A Case Study Documenting Specific Configurations and Information Exchanges in Designer-Artifact-User Complex Systems

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1. Introduction

Previous work has identified a high level model of engineering design known as the Designer-Artifact-User (DAU) system, which has been shown to be a Complex Adaptive System. Within a DAU system, information is exchanged between designer-artifact, designer-user, and user-artifact. However, recognizing that these exchanges are not uniform, nor necessarily bi-directional, this paper presents a case study that has been done to identify specific configurations of the DAU system. The case study was conducted *a posteriori* through a study of a completed undergraduate mechanical engineering student design project. The original design goal, sponsored by a major automotive OEM, was to develop a new fixture for an assembly-line operation. The case study, following standard protocols, is used to identify and illustrate different DAU configurations. This paper also uses the findings of the case study to suggest which exchanges of information should be strengthened to enhance overall DAU system performance.

1.1 Frame of Reference

In previous work the authors have argued that the concept of complexity can aid engineers in understanding the behavior of complex engineering systems, as well as the design of such systems, and design in general. To study the complexity of design, we defined the complex system of interest as the Designer-Artifact-User (DAU) system (Figure 1), which we proceeded to demonstrate behaves according to the cycle proposed by Gell-Mann [1994] that describes Complex Adaptive Systems (CAS) in general [Maier and Fadel, 2006].

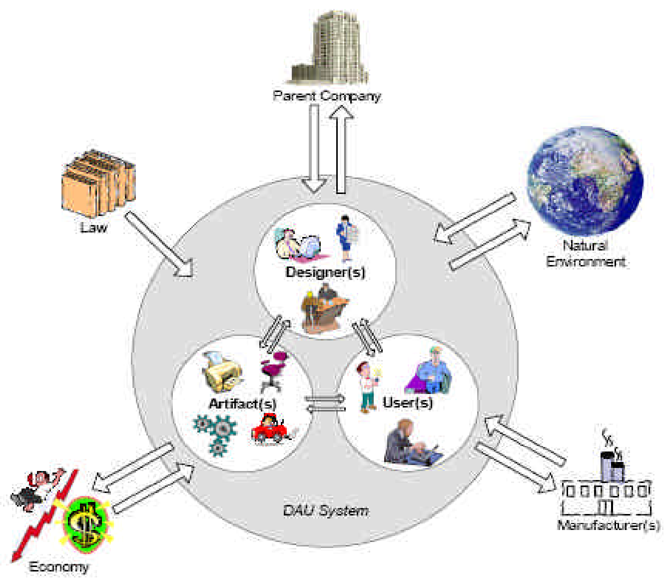


Figure 1. Generic DAU System

Gell-Mann identifies the cycle in which all CAS appear to operate [Gell-Mann 1994:25] as follows:

I. Coarse graining of the information from the real world
II. Identification of perceived regularities
III. Compression into a schema
IV. Variation of schemata
V. Use of schemata
VI. Consequence in the real world exerting selection pressures that affect the competition among schemata.

The identification of each stage in the CAS cycle with stages in a typical design process is relatively straightforward:

Coarse graining of information from the real world:
In a DAU system, coarse graining occurs in the problem definition stage of design. Here the designer's goal is to understand the problem at hand. This must be done by a process of "coarse graining," in other words a process of sampling, surveying, and gleaning information about the design problem from wherever possible in the real world.

Identification of perceived regularities:
In a DAU system, the identification of regularities occurs as designers further refine their understanding of the design problem by sorting out the initial data gathered in the coarse graining phase, which is often contradictory and/or incomplete.

Compression into schema:
After designers sufficiently understand the problem to continue design work, the broad design space available to the designers must be narrowed in order to arrive at solution concepts. Thus the CAS compression into schema phase is equivalent to the conceptual design phase in a DAU system (where the terms "schema" and "artifact concepts" essentially become interchangeable). This involves exploration of the design space using ideation techniques as well as combination and selection of concepts. The resulting schema is thus a full system solution concept.

