities are happening?

Where or in which location is the product placed?

When or under what circumstances do customers use the product or service?

Why do the customers need this? What kind of value does this product achieve?

The EW checklist has a total of 15 checklists, each of which asks one question. In this case we only measured checklists 1, 2, 3 and 10 because they best correspond to the 5W's. Checklists 1, 2, 3 and 10 are

Checklist 1. Strategic Alignment: Does the team understand the strategic objectives, the boundary conditions within which they need to operate, and the target market for the product?

Checklist 2. Understanding User and Customer Needs: Has the project team verified the target market segment, its attractiveness in terms of size and growth rates, and identified the fundamental needs of the market, e.g., productivity, cost effectiveness, ease of use?

Checklist 3. Localization: Are the variations in user needs and compliances understood by geography?

Checklist 10. Core Competencies: Are all the core competencies, required for successful deployment of your project, identified and accessible?

These questions relate to the 5 W's as follows:

Checklist 1. Strategic Alignment addresses "When" by asking the team the situation, or the boundary conditions within which they need to operate. ***Checklist 2.*** *Understanding User and Customer Needs* deals with "Who, What, and Why" by verifying the specific needs of the user and the customer. ***Checklist 3.*** *Localization* corresponds to "Where and When" by asking the factors associated with the geography or the setting. Finally, ***Checklist 10.*** *Core Competencies* asks for

the core competencies of the team, which the team should have identified at the beginning of the Scenario Graph. The five questions from the Product Definition Checklists are mapped to the 5W's in
Table **1**.

Table 1: Checklists 1, 2, 3 and 10 of Product Definition Checklist address the 5W's: Who, What, Where, When and Why. Circles indicate which W corresponds with which checklist.

	1. Strategic alignment	2. Understanding users and customers	3. Localization	10. Core competencies
Who		o		
What		o		o
Where			o	
When	o		o	
Why		o		

To measure the improvement in the team members' understanding of the project scope, the survey was given to each team twice: once at the beginning of the project and the second time at the end of the product definition phase. The answers to the survey were based on an ordinal scale from 1 to 5, 1 being, "Not at all," 3, "To some extent," and 5, "To a great extent."

3.2 Using T-test to measure effectiveness

The difference in the teams' responses between the first and the second administration of the survey questions reflected the improvement in the level of understanding of their project scope. We assumed that this difference related to the understanding of the 5W's and measured the delta, or the difference, as the primary outcome. Our premise was that for amorphous projects, design teams that used Scenario-based Design for Amorphous Systems would have a different level of understanding of their project scope, as measured by the Product Definition Checklists 1, 2, 3 and 10, than would the design teams who did not use Scenario-based Design for Amorphous Systems. The research or the alternative hypothesis then becomes
The difference between the levels of understanding exhibited by teams in responding to the first and second administration of the Product Definition Checklist questions was different for the team that used Scenario-based Design for Amorphous Systems than for the team that did not use Scenario-based Design for Amorphous Systems.

$$H_1 : \Delta\overline{X}_{Ai} \neq \Delta\overline{X}_{Bi} \qquad \text{Equation 3-1}$$

Where $\Delta\overline{X}$ is the mean difference in the level of understanding between the 1st and 2nd survey, A group used Scenario-based Design for Amorphous Systems and B group did not use Scenario-based Design for Amorphous Systems, for i = 1, 2, 3 and 10. Then the null hypothesis becomes

$$H_0 : \Delta\overline{X}_{Ai} = \Delta\overline{X}_{Bi} \qquad \text{Equation 3-2}$$

For this study, we designed a t-test of two independent samples with unequal sample sizes and variances to determine whether there is a statistically significant ($p = 0.05$) difference or whether the difference could be attributed to random chance.

Because small sample sizes tend to result in considerable error, we used the separate-variance t-test:

$$t = \frac{(\overline{X}_1 - \overline{X}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_3^2}{n_2}}} \qquad \text{Equation 3-3}$$

where $\overline{X}_1 - \overline{X}_2$ represents our experimental results and $\mu_1 - \mu_2$ represents the expected difference or the null hypothesis (Cohen, 2008). The t itself is a ratio, where the numerator is the difference between the two means and the denominator is the measure of variability or the spread of the squares. In other words, t is basically a signal to noise ratio showing that the signal or difference of the two means is significant compared to noise (Trochim, 2006).

