# Demystifying Ambiguity in
# The Design of 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. This research begins with the observation that, at the onset of an amorphous system-oriented project, design teams struggle because they are limited to knowledge of fewer than 4 of the 6 W's (*Who, What, Where, When, Why, How*); rather than having detailed functional or structural specifications as is the case with hardware or software products. The proposed scenario-based approaches enable 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. Based on the *Scenario-based Design for Amorphous Systems*, methods such as the Scenario Graph and the Scenario Menu help design teams through the exploration stage of a new system development. A case-study from industry demonstrates how a multi-disciplinary design team extracted high-level functions and requirements from scenarios dealing with an open-ended project theme. The integrated framework of *Scenario-based Design for Amorphous Systems* guides the design teams in visualizing and organizing scenarios and making decisions in order to define an amorphous system.

## The Ambiguity Inherent in the Design of Systems

Companies today have integrated hardware, software, firmware, infrastructure, policy and services into their products in an effort to expand their customer base, increase value for the customers, and differentiate their offerings from those of the competition. Figure 1 shows the hierarchical view of the definition.

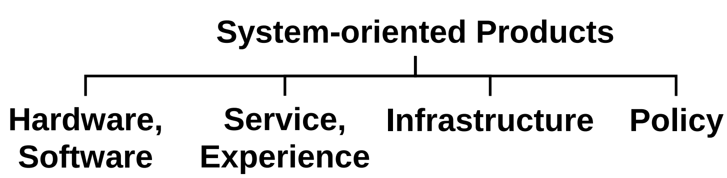


**Figure 1:** Systems-oriented Products consist of hardware, software, service, experience, infrastructure, and policy.

As a result of this broadened project scope, their product development process has become more complex, requiring multidisciplinary cooperation. Therefore, the design teams in many companies need a more structured approach for designing and developing system-oriented products that are open-ended or what we will define as “amorphous.”

The most time consuming and challenging part in the process of designing systems is identifying and formulating the problem. The impact of the decisions made during this stage can be larger than that of any other decisions made during the rest of the product development process, yet this stage is the one most frequently underestimated. (Barkan, 1995)

Identifying and formulating the problem translates to defining the product, and in many cases, product definition is even more difficult for system-oriented projects than for hardware or software-oriented projects. This is not only because projects dealing with systems-oriented products have more constituents but also because less information is available at the beginning.

Over the past five years, Stanford University has undertaken numerous amorphous projects through “ME317: Design for Manufacturability,” a ten-week, project-based course. In ME317, design teams that consist of full-time students and professionals, work with liaisons from project-sponsoring companies to solve a problem that the company presents. One finding from these projects is that the project descriptions submitted by the project sponsors at the beginning show more ambiguity than is seen in hardware or software-oriented projects.

We looked at 32 design teams participating in ME317 from 2004 to 2008 in order to find out what made systems-oriented projects more difficult than others. One result of the observation was the insight that the level of understanding of the factors[1] relevant to product definition was directly related to the availability of focused information at the beginning, which, in turn, was inversely related to the time required for the team to move on to the solution generation stage. This was consistent across all projects regardless of team dynamics, background, etc.

In order to find out what contributed to the discrepancy between the level of understanding acquired at the beginning of ill-defined and well-defined products, we went back to the starting points of the projects and examined what was different for each of the design teams. At the onset of a new project, the first way in which the design teams are presented with information is through a one-page project description and a presentation on the project, both prepared by a liaison representing the company sponsoring the project. The two media contain identical content, which is the theme or the direction of the project. The information they thus acquire serves as a guideline for the design teams, and they refer to it throughout the 10 weeks.

We determined that the degree of specificity with which liaisons described their projects differed considerably. Some project descriptions were very specific while others were very vague. Usually for hardware or software-oriented projects, the descriptions were focused and clear. On the contrary, systems-oriented projects had ambiguous descriptions and broad focuses.

Following are excerpts from two project descriptions that demonstrate the difference between a well-defined and an ill-defined product scope. The nature of the first project description is a re-design of a manufacturing process for a composite blade. The objective of the project is noticeably focused.

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[1] Edith Wilson Product Definition Checklist (Wilson, 2002): A checklist for gauging whether a design team understands the factors that are essential in defining the product.

*[Our Company is producing a new, all-composite main blade which contains a laminated graphite cuff used at root end of blade for attachment to rotorhead. Manufacture of this detailed part involves manual placement of thin layers of graphite material (woven graphite cloth impregnated with resin) around a male rotating mold. The orientation and placement of these layers, called plies, is critical to the resultant part's structural properties. There are approximately 100 individual plies that are placed on the mold to complete a cuff laminate. Each of these plies requires hand placement and "smoothing" onto the mold and previous plies to ensure correct drape and to avoid trapped air. Hand placement of these graphite plies is time consuming and ergonomically unfavorable because of the repetitive motion and related wrist trauma. Size and convex/concave part geometries have made layup automation unattainable (to date). In anticipation of near future production ramp-up, method of reducing cuff layup labor content and associated repetitive motion is highly desirable.*
***Vacuum Bagging:*** *After completion of part layup, cuff plies require cure which is accomplished in an autoclave with applied elevated temperature and pressure. Because cuff is layed up on a male mold and because uncured impregnated graphite material is approximately 30% bulkier than cured material, external pressure during cure must be uniform to avoid unacceptable part wrinkling and thickness variations. Attempts are made to satisfactorily distribute autoclave pressure through the use of caulplates. Shape, thickness and stiffness properties of these caulplates all directly affect cured part outside geometry and can mean the difference between an acceptable and unacceptable part.*

***Project Deliverables****: Suggested project would be to devise an optimum layup and caulplate pressure method that eliminates issues related to existing process/tooling design. To be considered are: layup automation, layup hand tools that isolate wrist trauma, alternate caulplate arrangements, alternate means of applying external part pressure during cure.]*

**Figure 2:** An example of a project description for a hardware-oriented product (ME317 Project Description, 2004)

The second project description is from another transportation company with a focus on developing a novel system using communication technology. In contrast to the first one, this one has a broader scope.