Variation of schemata:
Once an initial system concept is found, the designer must improve, test, and refine that concept in order to arrive at a final production worthy artifact. Often this process requires extensive iteration of earlier phases of the design process. In other cases, the entire design project may be an exercise in variant design, where an artifact already exists, but the objective is to modify it to suit new circumstances. These design activities within a DAU system are thus equivalent to the variation of schemata phase in the CAS cycle.

Use of the schema:
In a DAU system, the schema is used when the artifact is released on the market as a finished product. In many systems, this first must be preceded by a manufacturing step. The schema may be used by a variety of users described by the DAU system's user subsystem, including people involved in any manufacturing process necessary, end users, maintenance and service personnel, etc.

Selection pressures that affect the competition among schemata:
In a DAU system, selection pressure is exerted from the outside environment. This pressure may come from the economy and changing user whims, which would feed back into the DAU system affecting choices and ideas for variant designs.

In this paper, we build upon the theoretical arguments put forward in our previous work (as summarized above) by studying the interactions within an actual DAU system. Following a case study protocol, we investigate the exchange of information between the designers, artifact, and users engaged in the design of an automotive component as part of a senior design class at Clemson University.

1.2. Case study research

Case studies are important tools used by researchers as a method for collecting qualitative data. They provide a structure to observe something ("an event, an activity, a process or one of more individuals" [Creswell, 2004]) within a context [Yin, 1984, 1993]. Case studies can take on several forms: they can be used as an explanatory tool, an exploratory method, or to arrive at some sort of description [Yin, 1984, 1993].

In this particular case study, the DAU relationship is examined over the course of a senior design project produced for the Clemson University Mechanical Engineering Department. The students are required to follow a relatively structured design process. They must also submit reports, updates, and meeting minutes. The completeness of the project documentation lends itself to later case study research, as is the subject of this paper.

Our research team has the added advantage of utilizing the Participant-Observation style of case study research [Yin, 1984]. Rather than having the researchers observe from without the project, one of the authors was an active member of the original design group. This observation from within provides us with several advantages including the ability to observe and perceive the situation from a more realistic viewpoint [Yin, 1984].

Yin is careful to point out that having someone both participating and observing may influence the other team members in an unpredictable and perhaps detrimental fashion [Yin, 1984]. However, in this case the researcher was first a participant in the design exercise, and then became a researcher in the topic only after the original project was concluded.

A clear purpose statement is necessary for any case study to provide focus and give notice of intent [Creswell, 2003]. The purpose statement for this case study is as follows:

> The purpose of this case study is to describe the manifestations of DAU relationships between the design team, the striker plate, and the automotive OEM in a senior design project. Furthermore, these relationships will be analyzed to determine how their structure affects the progression of the project, and recommendations will be made to foster greater success in future projects.

2. Case study: background

2.1. Course description

The ME 402 course at Clemson University is titled "Internship in Engineering Design," which indicates the emphasis on application of previously learned subjects in a real world manner. Students are placed on four person teams based on a short survey of interests and experience. The teams are assigned design projects in an industry setting. Students are expected to report project progress throughout the semester in both written and oral forms, both to the faculty and their industry sponsor. The team members are encouraged to keep detailed accounts of the progress throughout the project. Other deliverables include alternative conceptual designs, embodiment of at least two ideas, test plan, and prototype. The project groups were also asked to submit copies of email and written correspondence between team members, project advisor, and the industry point of contact [Course Guide, 2005].

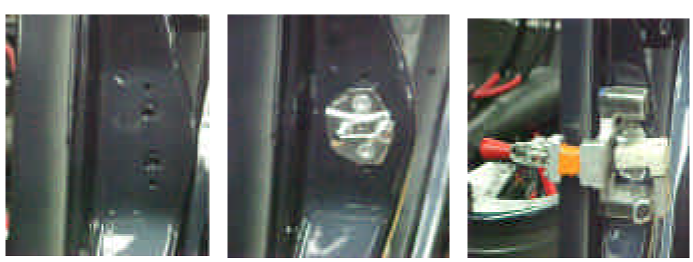
The project teams are encouraged to keep close contact with their advisor and the industry sponsor. They also have the opportunity to use a design "War Room" with dedicated computers for design work along with a graduate student staffing the room [Course Guide, 2005].

