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1 Introduction

This summary is the result of observing project meetings for the redesign and seismic upgrade of an existing facility to house Systemix's bio-chemical facility. Specifically we focused on the communication among design team members through the conceptual, schematic, and design development phases. The purpose of this experiment is to identify problems in communication and notification of design changes and information exchanges.

The information required to perform design can be broadly classified into three categories: (i) Domain specific, (ii) Experiential, and (iii) Project specific. Each of the three categories contain both existing and generated information. The latter may be either generated by each professional in her/his [1] design process or is generated as a result of interaction among design team members. Existing information is represented in the form of codes, design standards, previous similar cases, and equipment availability. The program book is a special kind of information defining the client's requirements and specifications of the facility. This

[1] In the rest of this report only he is used to represent the design team member.

information is used by all the consultants to guide their design process. Section 2 of this report categorizes the problems observed. Some of the problems are inherent to the design process currently adopted, while others are unique to the observed design scenario. The final section is an attempt to estimate the impact of the problems presented in Section 2. It must be noted that the consultants are aware of the existence of most of these problems and work towards reducing their occurrence and in mitigating their effects. Estimation of the impact of these problems and suggested preliminary and long-term approaches to addressing them are presented in Section 3.

2 Communication and Notification Problems

Communication in design is essentially a process of negotiation among the design team members. The issues of negotiation regard the features of the facility being designed, such as, space, dimensions, features, equipment - type, specification and arrangement, parts, layout, penetration, sensitivity to heat, lighting, and ventilation, insulation, vibration, loading safety, and fire proofing.

The rest of this section addresses problems observed in the current communication process. We identify three categories of problems: (i) Information transfer problems, (ii) Understanding design intent problems, and (iii) Storage problems.

2.1 Information Transfer Problems

Information transfer problems are caused by:

1. **Incompatibility of format of notification.** Graphical data is currently representation in the form of CAD drawings (blue prints). The standard medium of communication used by all the team members to transfer the results of their design is through floppies containing the formated CAD drawings. This form of information transfer may cause a communication mismatch due to the incompatibility between the formats of the graphical data specified by the different CAD software (and associated hardware). Each designer is required to reinterpret the information contained in order to use it. For example, the exchanged AUTOCAD files were incompatible as the versions of the software used by the architect and the mechanical engineering consulting firms were different.

2. **Delay in Notification among design team members working concurrently.** This situation occurs when a design team member is solely responsible for a particular decision. His decision however affects the design in other domains. Although the team member is aware of the effects of his decision he delays its communication. For example, the mechanical engineer is provided with the architectural changes (on a floppy disk) after he has proceeded with the design of the ducting based on an earlier layout. To make his design compatible with the current version of the architectural layout, the mechanical engineer needs to overlay the duct design on top of the new architectural plan. This requires reinterpretation of the latest version of the architectural plan, and identification of the inconsistencies between the changed architectural plan and his ducting design. Another example was a situation in which the electrical consultant swapped the location of the transformers between two adjacent spaces. Later in the design process, the architect observed that this decision of the electrical engineer affected the mechanical design due to a reduction in the mechanical shaft dimensions.

In a private communication, the mechanical engineer mentioned that it is fairly typical to detect errors at the construction stage and for quick-fix solutions to be proposed at that time.

3. **Missing information.** This involves situations in which a design team member lacks relevant information at the time of his design. The following cases are instances of this scenario:

   (a) *Information is unavailable because a design decision has not been taken.* For instance, the contractor requested the specifications for the doors in the facility to issue the relevant sub-contracts. However, these specifications were not available at that time, as the design team had not discussed the required fireproofing specifications that the doors needed to satisfy.

   (b) *Information is unavailable to the particular design team member although the consultant generating this information has already taken the relevant decisions.* This information may be obtained upon request by the consultant requiring the data. The physical media of data request and transfer include FAX messages, phone calls or secondary meetings between the parties involved. For example, the structural consultant required the specifications of the mechanical equipment to determine the design loading for which he had to design the slab.

   (c) *Information is unavailable because of a change in the design team.* For instance, a design team member responsible for some information is no longer associated with the project (e.g., an architectural team member was moved to another project early in the schematic phase and was therefore unavailable to provide certain

information).