***Title:*** *How can we create the new world with car communication technologies?*
***Objective:*** *Our goal is to figure out what kind of new world we can create with communication technologies on cars. Then to clarify what kind of communication technologies we should develop.*
***Background:*** *In recent years, with "communication product," introduced by our Company, customers can get much information, such as restaurant, direction, map, music… But these services are similar to the internet access at home. Are they enough for a car? We think there will be better communications for "Ecology", Safety" and "Convenience of movement", which are the top objectives for cars.*
***In this Project:*** *(1) What kind of new world we can create? We would like to identify the market, customer… Customer Scenario, Potential Customer, (2) What kind of technologies we should develop? New communication method for the Customer Scenario, Smarter and more effective communication. For example: multiplex communication on the light of traffic signal (no need to build new infrastructures, few blockages) (3) Propose new Business Model. In this project, we would like to focus on the investigation for the United States.]*

**Figure 3:** Project description for a system-oriented product (ME317 Project Description, 2006)

The two project descriptions above communicate two different levels of detail and scope.

## *1.1 Deciphering the Project Description*

Looking at these two project descriptions, we asked ourselves how the teams might extract project-specific information from them. Our approach was to categorize the questions the teams might ask according to the so-called 5W's and 1H or simply, the 6W's. The 6W's are, *Who*, *What*, *Where*, *When*, *Why* and *How*. They are the basic elements that describe the facts of an event, and this approach is commonly used in journalism. There are many ways to formulate questions using the 6W's. We did so as follows:

*Who* are the customers or the stakeholders involved with the product and the project?
*Where* or in which location is the product placed?
*What* activities are happening at the time?
*When* or under what kind of circumstances will the customers be interacting with the offering?
*Why* do the customers need this? Which value or goal does this product achieve?
*How* can the customer achieve this goal or value?

By answering these six questions, the design team should be able to gain a fundamental understanding of the project requirements. In the two cases above, the first project description contains more information than the second one. The table below categorizes the 6W's extracted from the two project descriptions mentioned above.

**Table 1:** 6 W's categorized for a project with a specific focus.

| Mfg. Process for Graphite Plies | |
|---|---|
| Who | Operators, Production Manager |
| What | Lay-up, apply pressure |
| Where | Factory |
| When | Repetitive |
| Why | Reduce cost |
| How | Layup automation, tools, arrangements |

In answer to the question, "*Who* are the customers or the stakeholders involved with the product and the project?" the description implies that the operators and the product manager are the main stakeholders. In answer to, "*Where* or in which location is the product placed?" the description assumes that it is the factory. In answer to, "*What* activities are happening at the time?" the description mentions lay-up and applying pressure. For the question, "*When* or under what kind of circumstances will the customers be interacting with the offering?" the answer is, a work environment that requires much repetitive motion. "*Why* do the customers need this? Which value or goal does this product achieve?" The value is in reducing manufacturing cost. "*How* can the customer achieve this goal or value?" The liaison suggests a few approaches: "To be considered are: layup automation, layup hand tools that isolate wrist trauma, alternate caulplate arrangements, alternate means of applying external part pressure during cure."

In comparison with the above table, the second project description contains far less information.

**Table 2:** 6 W's categorized for a project with an open-ended focus.

| Car Communication | |
|---|---|
| 6W's | 6W Details |
| Who | |
| What | Communicate |
| Where | USA |
| When | |
| Why | |
| How | |

In answer to the question, "*Who* are the customers or the stakeholders involved with the product and the project?" the liaison is actually asking the design team to identify the potential stakeholders. The answer to, "*Where* or in which location is the product placed?" is simply \the United States as the market. "*What* activities are happening at the time?" The description focuses on various communicating activities. For the question, "*When* or under what kind of circumstances will the customers be interacting with the offering?" the description does not provide a clear answer. "*Why* do the customers need this? Which value or goal does this product achieve?" Again, the description does not state a specific motivation of this project. To assume that the value is in increasing revenue, which is the generic motivation for companies, is too broad to be meaningful in a design project. "*How* can the customer achieve this goal or value?" Again the liaison is asking the design team for the answer.

**Defining Amorphous.** Repeating the categorization process for the rest of the 30 projects, we found that 18 projects had fewer than 4W's in their project descriptions. We define those projects with three or fewer W's as "*Amorphous.*" These amorphous projects are more open- ended because they have fewer constraints than the well-defined projects.
Another common attribute of these "amorphous" projects was that they were mostly system-oriented. As Table 3 shows, the projects with fewer than 4W's involve more than just hardware or software. They focus on amorphous system that involves service, policy and infrastructure.