The students themselves are seniors in the mechanical engineering department with traditional class work in statics, dynamics, mathematics, thermodynamics, and mechanics of solids and fluids. The individual team members had experience in CAD based vehicle design, metal fabrication, and FEA analysis.

2.2. Project description

The project was presented to the design team as follows:

> [Automotive OEM] requires redesign of door striker fixtures for the front and rear doors of an in-production vehicle. Fixtures are used to position, location [sic], and hold doors in relative position during assembly processes. These are manufacturing fixtures that should improve the efficiency of the process and reduce the waste that occurs in the current process. Detailed design drawings will be delivered in addition to the requisite analysis with respect to tolerance design. [Course Guide, 2005]



(a) (b) (c)

Figure 2. (a) Pillar without striker, (b) Pillar with striker, (c) Pillar with fixture attached

The current method used by the automotive OEM for aligning the door striker plate begins by loosely installing the door striker plate to the specific pillar. The operator places the fixture onto the door striker plate, manually engaging the clamp which secures the fixture against the inside surface of the pillar (see Figure 2c above). The placement bolts are tightened to a specified torque and the fixture is removed.

The automotive OEM's major problems with the current fixture and process were as follows: The pinch points caused by the clamp, the force required to manually engage the clamp, the wear of the nylon and felt pieces from the friction produced by the direct contact with the metal surfaces, and the lack of differentiation between the front and rear pillars.

2.3. Case study protocol

In order to properly identify all DAU interactions in this specific ME 402 study, a strict protocol was followed. First, all necessary information regarding the ME 402 project was gathered and sorted based on the relevance of the material. Since it was required for the students that were involved in the project to keep a design notebook, it was very simple to gain specific information about their design experience and process. Furthermore, the participating students submitted electronic copies of all web based information and document revisions, including communications with product supply companies and communications between designers. An email account containing all customer communications was also disclosed for the study.

Specific design stages were identified to clearly delineate when the DAU relationships were occurring during the design process. The material provided by the design team (see below) were then examined for evidence of DAU relationships and where they correspond with the design stage. Saved emails, team correspondence recalled by group members, and the deliverable report itself provide evidence as to the nature of the DAU relationships.

2.4. Project documentation

The design notebook created by Automotive OEM Striker Group #2 was divided into the following sections: introduction, time table, executive summaries, meeting notes, meeting minutes, communication, revisions, and publications.

The sections that yielded the most important information regarding DAU interactions were the Time Tables, Executive Summaries, Meeting Notes, and Communications. The Gantt chart supplied in the Time Tables section described the design path used by the group and placed the events in chronological order giving a direction of flow to their work. The executive summaries located in the design notebook describe the group's weekly achievements and advances, and the executive summaries mirror the Gantt chart almost exactly. There were few areas in the design process in which the design team veered from the time allotted in the Gantt chart. The meeting notes portion of the notebook describes all of the actions that took place in a specific meeting. All of the documents are dated and signed for verification. The meeting notes yielded more information regarding the interaction between the design team than the executive summaries did. The documents are more in depth and far more descriptive when it comes to designer-designer interaction as well as designer-user interaction. The communication section of the notebook was simply a print out of all of the interactions between the design team and the customer company. The information from this section was limited because the printed correspondence was only between the design team and the company, and not vice versa. After inspection, it was determined that the communication with the customer almost completely stopped once the problem was defined. Since there is a large rift in the communications between the design team and a lack of communications between the designers, the electronic information was examined.