3.3 Survey Timeline

The two spaced-apart surveys measured the difference between the control and the test groups' understanding level. The timeline in Figure 3 shows when the research team administered the surveys. The first survey was given at the beginning of the project to measure the baseline of the teams' understanding. The second survey was given at the halfway point of the projects, at which point the design teams were expected to have a clear project scope. The test group used Scenario-based Design for Amorphous Systems methods such as Scenario Graph, Scenario Menu, Observation/interview techniques, Scenario Prototyping Rapidly, Scenario selection, etc. The control group did not use Scenario-based Design for Amorphous Systems methods but only conventional DFX methods such as CVCA (customer value chain analysis), Quality Function Deployment, Project Priority Matrix, etc.

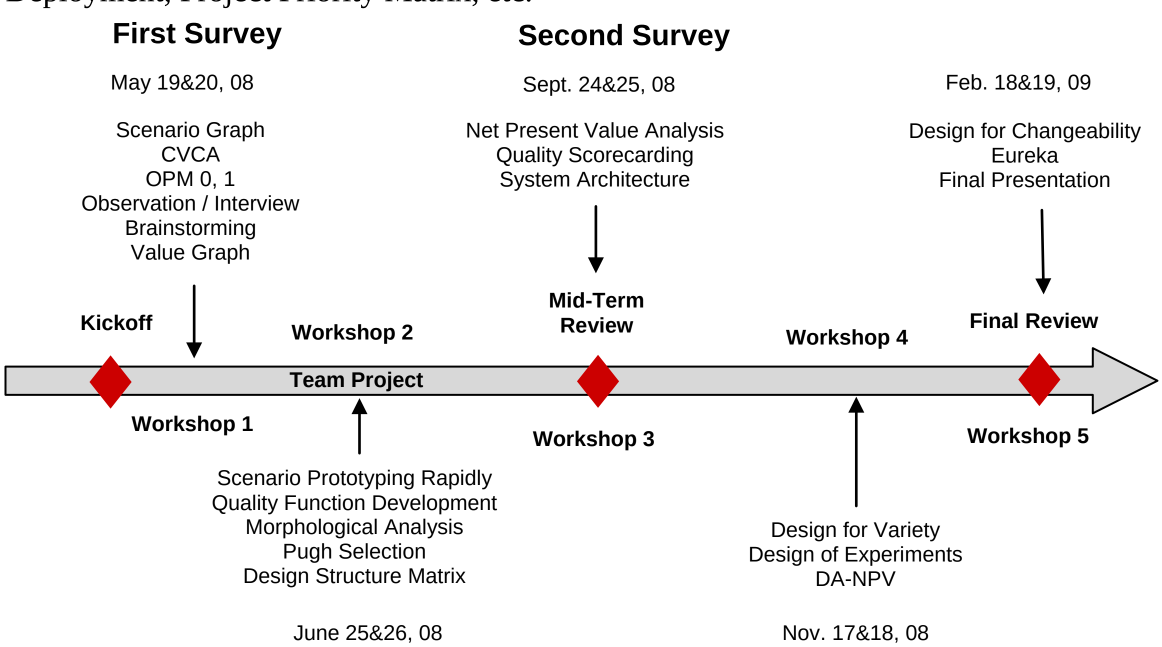


Figure 3: The survey was administered at the beginning and at the halfway point of the project.

Both the test and the control groups were expected to have clearly defined their problem and the scope of their project by the time of the second survey. Although the exact duration to reach the halftime of the project timeline were different (seven weeks for the test group, five weeks for the control group), observation suggested that the actual time the design teams spent on the projects was almost the same. One researcher stated that the test group worked on the project only for two weeks prior to the deadline of the presentation. In other words, the total time spent working on the project was almost the same for both the test group and the control group.

3.4 Flow of Study Population

In order to gather the survey data, we looked for design teams that would fit two criteria. The first criteria was that the teams that used DFX methods. The second criterion was teams whose projects were amorphous in nature. The goal of the test was to compare the effect of Scenario-based Design for Amorphous Systems methods to the status quo effect of the DFX framework and methods. Since Scenario-based Design for Amorphous Systems methods were specifically developed to address project scopes, we wanted to see whether using Scenario-based Design for Amorphous Systems methods affected teams working on amorphous projects.

The participating design teams were blinded to the knowledge that they were being taught a new method. The experiment was a single-blind trial because some researchers were aware of the new methods but the design teams were not, in order to prevent a placebo effect.

