A PROCESS MODEL OF EXPERTISE IN THE DESIGN OF WAREHOUSING AND DISTRIBUTION SYSTEMS

NATALIE F. ZERANGUE, DOUGLAS A. BODNER, T. GOVINDARAJ, KARTHIK N. KARATHUR, LEON F. MCGINNIS, MARC GOETSCHALCKX, AND GUNTER P. SHARP

Center for Human-Machine Systems Research and Keck Virtual Factory Laboratory
School of Industrial and Systems Engineering
Georgia Institute of Technology, Atlanta, GA, USA 30332
t.govindaraj@ieee.org

Abstract

An ideal warehousing and distribution system has no inventory and operates with minimal handling. In an attempt to achieve this ideal, expert designers rely on their intuition, together with analytical models and procedures formalized over years of experience. Understanding the processes that experts employ to realize their designs can have great benefits, for instance, in developing computational tools to assist in design. We have conducted an ethnographic study of an expert design team during actual system design. In this paper, we describe our observations and a process model of design.

Keywords

Warehousing, distribution systems, expert model, ethnographic studies, industrial logistics, design.

1 Introduction and Background

Warehousing and distribution centers are key components of supply chains. Although they provide storage, additional product or 'value-added' services such as labeling and packaging, and movement of product from one location to another, an ideal system would require minimal storage and move products while simultaneously offering rapid response time and product customization. Warehouse designers routinely encounter many challenges as they strive to develop ideal systems and configurations.

The design of warehousing and distribution systems has long been a research area in the field of industrial engineering. Researchers have developed an assortment of analytical models to improve the practice of design in these areas. However, this research and actual design practice have little in common. Designers seldom benefit from or employ the results of the research, and researchers do not seem to be developing models or methods usable in contemporary design practice.

Our studies of expertise and design reported in this paper provide a foundation for understanding the actual design process. Designers gain expertise in their domains through experience, and expert design is more often an intuitive art than a formal, rationalized, or rigorous process. While expertise plays an important role in design, the design process is difficult to define. Resulting from long periods of experience working on a variety of design problems, expertise is implicit in the decisions and actions carried out by the designers during the iterative design process. General design models provide insight about the essential high-level steps in the design process, but even a design model within a particular domain cannot provide a 'recipe' or specific steps to follow to reach a solution for *any* project in that domain.

In this paper, we describe research towards formalizing the warehouse design process used in industry, in an effort to bridge the disconnection between industrial engineering research and actual warehouse design practice. The first step is to develop a process model of design based on an ethnographic study of expert designers, by observing and documenting events and techniques as they occur during actual design exercises. Such a study can offer valuable insights into the relationship between expertise, design, and actual practice. Although it is unrealistic to expect that a general warehouse design model could be applied to all design problems, a process model *can* provide a basis for the development of computational tools to be used by expert designers. To provide the overall context, we begin with a general background on characterizing expertise and warehousing and distribution systems.

2 Expertise and design of warehousing and distribution systems

As a designer gains experience by solving problems in a domain over a period of time, and assimilates the experience into knowledge, the resourcefulness and confidence in solving new design problems improve steadily. Expertise is knowledge that broadens and changes as a result of increasing experience, which comes only through individual practice and on-the-job training. In addition to expert knowledge, implicit knowledge displaying itself in judgment and working skills is also essential to engineering design [20]. Green [9] also identifies traits possessed by experts in routine design environments: supplying context, decision ordering, parameter abstraction, and heuristic classification.

The thought processes of experts are difficult to capture due to the presence of intuition in expert decision-making. Intuition is related directly to creativity and is separated from reasoning, which is more rule-based [11]. Regardless of the reasons, a difference often exists between what experts do and what they say they do [18].

Separate from studies of design and expertise, researchers have extensively investigated individual warehousing topics. These subjects cover a wide range of topics and include material handling systems ([1], [8]), storage policies ([3], [15]), facility layout and location ([13], [4], [6]) and order picking ([10], [17], [7], [19]). However, in general, research studying actual design practice is very limited compared to research on general problem solving tasks and on design in laboratory environments [9].