The electronic information gathered by the design team was submitted in the form of a CD. The disk contained all files that were used in the design process as well as all report and timesheet revisions. The information on the disk was not helpful for the identification of DAU interactions. However, the information gathered from the email account proved to be very useful. The account was set up to serve as a central hub for all emailed information. All correspondence between designers, customers or suppliers was required to be carbon copied to the team account so that the information would not be lost over the course of the semester. All of the design team members had access to the account. The information gathered from the email account filled in the gaps that were missing in the design notebook. It was determined that the interaction between the designers was much more prevalent than interaction between the design team and the customer.

3. Case study: results

The project information provided by the team was scoured examined for DAU relationships. In this case the designers are obviously the students working on the project, the artifact is the striker binder, and the user is the OEM. The OEM is classified as the user because they are the customer that the product is being designed for. The parent company would be Clemson University in this case, with manufacturing being handled in house. These results are presented as evidence of the nature of the DAU relationships. The results are organized into three phases of the project: problem definition, concept generation, concept selection, and detail design.

3.1. Problem definition

3.1.1. Expectations

This stage of the project should be dominated by the designer and user relationship because the designers are gathering as much information as possible about the problem. Very little time should be spent on the artifact itself.

3.1.2. Observations

The team met initially to review the design problem presented by the Clemson faculty and identify knowledge gaps that were expected to be bridged during a meeting with the automotive OEM representatives. The gaps were primarily related to the physical manifestation of the problem along with questions about the current system in place. It is important to note that the team established a single email account to facilitate communications and enable instant information dissemination. The single address provided a contact point for the OEM that each team member could access.

The group received a four slide presentation on the problem from the company. It included pictures and a description of the problem in general terms. This provided the group with a better understanding of the design issue and led to the development of four problem constraints including ergonomics, material needs, cycle time targets, and dimensional tolerances. It also led to a revision of the objective statement.

The team went to the OEM's facility to meet with company representatives. They had a list of questions to be answered and were given a tour of the facility. The conveyed information led to the development of a refined list of constraints and criteria. This new list was sent to the OEM for verification and approval.

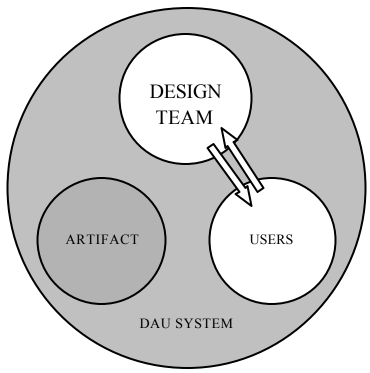


Figure 3. DAU system during early problem definition

Figure 3 shows the interaction between the design team and the users during the first stages of the problem definition stage. In this period the design team was collecting any information that was necessary in order to understand the fixture system. The diagram above demonstrates the even exchange of information between the design team and the user during the stage of problem definition.

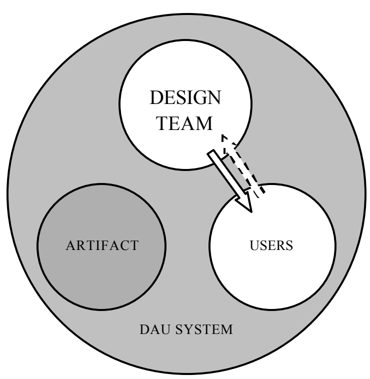


Figure 4. DAU system during the late stages of problem definition

Figure 4 illustrates the interaction between the design team and the user once the initial research has been completed. The design team gathered all information necessary to formulate the problem statement as well as a list of constraints and criteria. The gathered information was promptly given to the user for verification. Minimal response was necessary from the user in order to validate the problem statement and constraints and criteria. Since only a slight amount of information was returned to the design team, the interaction is pictured above using a dotted arrow.

3.1.3. Significance

Because of the unidirectional nature of the designer-user relationship, the project was stymied at an early stage. Mandatory weekly meeting between the design group and the OEM could have been established to head off this disconnect before the project even started.

3.2. Concept generation

3.2.1. Expectations

Because the design team is exploring the design space at this stage, they should not be interacting significantly with the user.