**Table 3:** Amorphous projects (3W's or less) are system-oriented whereas projects with 4 or more W's tend to be hardware or software-oriented.

| | **Year** | **Project Theme** |
|---|---|---|
| 1 W | 2004 | New Market for Bodywarmer |
| | 2005 | Future of Fuelcell Powertrain |
| | 2005 | Integrate Equipment Engineering System for Chemical Mechanical Polisher |
| | 2006 | Car Communication |
| | 2008 | Optimize Supply Chain |
| | 2008 | Sustainable Mobility/Plant |
| 2 W's | 2004 | Hydrogen Mobility |
| | 2005 | New RFID System |
| | 2005 | disaster-safe vehicle |
| | 2006 | Ensure Quality for Supply Chain Platform |
| | 2007 | Friendly Engine Global Factory |

| | | |
|---|---|---|
| | 2007 | Personal Fluid Control System |
| | 2008 | Desalination Business Model |
| 3 W's | 2005 | Wireless ICD Programmer |
| | 2006 | Smart Assembly Line |
| | 2007 | Flexible Vehicle Architecture |
| | 2007 | Zero Automotive injury |
| | 2008 | Optimize Automation for Assy |
| 4 W's | 2004 | Optimize HybriDrive Design |
| | 2004 | Optical Sensor into ICD |
| | 2005 | Optimize Power Management Module |
| | 2005 | Mfg. Process for Catheter |
| | 2006 | Mfg. Process for Stent |
| | 2006 | Optimize ICD design for Assembly |
| | 2007 | Stent Graft Mfg |
| | 2007 | Optimized drug-eluding patch design for Mfg. |
| | 2007 | Reliable Fuel Cell |
| | 2008 | Substation Evolution |
| 5 W's | 2004 | Evaluate Mfg. Automation |
| | 2005 | Serviceability for linear collider |
| 6 W's | 2004 | Mfg. Process for Graphite Plies |
| | 2004 | Serviceability for linear collider |

After categorizing information extracted from the project descriptions, we plotted them over the last five years to see the percentage of amorphous products from 2004 to 2008. Figure 4 shows that from 2004 to 2008, the number of these projects in relation to the total seems to have increased from 25% to 80%. Evidently, the industry is turning more to academia for ways to improve the design process for amorphous products that are system-oriented.

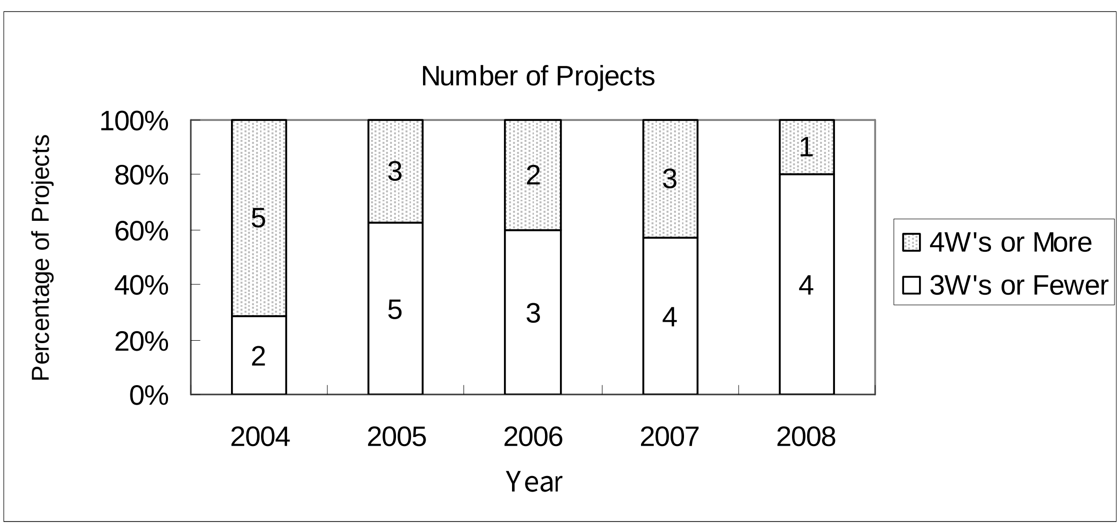



**Figure 4:** The percentage of amorphous projects has increased from 25% to 80%.

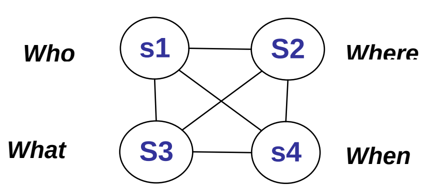
### *1.2 Past methods did not characterize Where and When*

The current dfX framework is missing a tool that addresses this ambiguity in designing amorphous systems. Because the previous projects were mainly improving designs of existing products, project liaisons assumed that the context (*Where*, *When*) or the activities (W*hat*) of the product were well known. In order to address the missing *Where and When*, learn about the voice of the customers or stakeholders (*Who*), CVCA (Customer Value Change Analysis) is the first step in the dfX approach. Then the Value Graph defines the customer needs (*Why*) and requirements. After prioritization of the requirements and further analysis through tools such as QFD (Quality Function Deployment), comes the solution generation stage in which the design team develops concepts (*How*).