Figure 4 shows the flow of participating design teams through enrollment and intervention. We investigated the design teams who met the initial eligibility requirement of using the DFX curriculum for their project. A total of 76 design teams' data were eligible for the experiment because they used DFX. We divided the 76 teams into a control group of 63 teams and a test group of 13 teams. The control group used DFX methods without the scenario-based approach while the test group used DFX methods with the scenario-based approach. The data from the control group were from the Stanford University's project oriented course, ME317: Design for manufacturability, during the years of 2004 to 2008. The data from the test group was from the 2008 Keio University's project oriented course, ALPS: Active Learning Project Sequence.

Out of the 63 control group teams, 31 teams were disqualified because their projects were not amorphous, meaning the project description had more than 3 W's constrained at the onset of their projects. Of the remaining 32 teams, only 7 teams completed the two surveys that yielded the data showing the difference between understanding at the beginning and at the end of the product definition phase.

The test group began with 13 eligible teams, but one did not complete the survey, so only 12 teams qualified for the data showing the difference made by Scenario-based Design for Amorphous Systems. In total, only seven from the control group and 12 from the test group remained available for analysis.

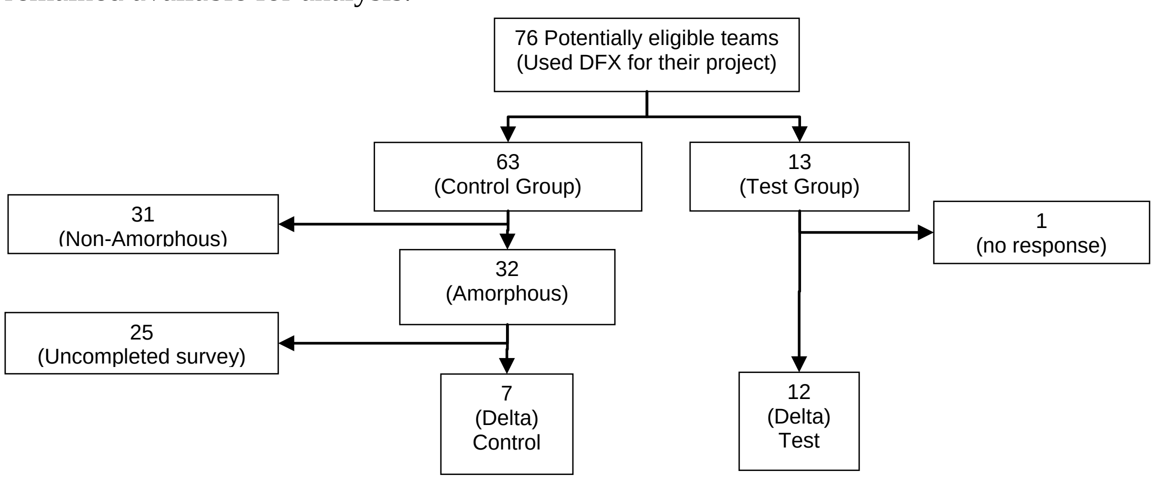


Figure 4: Flow of Study Population

3.5 Results and Discussion from Statistical Validation

The descriptive statistical results in Table 2 tell us to accept the null hypothesis and reject the alternative hypothesis. The fact that all p-values are smaller than alpha, 0.05, indicates that there was no significant difference in the level of understanding between the test group and the group for the checklists 1, 2, 3, and10. For checklist 1, t1(17)=1.23 at P1=0.24, t2(17)=0.97 at P2=0.35, t3(17)=0.55 at P3=0.59, and t4(17)=0.19 at P10=0.85. That is the average understanding levels of test group (M1=1.010, M2=0.562, M3=0.844, M10=0.912) were not significantly different from those of the control group (M1=1.398, M2=0.988, M3=1.014, M10=0.979).

Table 2: P-values of higher than 0.05 indicate that the results are not statistically significant.