3.2.2. Observations

After the meeting with the OEM the team populated a morphological chart. The chart identifies specific sub-functions of the mechanism and provides room for possible means of performing these sub-functions. The team members populated the chart with means independent of how they affect the overall system function. The combination of these means produce possible problem solutions, and in this case the number of possible solutions was 4,800.

This process represents the first interaction between the designers and the artifact itself. Previous work was primarily focused on the manifestation of the problem, not the solution *per se*.

Other generation activities included quantifying attributes to aid in the selection process. Testing methods were developed individually to test issues related to the material selection, latch selection, striker holder design, and design modularity.

A house of quality was produced to relate the user wants with engineering attributes. The team also quantified the importance of the various characteristics. This represents a strong relationship between the designer and artifact which draws from the designer-user interactions.

Figure 5 shows the interaction between the design team and the user as well as the design them and the artifacts during the early period of concept generation. All of the interaction during this time is unidirectional from the design team to the user and the artifact.

An important aspect of this stage is the absence of communication between the designers and users. The OEM had not approved the problem statement, constraints, and criteria that the design group sent to them. This is a relevant issue because while the designers may be able to proceed with the process, the confidence in their work can be undermined by the possibility that the user will demand significant changes to the constraints and/or criteria.

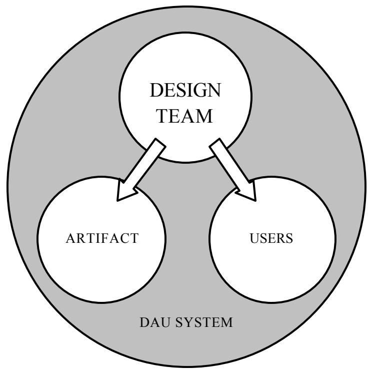


Figure 5. DAU system during concept generation

Essentially, the designers are apprehensive about proceeding without approval. The team finally decided that they should assume that the list received the OEM's approval and that they should continue with the project. This situation represents a serious breakdown in the designer-user relationship which actually should be taking place in the Problem Definition stage. It provides an interesting example of how the designer-user relationship has an impact on the designer-artifact connection.

The absence of communication also affected the design process because the designers were not able to get material support from the user. Specifically, the designers decided that they needed a sample door frame to aid in the process. The team had to resort to cutting the B-pillar out of a vehicle with similar geometric attributes to use as a model. This displays how the breakdown between the user and designers led to a degradation of the designer-artifact relationship.

The eighth weekly progress report indicates that the OEM's representative finally contacted the team and approved the constraints and criteria with only minor changes.

Figure 6 demonstrates the interaction between the design team and the artifacts and the users after OEM contacted the team and confirmed the constraints and criteria. This communication allowed the design team to begin to analyze major variations in the different design options. The addition of a small amount of information to the system allowed the design process to speed up and enter the next stage of design.

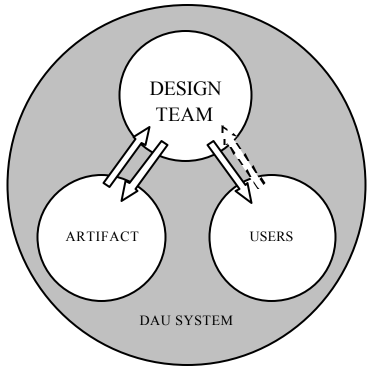


Figure 6. DAU system after contact

3.2.3. Significance

While regular interaction with the user is not necessary at this stage, the design group found that the infrequent requests for material went unnoticed. The team found that to generate concepts more effectively certain dimensions and geometries needed to be known. Even though a weekly meeting between the designers and users would not be an effective use of time, open communication channels must be present.

3.3. Concept selection

3.3.1. Expectations

Again, the designer-artifact relationship should be the most significant exchange in this stage.