For design improvement projects the design team already had *Who, Why, What, Where* and *When* before moving on to the solution generation stage. However, for amorphous systems, the design team was not given the context (*Where*, *When*) and the activities (*What*) associated with them. It is because of this that the design team struggled during the product definition stage. Only when at least four (*Who, What, Where, and Why*) of the 6*W*'s are constrained, can the design team proceed to better understand and further develop of the concept. In order to address ambiguity and let the design team converge on fundamental information effectively, we suggest an approach called *scenario-based design for amorphous systems.* (Kim, 2007)

## 2. Filling in the Missing *W*'s (information) through *Scenario-based Design for Amorphous Systems*

*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 5 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 5: 4W's make a scenario.**

As discussed in much of the literature, using scenarios provides multiple benefits for amorphous projects. First, it guides the design team from an ambiguous project theme to functions and requirements by leading the team to explore potential use-cases. Second, graphical and tabular documentation of the scenarios help the design team organize their ideas. Third, scenarios promote communication among management, potential customers, and most importantly, team members who are from different disciplines, by providing a common language that everyone can understand. Because scenarios are images or a series of them that users experience, they are at a level at which all stakeholders can understand and communicate.

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. Table 4 shows that Scenario Graph and Scenario Menu help the design team to specify *Where, What, Who,* and *When*. Then the Customer Value Chain Analysis clarifies the value chain of *Who,* and the Value Graph organizes the *Why* (values), and *How* (metrics).

**Table 4:** Scenario-based methods and dfX methods define the 6 W's of product definition.

| | Where | What | Who | When | Why | How |
|---|---|---|---|---|---|---|
| Scenario Graph | O | O | O | O | | |
| Scenario Menu | O | O | O | O | | |
| Customer Value Chain Analysis | | | O | | | |
| Value Graph | | | | | O | |
| Morphological Analysis | | | | | | O |

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. Not 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.

After the design teams identify the functions and requirements, they can easily utilize traditional product development processes. Based on this observation, our effort to guide the design teams during the product definition stage resulted in new design methodologies such as Scenario Graph (Kim, 2007), Scenario Menu, and Dynamic Customer Value Chain Analysis (Kim, 2008).

Looking at amorphous, system-oriented design 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 Design for Amorphous-systems* (Kim, 2007) 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.

| Framework | *Methods* |
|---|---|
| **Trend Analysis** | *VOX Analysis* |
| **Scenario Generation/Selection/Evolution** | ***Scenario Graph***<br>***Scenario Menu***<br>*Pugh Selection* |
| **Functions / Requirements** | *Value Graph*<br>*(QFD / CWA)* |
| **Concept Generation/Selection/Evolution** | *Morphological Analysis*<br>*Function-Sol. Elem. Map*<br>*Architectural View* |
| **Business Model / Roadmap** | *Dynamic CVCA*<br>*Worth-Feasibility Evaluation*<br>*Roadmap* |
| **Validation** | *NPV /*<br>*Decision-based*<br>*Analytic Scorecarding* |

**Figure 6:** The framework of scenario-based design for amorphous system

## 3. Case Study: From an E-book Device to the "Butler System"

In an effort to test the effectiveness of *Scenario-based Design for Amorphous Systems* and further refine the methodology, MML of Stanford University conducted a preliminary trial and applied it to a design team from a global conglomerate electronics manufacturer sponsoring this research. The company formed a multidisciplinary "Tiger" team, composed of members whose backgrounds range from marketing and planning to manufacturing and engineering. The team members were also from different product groups such as the mobile division, the semiconductor division, the digital media division, the personal computer division, the research and development division, and the software development division. They were given the task of designing a next-generation product but were not given a specific theme. Since their home departments were related to IT equipment, the area of interest was naturally in the IT industry. A teaching team from Stanford University was formed to guide the design team with the *Scenario-based Design for Amorphous Systems* methods.

The total duration of the IT project was six months. However, the Stanford teaching team only had a total of seven days of interaction in the form of five workshops divided over the course of the project, since the design team was located in Japan. In the workshops the teaching team supported the design team with *Scenario-based Design for Amorphous Systems* lectures and coaching for brainstorming sessions.

In May, which was the first month of the project, the design team began the IT project without the teaching team's intervention since the parties could not meet earlier. By the end of June, the design team had already come up with a concept-solution. It was a device that resembled a high-end "e-book" device, which replicates the book-feel in an electronic device. Of course the concept of an "e-book" device was just another iteration of a product that was already present in the market.

Table 5 shows the activities and the output of the design team before they used *Scenario-based Design for Amorphous Systems*. By using their past device-oriented product development approach, the design team was only able to come up with another device-oriented product.
The concept of an e-book device is limited in that it is another hardware or software-oriented product. As a result of not spending time on carefully defining the problem at the beginning of the project and progressing into generating solutions, the design team converged onto a concept too early, and by the time of the teaching team's intervention, the design team was in the rut of focusing on incremental feature improvements to an existing product.

**Table 5:** Before using *Scenario-based Design for Amorphous Systems*, the design team conceptualized a device-oriented product, the high-end "e-book" device.

| Workshop | Design Phase | Activities | Output |
|---|---|---|---|
| | Team Forming | | 10-member team |
| Before Using Scenario-based Design for Amorphous Systems (June) | Collecting Customer Requirements | Benchmarking Specifications | Specifications (processing time, transfer rate, storage capacity, cost, size, energy consumption rate, portability, robustness) |
| | | Benchmarking Alternatives | Alternatives (paper, magazines, printed material), |
| | | Analyzing Users | Activities (work at home or at the office, information gathering, information searching) |
| | | Benchmarking Existing Products | Products (operating systems, resolution, iPod, MP3 players, electronic books) |
| | Generating Solution | Generating Concept | An electronic device that feels like a book |

In July, when the teaching team began working with the design team, they took the design team to the first step of scenario-based design for amorphous systems, the VOX analysis.