4. **Misplaced information.** FAX messages, meeting minutes, and telephonic conversations are volatile media of data storage and can be easily misplaced. An interesting episode illustrates the loss of information during transfer: A floppy containing the electrical equipment matrix was sent to the architectural firm but was misplaced within the firm. The architect feared that the floppy was incorrectly classified and may have been formated again for reuse. Although this was an extreme and isolated occurrence of data loss, this raises the following issues: (i) the volume of data that is communicated (transferred) among the design team members, (ii) the identification and classification of this transferred data both at the source as well as the destination of the communication. The cause of the above problem of data loss through mis-handling of the floppy may due to various reasons, such as: (i) incorrect labeling of the floppy by the electrical engineering firm (source of the information), (ii) wrong interpretation and lack of identification of relevancy of the data at the architectural firm (the destination).

2.2 Understanding Design Intent Problems

An explanation may be requested when there are differences in the understanding of the same issue by each design team member or mis-understanding a design decision. The need for explanation of design intent arises when:

1. A design team member understands how his decision might affect the other design domains but may want to double check that it is understood by others. For instance, the architect made an innovative design decision represented by a corridor lighting feature in the form of a skylight. He requested the mechanical and electrical consultants

to analyze this architectural feature and to provide a feasibility evaluation.

2. A design team member is uncertain how his decision affects others and may request their input in trying to understand the ramifications of his decision. For example, the electrical consultant described her design of the lighting facilities for a laboratory with the intention of getting other consultants to analyze the effects of her design on their domains.

3. A design team member may be requested for an explanation of the rationale behind his decision although he may be unaware of any critical effects on other domains. During our observations the mechanical engineer was requested to justify his decision to select stainless steel fume hoods for radioactive waste.

We observed the design consultants to employ different ways to express their ideas, such as: verbal explanations, partial sketches on the blackboard, overlays and markings on blue prints, and tabulation of equipment specification.

2.3 Storage Problems

This class of problems is associated with the physical storage of data or incompleteness of data. Observed cases are:

1. **Lost versions.** Data is added incrementally throughout the design process. As the design progresses previous versions are deleted. However, in certain design situations the consultants may wish to backtrack earlier configurations which may now have to be reconstructed.

2. **Missing justifications.** The rationale and justifications behind design decisions are not stored. Only the resulting configuration is stored. A consultant may have to re-

evaluate an earlier decision in the light of later changes. However, the consultant may fail to recollect the reasons for his earlier decisions.

3. **Reconstruction of justifications.** An extension of the above scenario occurs when the design team is requested to justify an escalated project estimate of the design to the client. The project has to be cleared by the Palo Alto City Council which may question certain features of the configuration and verify that the safety requirements have been met. Both justifications require explication of the underlying assumptions made during the design process. As these assumptions and justifications are not stored, a lot of effort needs to be invested in recreating them.

3 Discussion of the Impact of Observed Problems and Proposed Approaches

This section summarizes the impact of the problems described in the previous section and presents both preliminary and long-term approaches to address the stated problems. It must be emphasized that the consultants are aware of most of the problems and take steps to minize their occurrences and impact.

3.1 Information Transfer

3.1.1 Incompatibility of format of notification

Problem Statement: Incompatibility of different software tools as well as between different versions of the same software (including current versions that run on different platforms).
Impact: Data is available but cannot be directly used by the different consultants in the format it has been created, i.e., the data needs to be reinterpreted from the original data file for the new platform.

Preliminary Approach: For each situation, an ad-hoc reinterpretation of the transferred data-files is performed.

Long-term Approach: This is a very serious problem confronting the software industry, and is being addressed at two levels: (i) at the software level, and (ii) at the data model level. Software vendors are trying to solve the problem of incompatibility among software tools. Developing standard data models for representation and transfer of data (the PDES / STEP initiative) represent long - term efforts for the industry.

3.1.2 Notification Delays

Problem Statement: Delay in notifying other design consultants of changes made to the design in a specific domain.