In a comprehensive review article, Rouwenhorst et al. [16] discuss warehouse design, as well as redesign, and offer a structure for internal operations and configurations. After characterizing warehouses, the authors examine issues such as performance criteria, typical design concerns, necessary decisions, and design constraints. While supporting the benefits of current research, they also state that most papers analytically investigate well-defined problems in isolation from other warehouse issues. They emphasize the need for combined models and techniques to develop a complete warehouse design approach, which is consistent with the philosophy at Georgia Tech.

Past research provides information and insight about warehousing issues and current model capabilities, but there continues to be a disconnection between the analytical models and actual design practice. As a result, a need exists in these research areas for computational tools established on a solid scientific basis to assist designers. An understanding of the design process, based on an ethnographic study of experts during actual designs, can provide a key component of this scientific basis.

3 An Ethnographic Study of Designers

Formalizing the warehouse design process is a difficult task since each design problem is unique, every designer analyzes and makes decisions differently, and designers cannot observe their own actions objectively and report them for incorporation into models. Rather than having designers document their own techniques, an ethnographic study by outside observers can document the process more accurately in sufficient detail. The purpose of ethnography is to participate in and record initially unfamiliar experiences by becoming immersed in other people's worlds [5]. Specifically in work environments, ethnographers examine aspects such as the social features of work and judgments, the use of local knowledge, and awareness of other people's activities. Although ethnography can be used as simply an information study, it is especially useful in accurately displaying situations for the purpose of assistance, problem discovery, and improvements [2]. An ethnographic study of designers was chosen for these reasons.

Warehouse design can either be a redesign of an existing facility or design of a new facility, known as Greenfield design. A redesign may be alterations within, or an expansion beyond, the current facility. The case study described here covers the redesign of an apparel warehouse and distribution center. The top-level tasks of the designers were to determine the maximum capacity of the existing facility and to make modifications to the current facility and operation in order to meet the projected volume in inventory. The forecast was that the inventory quantity would double within five years, and the designers needed to understand the current operation and the impact of the volume increase on operation. Depending on the capacity of the existing facility, the designers were to recommend whether the company should continue operating in the same facility, expand the facility, or use a new facility.

After the designers were notified of the project, they began to gather basic information and to determine the project objective. They performed operation comparisons and collected details concerning the company's business, activity rate, and return on investment figures. Visits to the client site allowed the designers to meet with the project contact and other operational decision-makers, and to gather critical visual data about the current warehouse operations as well as general contextual information.

With limited information in the case study's initial stages, the designers analyzed many topics concerning operational efficiency and throughput. Certain visual aids were prepared, such as a facility layout diagram indicating positions and sizes of each activity area, and a seasonality chart providing the product seasonality of the client's operation. At this point, the designers submitted a written proposal and presented the proposal content to the client group, which included introductory information and outlines of potential design solutions.

The designers submitted an extensive data request and then performed specific analyses with the client's data files, primarily the product and order data files. Following both data and data file analysis, the designers met with the client group and developed the top design recommendation areas. After sufficiently investigating the alternatives and determining improvements to match the client's objectives, the designers formalized their improvement plan, presented it to the client group, and prepared for implementation after plan approval.

The designers' expertise was of great benefit throughout the design project, as we observed during our case study. Their working knowledge of warehouses and distributing systems was comprehensive, and allowed them to compare the current project to past projects and to industry standards, understand the potential difficulties of the operation and future changes, and intuitively and actively pursue the areas with the highest improvement potential.

Providing a perspective of the general design process for both redesign and design, the designers discussed a Greenfield design approach for both the case study and new facility design projects. Based primarily on these discussions, it appears that the key difference between design and redesign is that Greenfield design projects have fewer constraints, thus providing designers with increased freedom throughout the process. The other important differences are not in the sequence of activities followed during the design process, but instead concern information and observations. For new facilities, data files might not be available, and facility data might be mostly speculative and not based on actual operation. Designers cannot gather visual information by visiting an operating client site, touring activity areas, and observing current processes and conditions. As a result, designers follow more rule-based procedures for analyzing known data and generating potential alternatives, and then they use experiential knowledge to evaluate the feasibility and benefits of alternatives.