Checklists	#1	#2	#3	#10
P	0.24	0.35	0.59	0.85
T	1.23	0.97	0.55	0.19
Degree of Freedom	17	17	17	17
Mean Test	1.010	0.562	0.844	0.912
Mean Control	1.398	0.988	1.014	0.979
Standard Deviation Test	0.730	0.617	0.770	0.680
Standard Deviation Control	0.613	1.031	0.571	0.738

One reason that led to statistically insignificant results was the small sample size. Since we cannot determine the absolute values of the Product Definition Checklist, following Cohen's (1998) convention rule and approximating the size of each sample for a two-sample, two-tailed t-test with alpha level 0.05, the following relation yields an approximate power of 0.80 (Lehr, 1992):

$$n = \frac{16s^2}{d^2} \qquad \text{Equation 3-4}$$

For our case, s = 0.7 for standard deviation, and the difference we would like to detect is 0.5 between the mean response of the test and the control group.
Using equation 5.4,

$$n = \frac{16 \times 0.7^2}{0.5^2} = 31.4$$

we find that we need at least 31 for each group to achieve statistical significance.

Aside from the small sample size, other factors may have led to errors. Errors may have been introduced by the linguistic and cultural differences between the control groups and the test groups. The control groups were Stanford University students in the United States, and the test groups were Keio University students in Japan. The US and the Japanese groups have different proficiency levels of English, which was the main language the methods were taught in and the survey was conducted in. This language discrepancy could have affected both the understanding of the methods and that of the interpretation of the survey questions. The teaching staff made an effort to mitigate the linguistic challenge through thorough explanation of methods, translation of important points during lectures and annotation of jargon. In addition, the cultural difference could have influenced the confidence level in the responses to the survey. Japanese culture is usually more reserved and prizes humility more than United States culture, where directness and confidence may be considered virtues. The teaching staff tried to instill confidence and enthusiasm to abate for this difference. Educational background also could have introduced differences between the two groups. The control groups were mainly master's level graduate students with an undergraduate degree in mechanical engineering, while only 20% of the test group students had engineering backgrounds, and the rest were from finance, journalism, business, and so forth (Ishii, 2009). The control group may have had more exposure to the product development processes, which gave them an advantage in absorbing the methods.

In addition, every project was different. Because the test group's projects were more open-ended and had less guidance, they may have had a bigger challenge to overcome ambiguity. The control groups' projects, conversely, were company-sponsored and hence more focused. Additionally, project liaisons helped the control design teams converge and reach consensus more easily. To balance this assistance time, during the workshop periods, the teaching staff tried to spend more time coaching the test-group students on their projects.

All of these factors could have skewed understanding or the confidence level of the team members regarding their products, introducing a higher noise level than might be found in a tightly-controlled experiment. Future research should address these challenges to improve the validation of design methodologies.

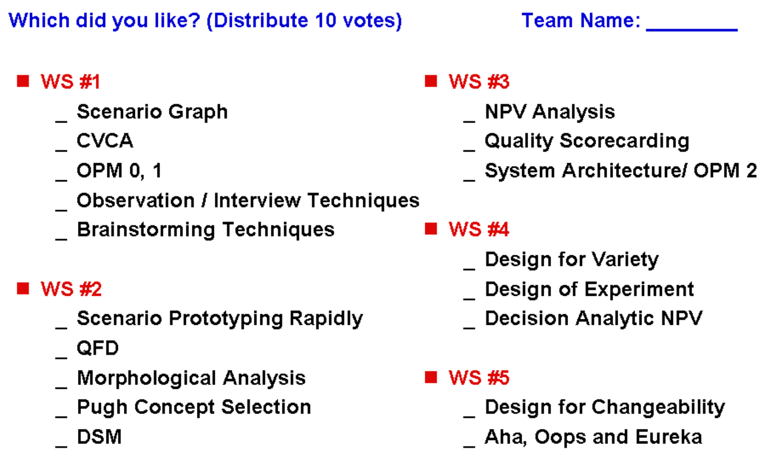
Sampling errors or rounding errors are also common types of errors, and given the small size of the sample, they could have had a significant effect on the results, especially if there were any outliers such as the one in the second checklist question.

Finally, the survey questions of the Edith Wilson checklist themselves have shortcomings in measuring the level of a design team's understanding of their project scope. First of all, it is challenging to compare absolute values of the level of understanding with those of other teams using only an ordinal scale. The meaning of five (excellent) for one team may be different from that of another because it is subject to the team's interpretation of what excellent means. Another shortcoming is that the checklist was originally developed for hardware-based products, while we are applying it to systems-oriented products. We are currently developing a new survey that will capture more appropriate metrics.