3.3.2. Observations

The team generated seven solutions for the door striker plate problem and reduced them to the five most promising. The team then utilized a decision matrix to determine which options stood out according to the criteria. The matrix includes weighting the criteria and determining how well each design addresses that particular criterion. What is particularly interesting in this stage of the process is the relative importance of the activity and the complete lack of input from the user, either in relation to the designers or the artifact.

Figure 7 represents the interaction between the design team and the artifact(s) during the concept selection and concept expansion stages of the design process. The transfer of information during these two stages is exclusive to the design team and the artifacts. Little interaction is seen between the design team and the user and no interaction between the artifact and the user was observed.

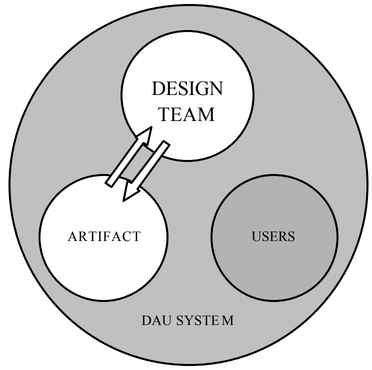


Figure 7. DAU system during concept selection

3.3.3. Significance

This stage indicated a manifestation of the DAU model to be almost identical to that which was expected. The project encountered fewer setbacks during this stage, signifying that the adherence to the original model promotes an effective design process.

3.4. Detail design

3.4.1. Expectations

The designers should be primarily focused on the artifact with little input from the user because the process involves expanding and refining their chosen concept.

3.4.2. Observations

The development of the Failure Mode and Effects Analysis (FMEA) does not draw as heavily on the designer-user relationship. In fact, it represents a very strong artifact-designer bond because the group members need to address the artifact according to its physical attributes, rather than in abstract characteristics. In addition, the students used the results of the FMEA analysis to carry out a stress and strain failure analysis at the critical points of the design. Upon completion of the stress and strain tests, a fatigue study was conducted to determine whether the design will resist fatigue over time. These three studies demonstrate a strong interaction between the design team and the artifact during this stage of design, as seen in Figure 8.

Absolutely no interaction was identified between the design team and the user or the artifact and the user, showing that the interaction in this phase of the design process is exclusive to the design team and the artifact.

3.4.3. Significance

Again, this design stage paralleled the expected DAU model and once more the process continued in a more efficient manner than those identified in the early stages.

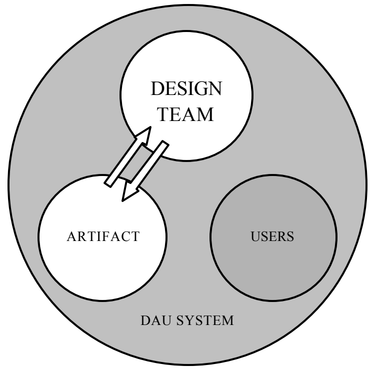


Figure 8. DAU system during detail design.

4. Summary remarks

The data indicate that the DAU model provides design groups with a reasonable model of interaction between the design group, the customer, and the object itself. Diversion away from the model led to ineffective group dynamics and an overall reduction in productivity in this case. Since the designers are a subsystem of a larger system, their productivity can be related to the DAU output (production level, quality, economic stability). Conversely, the stages that adhered to the model more closely progress in a smoother manner with fewer setbacks experienced by the design group. This case study shows that the DAU model is indeed a complex adaptive system which has at least some level of predictability. This leads to the idea that the design process structure itself can be improved through fostering more effective communication modes.

The future ME 402 class could benefit substantially by conforming the course structure to reflect the DAU model and give the student groups a more efficient configuration. Furthermore, these findings can be applied to other senior design project that have the same objectives that ME 402 has at Clemson University. Other universities that are emphasizing closer contacts with local industry can utilize this case study. While the senior design project can have vast differences with the project structure found in professional engineering settings, there are significant parallels with the undergraduate work. Future case studies could be conducted on design groups in industry along with the studies performed to observe the effectiveness of explicitly including the DAU model in undergraduate institutions.

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