4 A Process Model of Design

Based on literature research and the results of the case study, a general design activity sequence began to emerge. The sequence demonstrates a pattern of activities that occurs multiple times throughout the full design process, once for each work product. A work product is a high-level result of the design process that is necessary to continue moving forward in, or to complete, the process. The work products of the case study, and therefore of the following warehouse design process model, are the proposal, top alternative areas, and final decision. The activity sequence, including the manifestations of expertise and iteration between steps, is shown in Figure 1.

In the warehouse design activity sequence, designers receive information from various sources that are data collections, client and colleague interactions, and facility observations. They transform this information into clear requirements, constraints, and objectives for the design project. Once designers determine an initial problem definition, they perform information analysis and generate alternatives. These three steps are iterative since developments in one may change another, such as analysis results that redefine constraints. After alternative generation, designers evaluate alternatives, select a combination of alternatives, and perform detailed analysis for the final recommendation. Expertise influences all stages of the activity sequence, and designers repeat the sequence multiple times to complete all the work products.

Designers consider and act at different levels of detail within the work product activity sequence since a warehousing system has various levels of activities and objectives. At its most abstract level, a warehousing system has the goals of being a successful business and generating a profit, and it attempts to achieve these goals by satisfying its customers and by running an efficient operation. Designers typically have higher-level considerations, such as the current and desired customer service levels and operational efficiency, at the beginning of the activity sequence during the data collection and problem definition stages. At the lowest level of abstraction in a warehousing system are the details of the operation, such as the equipment, product cases, and so forth. As designers move through the activity sequence, they perform at a less abstract level since they tend to focus on details of all topics relevant to the project and determine specific ways to fulfill the goals.

The activity sequence, then, is a general series of events, progressively less abstract concerning the warehousing system, leading to a work product. The warehouse design process model is a more detailed explanation of the expert design method from project notification to final recommendation and includes all work products. The process model is based on the case study, and it is an attempt to incorporate data, analysis, alternatives, decision-making, and most of all, the order in which activities take place and the knowledge used for those activities. Figure 2 shows a rough division of the process model steps.

Although difficult, the design intent is to have a generic model with examples from the case study for emphasis and clarity. Admittedly, the process is difficult to model since the steps are not separated so distinctly from each other, in many cases may be iterative, are ambiguous regarding detailed investigations and solutions, and may be difficult to follow for novice designers. Although a framework cannot completely define the process, this is an effort to understand the type of knowledge used, analytical methods applied, and general process followed in expert warehouse design.

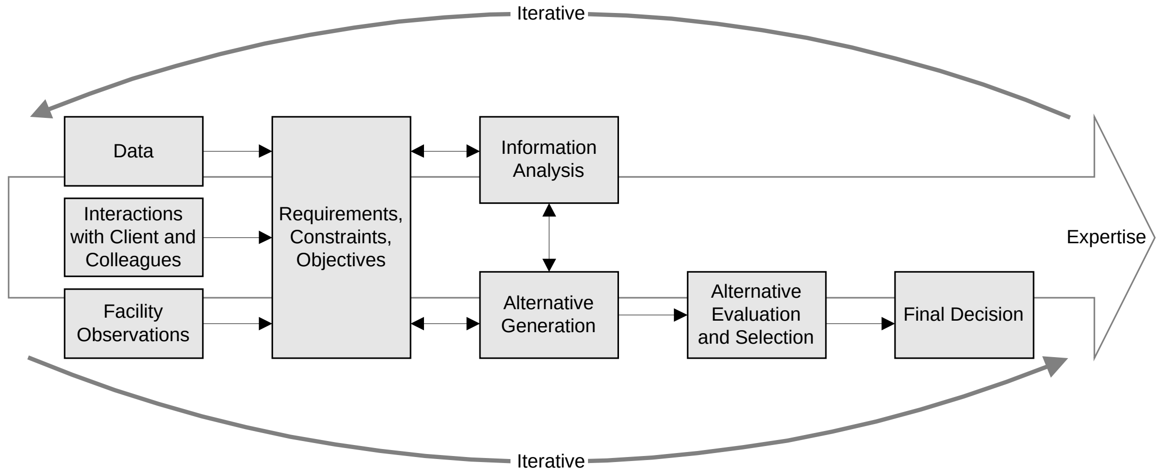

Figure 1: Work Product Activity Sequence.