The preliminary conclusion we can draw from this statistical validation is that we need further analysis with more sample data to achieve statistically significant conclusion of whether Scenario-based Design for Amorphous Systems helped design teams to define their product in the early stages of product definition. However, the new approach to validation in itself is important and worth further exploration. In order to compensate for the limitations of this statistical validation, we employed additional methods such as the method votes and interviews explained in the next section.

4. Voting Approach

To measure how much Scenario-based Design for Amorphous Systems tools contribute to the success of the project, we conducted a survey of methods used throughout the course of the project. We collected votes from the test group that used the Scenario-based Design for Amorphous Systems methods. A total of 13 teams participated in the survey. The team members decided which tools significantly influenced their project. The survey question in Figure 5 asked them to distribute 10 points among the 18 methods that they had learned.



Which did you like? (Distribute 10 votes) Team Name: ________

- WS #1
  - _ Scenario Graph
  - _ CVCA
  - _ OPM 0, 1
  - _ Observation / Interview Techniques
  - _ Brainstorming Techniques
- WS #2
  - _ Scenario Prototyping Rapidly
  - _ QFD
  - _ Morphological Analysis
  - _ Pugh Concept Selection
  - _ DSM
- WS #3
  - _ NPV Analysis
  - _ Quality Scorecarding
  - _ System Architecture/ OPM 2
- WS #4
  - _ Design for Variety
  - _ Design of Experiment
  - _ Decision Analytic NPV
- WS #5
  - _ Design for Changeability
  - _ Aha, Oops and Eureka

Figure 5: Method vote form for ALPS 2008, Keio University

Three out of 18 methods taught at ALPS were new Scenario-based Design for Amorphous Systems methods: Scenario Graph, Observation/Interview Techniques, and Scenario Prototyping Rapidly. These three methods received 24.5% of the votes, indicating the significance of Scenario-based Design for Amorphous Systems methods to the projects. Other existing DFX methods that used the scenarios as a vehicle are Pugh Concept Selection and Morphological Analysis, which together received 23.1%. Figure 6 shows the breakdown of the votes. These five methods totaled 36.2%.