Before diving into the scenario-based methods, the design team needed to look at the big picture of the market. VoX Analysis helped them conduct a broad survey of the company's direction so they had a better idea of the context and main factors that would drive or influence their concept.

## *3.1 Trend Analysis*

**VoX Analysis.** VoX analysis helped the design team get an overview of the various voices from internal and external parties that influence the potential direction of potential businesses. These voices are guidelines that anchored the design team and made it focus on a theme throughout the project. VOX is an acronym for "voice of X," X being society, technology, competition, and business. The components of VOX can be divided into those that are internal and those that are external to the company. The voices of society, technology and competition are external to the company; the voice of business is internal. The voice of society includes market trends, sources of change, and societal changes. The voice of technology refers to scientific changes. The voice of competition includes the competitive landscape. Internal to the company, the voice of business includes mission and vision, target markets and customers, differentiation and positioning, core competencies, and the business model.

After extensive benchmarking, the team gathered the following voices: For the Voice of Society, the design team identified “Busy, Save Time, Personalization, and Mobility.” For the Voice of Technology, “Miniaturization, Faster Processors available and Ubiquitous Information” while “Efficient and Accurate” emerged for the Voice of Business.
After much discussion, the team decided that their theme was, “Assist one’s daily life by providing the right info, at the right time, at the right place, to the right person.”

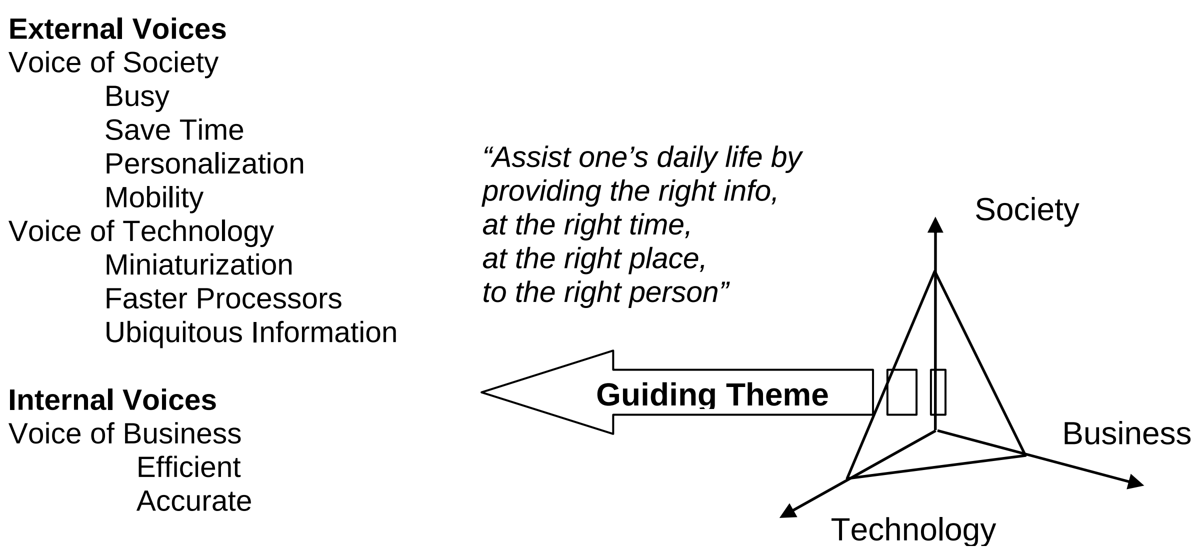



**Figure 7:** VoX analysis helped the design team extract the theme, “Assist one’s daily life by providing the right info, at the right time, at the right place, to the right person.”

With this theme in mind, the design team began to think about the potential contexts where they could meet the needs, based on their core competencies.

## *3.2 Scenario Generation and Selection*

**Scenario Graph.** Scenario Graph is a structured mind-mapping method that aids design teams in generating the necessary 4 W's for various scenarios. This method helped the design team explore unmet needs by imagining different possible uses and situations for their core competencies, in order to extract information from each of those scenarios. By linearly walking through each case, the design team revealed potential user locations (*Where*), activities associated with the location (*What*), people involved with the activities (*Who*), user circumstances (*When*), and the corresponding user states. The objective of the scenario generation stage is to assist engineers in discovering what customer needs exist in the scenarios relevant to the the design team's core competencies.

Figure 8 shows the overview of the Scenario Graph. The design team first started out by identifying the company's core competency in a broad sense, and then moved outward to explore the different scenarios related to those core competencies. Note that the core competency is not necessarily a company's current product, but rather a broader description of a company's offering or function, whether it be core or unique.

To map out the different scenarios related to a company's core competency, the design team branched in two directions and addresses each of the 4 W's. One branch is the Where (location), and the other one is the *When* (circumstance). Through these two main branches the design team could also derive the *Who* and *What*.

To approach the *Where* question, the design team brainstormed all possible locations in which their core competency can be put to use. After this is done, team members went out to interview or observe people, in those locations to better understand the location and the interactions that take place. Later the design team iterated through the *Who* (who could make use of or benefit from their core competency in that location?), as well as the *What* (what kind of activities take place there?). For *What*, using active verb plus noun format helped keep the meaning of activities clear. These questions in the Scenario Graph exercise led to extracting the needs (or the *Why*) of people carrying out such activities and the other parties involved. Next, the design team asked the *When* question by evaluating what possible environments or situations the potential users are in during their stay there. This step involved imagining the setting and how the user is responding to the physical environment and how that intertwines with the user's experience.