Impact: The impact of this class of problems is severe and difficult to handle. The cause of this problem is the inconsistency among the different versions of the plan used by the different consultants in each design step. Merging versions and detecting changes among versions is a non-trivial task.

Preliminary Approach: Currently, notifications among consultants are performed on the basis of individual cases. This is done at consultant meetings, as well as through private communications through FAX and telephonic messages. However, there does not exist a methodology that ensures that all changes that may be relevant are made available to the appropriate consultants at an early stage for the concerned consultants to incorporate it in their design, or to critique the change. The consultants are aware of this problem and try to minimize it. The ad-hoc notification process is based on the consultants' awareness and ability to envision the possible interactions. At times, these interactions may not be obvious and may be initially overlooked.

Long-term Approach: The long-term approach has to explore the automation of the process of change management and standardizing the protocols of communication among the different agents.

3.1.3 Missing Information

Problem Statement: Lack of relevant information from a different design domain at the time of decision making.

Impact: The designer is aware of the information needed from some other domain but does not have access to that information at the time he makes design decisions.

Preliminary Approach: The designer is aware of the consultant who generates the needed information and sends ad-hoc requests for that information. The request and actual data transfer is through phones calls, and FAX messages.

Long-term Approach: This class of problems raises the issue of real-time transfer of data and communication of design decisions. The use of networking facilities to transfer data need to be explored (as opposed to transfer of CAD drawings by means of floppies).

3.1.4 Misplaced Information

Problem Statement: Data loss by misplacing the volatile media (floppy disks) that store the data that is being transferred.

Impact: The isolated occurrence of data loss that occurred brings out the limitations of the current techniques of data handling and management. The ad-hoc nature and volatility of FAX messages to notify other design consultants of design decisions and the mailing of floppies to circulate the latest version of the facility configuration raise the following issues: (i) difficulty in labeling at the source, (ii) difficulty in classifying, managing, and querying

the data at the destination. Another important problem is the lack of a standard protocol for verification of data transfer, i.e., verifying whether data sent from a consultant was actually received by the person to whom it was directed. Such data loss in communication is critical and puts pressure on the consultants to be cautious about loss of critical information.

Preliminary Approach: Develop a standardized labelling scheme for sorting and handling data transfer (floppies, letters, minutes etc) to better classify the transferred data.

Long-term Approach: The long term approach is to develop a reliable system for data transfer, change notification and to develop protocols for receipt of data.

3.2 Understanding Design Intent

3.2.1 Explanation of Design Intent

Problem Statement: Lack of understanding of design decisions made by other consultants and the effect of those decisions on the design of a particular consultant.

Impact: Misunderstanding of design intents of the different design team members and conflicts among their design decisions.

Preliminary Approach: The design consultants use sketches on the blackboard, overlays on the plan, verbal explanation, notes in the meeting minutes, and tables representing the equipment matrix to explain and justify their design intents behind their design decisions. Meetings among the design team members provide the forum for the consultants to explain their design rationale and are particularly important in the preliminary design phase.

Long-term Approach: The long term approach is to develop explanation tools to aid the consultants to express their design intent and decisions.

3.3 Storage

3.3.1 Lost Versions

Problem Statement: Deletion of earlier versions of the design.

Impact: In the design process, data is updated incrementally. During the design process a consultant may wish to go back to an earlier configuration. Deletion of earlier versions would require reconstruction of that configuration.

Preliminary Approach: Maintain key versions at least until the completion of the project.

Long-Term Approach: The long term approach is to develop schemes to manage multiple versions. The issues that need to be addressed are: (i) labeling versions correctly, (ii) identifying differences between two different versions, and (iii) retrieving archived versions in real-time.

3.3.2 Missing Justifications

Problem Statement: Lack of documenting design rationale and justifications for design decisions.

Impact: The consultants need to justify certain design decisions both during the designing phase as well as at the time of obtaining approvals for the completed design. Since the justifications and design rationale are not explicitly stored, the design team members are forced to reconstruct justifications for earlier decisions.

Preliminary Approach: Notes may be kept to store justifications of certain important decisions. The notes on the meeting minutes record some design rationale.

Long-term Approach: The long term approach is to develop a grammar to effectively record justifications.