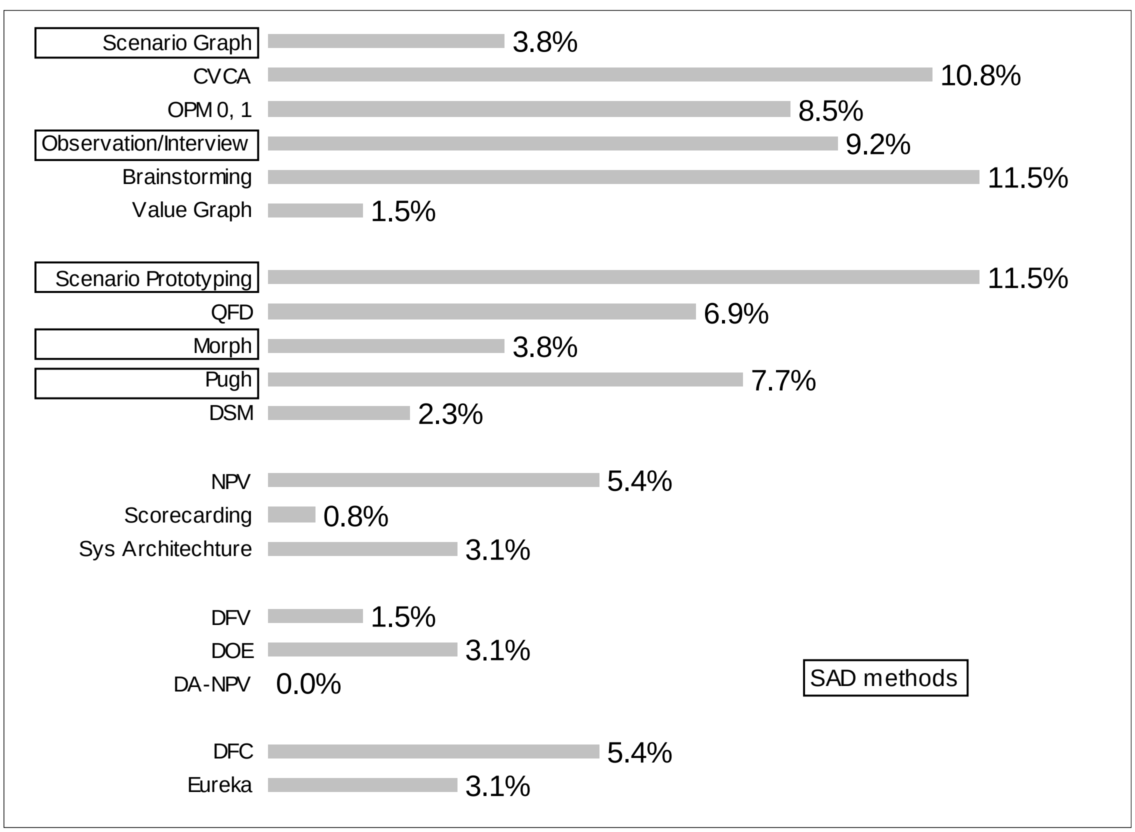


Figure 6: Survey results show that Scenario-based Design for Amorphous Systems methods (boxed text) comprised 36.2% of the tool votes.

Other findings are that 77.7% of the votes were concentrated in the first and second workshop, which shows the importance of the initial stages of project management. This indicates how important it is to strategically deploy the methods at the beginning of the project because the themes that arise during this beginning phase are most likely to determine the course of the project. Based on the results of the Scenario Graph, design teams were able to visit, observe the scenarios chosen, and interview stakeholders using the techniques taught at the second workshop. Afterwards, they were able to conceptualize the details through the activity of scenario prototyping and discover the latent needs that eventually led to functions, requirements and specifications.

Many of the discoveries also came through the process of using Scenario-based Design for Amorphous Systems methods. We used the terms, “Aha, Oops and Eureka” to explain the discovery of insights (Aha), failures (Oops) of the current approach and breakthrough (Eureka) ideas and concepts (Ishii, 08).

Table 3 shows at what methods employed by the teams during the workshops they gained key insights, became aware of mistakes and made breakthroughs. Again, many of the Aha’s, Oops’s and Eureka’s came about due to the Scenario-based Design for Amorphous Systems methods.

Table 3: Aha, Oops and Eureka along the projects (* Respondents wrote that all the methods during the above workshop influenced their Aha, Oops, or Eureka.)

Legend A: Aha O: Oops E: Eureka

		Teams											
Workshops	Methods	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2
WS #1	Scenario Graph							A					
45.4%	CVCA				A								
	OPM 0, 1												
	Observation/Interview	O						O	A,E	A,O,E		O,E	E
	Brainstorming	A	A					A				A	
	Value Graph						A						
			O*			A*							
WS #2	Scenario Prototyping								E			O	
32.3%	QFD												
	Morph	E		A									A
	Pugh	E	E	A			O						
	DSM												
						O,E*					A*		
WS #3	NPV			O	P					O	O		O
9.2%	Scorecarding												
	System Architecture						E						
WS #4	DFV												
4.6%	DOE												
	DA-NPV			E	O								
WS #5	DFC				E						E		
8.5%	Eureka												

From the graph and a follow-up interview, we were able to deduce that Scenario Graph, helped the teams come up with an initial set of scenarios and to discuss these scenarios to choose an optimal one from them. The team then used the information thereby obtained to visit the chosen scenario for further exploration of the actual needs. The team members went to the places (Where), met and talked to the stakeholders (Who), observed the activities (What), and learned what kind of situation they were in (When) and how they responded to the situation (User Response). The team further analyzed this rich contextual information to reconstruct the scenario and immerse themselves in the experience by prototyping it through situational enactment or scale models and mockups. During the Scenario Prototyping Rapidly stage, they learned about the details and unavoidable gaps in the activities. These discoveries were the Aha's, Oops's and Eureka's of the teams' projects.

In summary, the vote results, as well as the tracking of Aha, Oos and Eureka support the hypothesis that Scenario-based Design for Amorphous Systems helps design teams clarify their product definition for amorphous projects.

5. Interview Approach

After each workshop, the teaching staff distributed a blank survey form to solicit open feedback on the Scenario-based Design for Amorphous Systems methods from the design teams. Following are excerpted comments relevant to the Scenario-based Design for Amorphous Systems methods. Some of the keywords that emerged from the five workshops were "Clarify; Create; Interested; Helped; Stories; Creative; Fun; Sky-high Idea." These keywords reinforced our claim that Scenario-based Design for Amorphous Systems helps design teams visualize, organize and communicate their ideas for projects that involve amorphous systems.