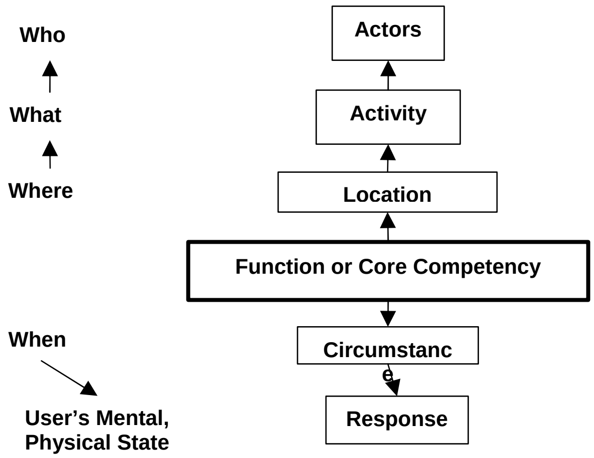



**Figure 8:** Scenario Graph stems originate in the order of Where, What, Who, When and stem from the project theme. (Kim, 2007)

Figure 9 shows an abridged scenario graph conducted by the design team. After agreeing that the mobile information system is their core competency, they brainstormed for various locations where an information system could provide value. Home, office, restroom, mountain, car, and restaurant were some locations that they listed. Thinking of these locations triggered images of activities that take place in those locations. For example, while picturing offices in their minds, the design team members also thought of scheduling and holding meetings as well as searching for information. Then the next thought led to the people involved in the location and the activities such as a male employee who is in his late 20s and a manager who is in his 50s. Finally to provide richer information, the design team thought about the environment of the office, during working hours, and immediately they associated that environment with the image of being stressed and tired.

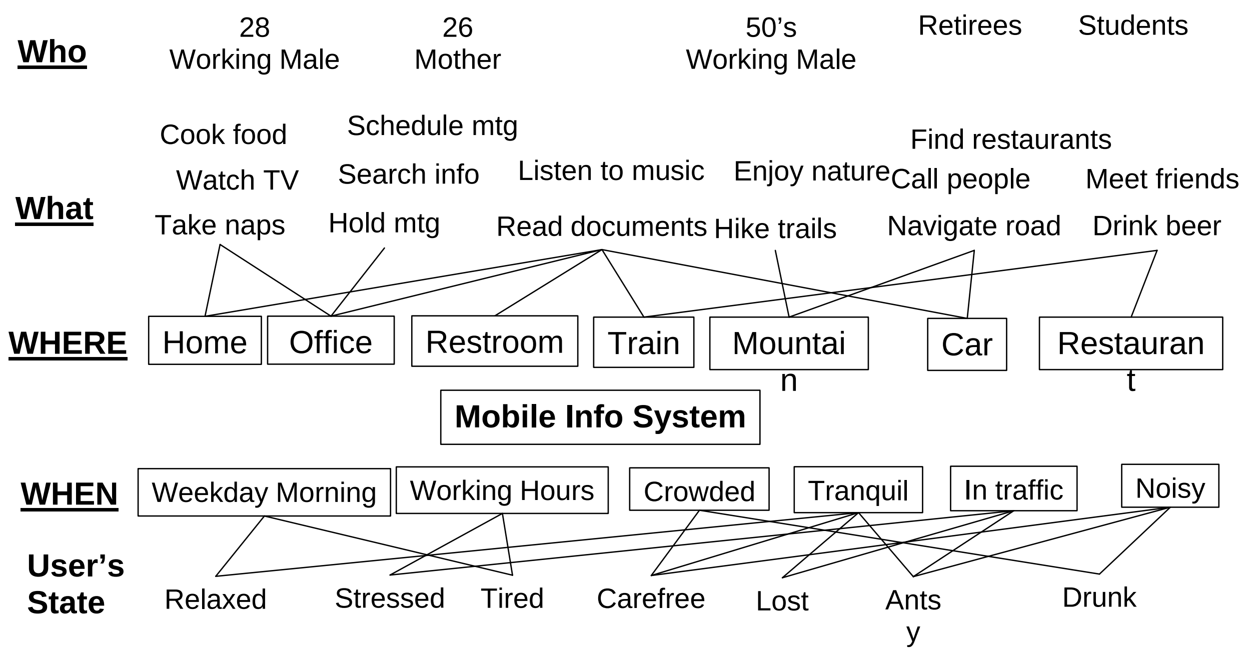



**Figure 9:** Scenario Graph of a Mobile Information System

**Scenario Menu:** Scenario Menu is another brainstorming template for design teams to generate scenarios by categorizing or breaking down the four-basic elements that constitute a scenario – *Who, Where, What, and When*. The approach follows the Morphological Analysis in that it is based on the scientific method of analyzing and synthesizing (Ritchey, 2006).

The Scenario Menu follows a similar order as the Scenario Graph. Just as Scenario Graph starts from the team's core competency, Scenario Menu starts from a broad project theme. The first step is to place the broad theme at the top of the table to remind and keep the design team focused on generating scenarios for that specific theme. The second step is to fill in the rows of Where, What, Who, When. Unlike the Scenario Graph, the order of brainstorming is less directional. The design team can do this by writing in short text descriptions or drawing in representative icons on each row. A useful technique is to use Post-it notes or index cards to record ideas and then filling in the rows. This technique allows the flexibility to change the location of the ideas when grouping them later. The third step is to select from each row and match them according to compatibility. Choosing more than one from each row is acceptable when grouping them. Table 6 shows the basic template for Scenario Menu.