First Impressions. The first survey took place at the end of the first workshop of the ALPS course at Keio University SDM, on May 20th, 2008. At the first workshop, the teaching staff taught the design teams Scenario Graph, Scenario Menu and CVCA. In advance, the design teams completed an overnight exercise that taught them the basic mechanics. Accordingly, most of the comments are merely first impressions of the methods, but what became clear was that these impressions were positive and that the participants were interested in the methods. Regarding Scenario Graph or Scenario Menu, respondents wrote, "I was very interested in scenario." "I'm sure it will help me a lot. In the next lecture, I like to hear the real stories concerning creativity more." Another respondent confirmed that the benefits of the methods are not limited to academic settings but also apply to industry settings: "I am bewildered [sic] for practice scenario work." (We determined the student's intended meaning in a verbal follow-up interview.) Yet another wrote, "I could clarify the method of the system and engineering," pointing out the visualization and organization benefits of the methods.

After applying the Scenario-based Design for Amorphous Systems methods to their projects.

The second survey was on June 26th, 2008, again at the end of the second workshop. Before it, the design teams had applied Scenario Graph, Scenario Menu, and Scenario Prototyping Rapidly on their projects and had had a chance to evaluate the effectiveness of the methods over the course of four weeks. A respondent acknowledged the benefits of the methods, writing, "I notice the importance of high level goal and concept…" Another wrote, "To create sky-high idea, we try [sic] to use various methods," when explaining that their team used the Scenario-based Design for Amorphous Systems methods to generate their out-of-the box ideas. Another member commented, "The next time, I promise you to show the creative scenario prototyping rapidly," indicating commitment to the Scenario-based Design for Amorphous Systems methods.

Fun was one factor we emphasized throughout the course because of the positive influence it has on the success of a project. We noticed that Scenario-based Design for Amorphous Systems methods contributed to the design team's excitement during the design process. Scenario Prototyping Rapidly turned out to be the most popular method, as shown in the previous section. One respondent confirmed this by writing, "Prototype rapidly was really fun…" Finally, another member showed the applicability of the Scenario-based Design for Amorphous Systems methods to the industry by commenting, "I think that tools you show us is important in our business. As a review, I want to use the tools on my business…"

All of these survey results reaffirmed the hypothesis of the statistical validation and compensated for the limited sample data.

We conducted a similar survey among the Toshiba teams who conceptualized the Butler System in 2007. This was the first time we taught Scenario-based Design for Amorphous Systems methods to design teams who applied them on a corporate project. They already had background knowledge of DFX but we introduced them to Scenario-based Design for Amorphous Systems methods, which became the catalyst in turning their project from a device-oriented e-book to a systems-oriented Butler concept. The following comments illustrate how the team members perceived the Scenario-based Design for Amorphous Systems methods.

Many team members acknowledged how Scenario-based Design for Amorphous Systems methods helped them break their mold and liberate their thinking by commenting, "I feel my brain become flexible." A few members appreciated the benefit of organizing their ideas through Scenario-based Design for Amorphous Systems methods by saying, "VOX framework…is useful," "Method of scenario selection …was clear," and "Divide and conquer…is useful." other members noted that visualization and communication aspects of sad methods, by commenting, "Trial using the brainstorming and WAIGAYA [storyboarding] …was the best," Action Flow around VOS, Scenario…is clear"

6. Conclusions

The first contribution of Scenario-based Design for Amorphous Systems is the 6W framework, which clarified the source of ambiguity and established formal definitions of previously loosely-defined terms such as *amorphous, product, service* and *system.*

Another contribution to the field of product development is the structuring of a logical approach based on both new and pre-existing methods. By stringing together these previously stand-alone methods and offering a step-by-step process, we have been able to construct a methodology which can be used by any design team. This is a step beyond philosophical principles such as "Immerse oneself in the needer group" or "Think outside-the-box" because Scenario-based Design for Amorphous Systems provides design teams with a tangible framework and methodologies for conducting focused brainstorming and discussions.

We acknowledge that many brainstorming guidelines and DFX techniques are well-accepted by experienced design teams. However, to our knowledge, little work has successfully established a structured approach in using scenarios to design an under-defined system. We believe that Scenario-based Design for Amorphous Systems bridges the divide of abstract Fuzzy Front End research and practicable DFX methods, streamlining the product development process—from finding customer values to converting them to solutions. In particular, in our opinion, Scenario Graph and Scenario Menu are two methods that embody original and effective methods based on cognitive science and educational psychology.

Scenario-based Design for Amorphous Systems methods also force design teams to break out of their standardized manufacturing-based thinking, yet, at the same time, help them to stay organized and focused on customer requirements rather than being swayed by strongly opinionated team members or managers. In short, Scenario-based Design for Amorphous Systems' focused brainstorming and efficient processes lead to a more robust outcome. This type of focused framework helps keep design teams on track and constantly reminds them of customer requirements. Another notable contribution is that our focus on using scenarios as a common language led to clearer communication, which was key in designing systems-oriented products requiring experts from different domains.

Case studies from industry suggest practical implications of using Scenario-based Design for Amorphous Systems for new product development. Not only did we apply Scenario-based Design for Amorphous Systems to real industry cases, but we also set up a form of validation protocols that evaluated the effectiveness of Scenario-based Design for Amorphous Systems. Past design methods have rarely included such a protocol. At the writing of this paper, 44 design teams have used Scenario-based Design for Amorphous Systems, and some of their results have been documented. Since the methods have found their place in the curricula of Stanford University's ME317 and Keio University's ALPS, we will see a wider range of case studies which will reveal opportunities for further refinement of Scenario-based Design for Amorphous Systems in the coming years.

In the immediate future, we will conduct further validation of Scenario-based Design for Amorphous Systems. Sound validation in the field of design research is extremely challenging and as a result is very rare. The main reason for this is the lack of adequate metrics or experimental environments in which data can be obtained in a reasonably short time. There are two ways of approaching validation: 1) measuring effectiveness (return on investment, etc.) or 2) measuring efficiency in the process (clarity, etc.). This paper looked at the former—measuring effectiveness—which leads to a better understanding of the requirements of the customers and the project. However, due to limited data and metrics, it was difficult to statistically measure the effectiveness the Scenario-based Design for Amorphous Systems. Therefore, we will be exploring a new set of metrics and developing new ways to capture and measure them.

7. References

INCOSE 2006 systems engineering handbook - a guide for system life cycle processes and activities, Version 3. ed. Cecilia Haskins.

Carroll, J., (1995), Scenario-Based Design: Envisioning Work and Technology in Systems Development, John Wiley & Sons, Inc.

Cohen, B. (2008) Explaining Psychological Statistics, John Wiley & Sons Inc.

Donaldson K., Ishii, K., and Sheppard, S.D., (2004), Customer Value Chain Analysis, Proceedings of the ASME Design Engineering Technical Conference, September 2004, Salt Lake City, UT. ISBN 0-7918-3742-1

Frey, D., Clive, D., (2006), Validation of Design Methods: Lessons from Medicine

Frey, D., Li, X., (2006) Model-based Validation of Design Methods

Ishii, K., (2001) Customer value chain analysis (CVCA). In: Ishii K(ed) ME317 dfM: product definition coursebook. Stanford Bookstore, Stanford University

Ishii, K. and S. Kmenta, (2004), Value Engineering (Value Identification and Functional Analysis) ME317 dfM: Product Definition Course book, ed(s): K. Ishii. Stanford Bookstore, Stanford University

Kim, S. K., Ishii, K., Beiter, A. K., (2007), Scenario Graph: Discovering New Businesses Opportunities And Failure Modes, Proceedings of IDETC/CIE 2007 ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, September, 2007, Las Vegas, Nevada

Kim, S. K., Ishii, K., Naoshi, U., Kyoya, Y., Beiter, A. K., (2009), Design for Service Innovation: A Methodology for Designing Service as a Business for Manufacturing Companies, Int. J. Services Technology and Management

Olewnik, A., Lewis, K., (2003), On Validating Design Decisions Methodologies

Pugh, S., (1991), Total Design, Addison Wesley, Wokingham, UK

Ritchey, T. (2006) General Morphological Analysis: a general method for non-quantified modeling, http://swemorph.com

Seepersan, C., Pedersen, K., et al (2004), The Validation Square: How does one verify and validate a design method?

Trochim, W., (2006) The Research Methods Knowledge Base, Atomicdogpublishing.com

Weilkiens, T., (2008), Systems Engineering with SysML/UML: Modeling, Analysis, Design, Morgan Kaufmann

Zachman, J., (1987), A Framework for Information Systems Architecture, IBM Systems Journal Vol. 26, No. 3, 1987

8. BIOGRAPHY

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