Table 6 shows an abridged scenario menu from the design team. They generated close to 100 combinations of scenarios in a few hours. According to the definition, since a scenario consists of *Who, What, Where and When*, the design team listed multiple scenarios by mix and matching the 4 elements: stakeholders, activity, location, and circumstance. For example Scenario 1 consists of a business person who checks stocks, news on the train during his or her commute to the office. In the next step, the design team selects and evolves the scenarios they would focus and further develop.

**Table 6:** Scenario Menu for Mobile Information System

| | Who | What | Where | When |
|---|---|---|---|---|
| Scenario 1 | Business Person | Check stocks, news, etc | In Train | During Commute |
| Scenario 2 | Employee | Automatic auction bidding | Outside | During Meetings |
| Scenario 3 | Anyone | Entertain oneself, Relax | at Home | Evening, Weekends |
| Scenario 4 | Single Person | Help choose dress and make-up | at Home | Before going out |
| Scenario 5 | Driver | Get traffic, accident, directions information | In Car | During driving |
| Scenario 6 | Business Person | Administration | Office | During Meetings |
| Scenario 7 | Business Person | Take Minutes | Meeting Room | During Meetings |
| Scenario 8 | Young Person | Recommend Stores and Items | Mall | Shopping |
| Scenario 9 | Busy Person | Data Analysis | Office, Home | Multitasking |
| Scenario 10 | Single | Recommend Dating Course | Outside | Planning |

The Scenario Graph and the Scenario Menu serve similar purposes. They both guide the design team in the process of generating potential scenarios in order to extract functions and requirements at a later stage. In both cases, the design team selected one or more elements from each W and synthesized them to constitute a whole scenario. The design team composed multiple scenarios and chose ones were important to further explore at the next stage.

**Scenario Selection and Evolution.** All projects have limited time and resources, so the design team must select one or a few scenarios out of many to target and explore in further detail. Then they must evolve and refine the scenario during this iterative process. There are many ways to choose and evolve scenarios such as, for instance, through Pugh selection (Pugh, 1991) or just by simple team voting. Scenario-based Design for Amorphous Systems employs the popular Pugh (Pugh, 1991) selection method to minimize the learning barrier. The Pugh selection is a decision-making technique that uses a matrix with criteria on the left column and multiple choices on the top row. All choices are compared against one reference concept called the datum (which is one of the scenarios) and marked "+" for superior, "−" for inferior, or "0" for same. The design team should consider the criteria that are fit for the stakeholders of the project.
Using the representative VoXs derived from the first step and some additional generic business criteria, the design team can determine which scenarios to proceed with. The general business criteria include (but are not limited to) potential market size, degree of market needs, leverage on core competencies, competition (barrier of entry), existence of adequate management, etc. Table 7 shows the Pugh matrix with the selection criteria in the left column and the multiple options in the top row.

**Table 7:** Selecting scenarios by Pugh Matrix using business criteria

| Criteria | Scenario A | Scenario B | Scenario C | Scenario D |
|---|---|---|---|---|
| Potential Market Size | | | | |
| Degree of Need | | | | |
| Leverage on Core Competency | | | | |
| Competition | | | | |
| Management | | | | |
| | | | DATUM | |
| + | | | | |
| – | | | | |

After deciding which scenarios best fit the company, the design team moves onto the next step. Multiple iterations are necessary, especially if the results are similar.

Table 8 shows the first Pugh matrix for the scenarios of a Mobile Information System. The datum was the home entertainment scenario because all the team members were familiar with it. They used the datum as the reference to compare each criterion across the 10 scenarios. For the criterion of potential market size, the team's collective decision after they evaluated the relationships was that scenarios 1, 5, 6, 7 and 9 were the "same" as the datum. For scenarios 2, 4 and 10, they decided the scenarios were lower. The design team conducted the evaluation for the rest of the criteria. After multiple iterations and evolutions of the scenarios, the team narrowed the scenarios down to a few promising ones. Then the team members went to the places representative of the scenarios to conduct observations, interviews and surveys to learn more about the setting as well as to verify the assumptions that led to their decisions.

**Table 8:** Pugh selection for Mobile Information System

| Criteria | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 | Scenario 9 | Scenario 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Potential Market Size | Same | — | Datum | — | Same | Same | Same | Same | Same | — |
| Size of Need | + | — | | + | + | + | + | Same | + | — |
| Desirability | + | + | | + | Same | + | — | Same | — | + |
| Technical Feasibility | Same | – | | — | + | S | — | Same | — | + |
| Technical Availability | Same | Same | | Same | + | S | + | + | Same | — |
| Business Model Feasibility | Same | — | Relaxing at Home | Same | + | – | + | Same | — | + |
| Business Model Availability | Same | Same | | – | + | – | Same | + | Same | – |
| Legal Risks | – | – | | + | + | – | + | + | – | – |

**Extracting Functions and Requirements from Scenarios.** The objective of Scenario Graph and Scenario Menu is to extract functions and requirements from scenarios so that the design team is able to generate solutions that address them effectively. By conducting in-depth observations, interviews, and immersing themselves in the scenarios selected from the previous step, the design team completed a list of essential functions for their mobile information system.

1. The system figures out which information the user needs.
2. The system figures out how to access the information.

3. The system figures out where the information resides.
4. The system identifies the relevant information.
5. The system retrieves the information.
6. The system understands, (interprets, analyzes) the information.
7. The system communicates information to the user.

The design team used these as morph keys to generate solutions while conducting morphological analysis.

Table 9 summarizes the outputs of the activities throughout the five months after the teaching team began the intervention. The final concept after the design team applied the *Scenario-based Design for Amorphous Systems* process was a system-oriented product called the "Butler." The "Butler" assists one's daily life by providing the right information, at the right time, at the right place, and to the right person. This offering includes service in which "Butler" coordinates and provides adaptive information to the users, based on their behavioral patterns and social networks. In other words, "Butler" co-generates information with the users. By going through iterations of scenario generations and selections, the team was able to identify a few main scenarios and to design a more system-oriented offering for potential customers.

The concept of the "Butler" shows the benefits of transitioning from a device-based thinking to a systems-oriented thinking by adding services. Since the "Butler" service would be offered through monthly or yearly contracts, its business model would insure stable revenue over a long term, developing, acquiring or partnering with network providers, database centers, contents providers, service providers, stores, etc. Over the long run, additional revenues would come from sales of interface devices, advertisement fees, technology licensing fees, sales of contents, and market analysis data. Thus, *Scenario-based Design for Amorphous Systems* succeeded in shifting from device-based thinking to system-oriented thinking.

**Table 9:** After using Scenario-based design for amorphous systems, the design team changed its focus from a hardware or software-based project to a system-based one. It conceptualized a system-oriented product, a personal "Butler" that provides customized information.

| Workshop | After using Scenario-based Design for Amorphous Systems | Scenario-based Design for Amorphous Systems Tools | Output |
|---|---|---|---|
| 2 (July) | Direction Setting | VOX Analysis | High-level Theme |
| 3 (Sep) | Scenario Generation | Scenario Graph | 100+ Scenarios |
| | Scenario Selection | Pugh | 3 Scenarios |
| | | Value Graph | Focused Theme |
| 4 (Oct) | Solution Generation | Morph | Solution Elements |
| | Solution Selection | Pugh | |
| | | Visualization | System Architecture |
| | Business Validation | NPV | NPV, Roadmap |
| | | Dynamic CVCA | Roadmap |
| 5 (Nov) | Prototyping | Storyboarding, Simulation, Faking | Final Presentation |

One challenge that the design team faced going through *Scenario-based Design for Amorphous Systems*, was the initial learning curve. In order to apply *Scenario-based Design for Amorphous Systems* methods, design teams took from 30 minutes to one hour to learn each of the main methods such as the Scenario Graph, the Pugh decision-matrix, the Value Graph, the Morphological Analysis, the NPV (net present value) Analysis, and the Dynamic CVCA. The teaching team provided each lecture according to the schedule in Table 9 and spread them over the course of the later four workshops. As a result of the delay, a few members of the design team were anxious about what to expect for the next step or about not being able to visualize the whole process in the beginning. Also the importance of iteration during the stages of generating and selecting scenarios and concepts was more apparent to the design team after it had gone through the process.

The scenario-based tools that contributed to breaking the mold of the device-based thinking were Scenario Graph, Dynamic CVCA, and simulation or prototyping skills. Scenario Graph helped the design team to expand its scope from just a device into a system, including services, then extracting elements from potential scenarios and guiding the design team into the functions and requirements domain. Dynamic CVCA helped the design team plan, visualize, and simulate a high-level roadmap of their business according to the risk-level. In other words, the design team was able to discuss possible partnerships with other companies, or timely investments in new technology or company. Details of this IT project and others will be documented in future publications.

## 4. Previous Approaches Using Scenarios

The literature on the use of scenarios in design is extensive. Carroll et al. found that scenarios are vehicles for communicating, envisioning concepts and extracting functions and requirements in the fields of human-computer interaction and software engineering (Carroll et al., 1995). However in the examples presented in Carroll et al., they mostly deal with detail-and-process oriented projects and used the scenarios for refining concepts rather than exploring potential markets in the early stage. Another shortcoming was that they did not devote much effort to integrating scenarios as a structured approach. They elucidated the potential of using scenarios in the development of computer systems and introduced case studies in which scenarios played a significant role in the product development process.

Erickson (1995) emphasized and explored the usefulness of using scenarios and stories as a communication tool between users and product designers but did not provide specific ways of using scenarios. He gave no explanations of how to address ambiguity at the level of problem definition.

Zachman Framework (1987) is a simple chart for organizing descriptive representations of an information system from multiple viewpoints. It provides a high-level checklist for documenting artifacts of an information system and defines the 6W's for categorizing data (What), function (How), network (where), people (Who), time (When), and motivation (Why). This ontology is adequate for the solution domain where the basic information of a system is already known but does not provide a method to formulate the undefined aspects of a system in the early design phase.

Beiter et al. (2006) explores the design of amorphous systems based on dfX methods but do not provide a bridge that connects the general scope to a specific project theme or application. They do cover ways to obtain the *Who, Why, What, How* but not the *Where and When.* Our *Scenario-based Design for Amorphous Systems* integrates scenario-based approaches into a mature dfX framework to effectively deal with the ambiguity during exploration stage of a new system development.

## 5. Conclusion and Future Directions

Today's products and processes invariably involve not only hardware and software, but also services, infrastructure, and policy, and they therefore are an amorphous system. 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. This paper has 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 has 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. More case studies as well as a validation of the method will follow in future research.

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