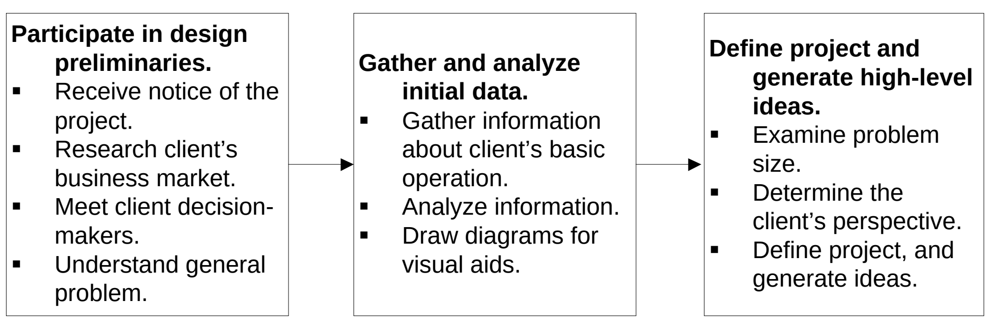

Figure 2a: Process Model Initial Stages.

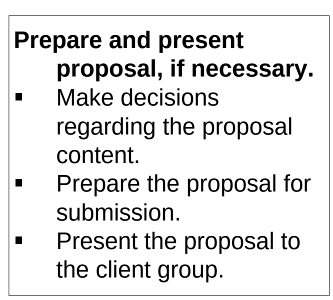

Figure 2b: Process Model Proposal Steps.

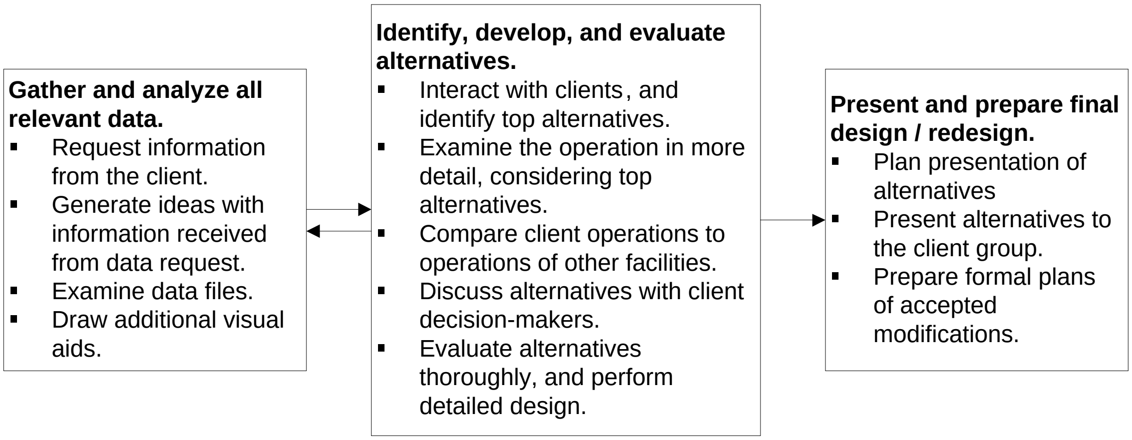

Figure 2c: Process Model Detail Stages

5 Discussion and Future Work

The formal preparation of the modifications accepted by the client marks the end of the design process observed in the case study. In actual practice, a designer may lend implementation support to the client. The process steps in our model follow the general design process from the initial notification of the project through project definition, detailed information gathering and analysis, alternative generation and evaluation, and communication of final results to the client. Many steps demonstrate the importance of expertise in the process. This is especially evident in this case study, since it was not a "standard" design problem. In more standard situations, designers can seek to perform these knowledge-based steps without much expertise, rather relying on a methodology developed within their organization (e.g., Systematic Layout Planning [12]). When a problem is not straight-forward, having the proper expertise is helpful for arriving at good design solutions and in achieving them more quickly, easily, and intuitively [14].

In order to reach solutions, we believe that designers follow a process model, which iterates through a work product activity sequence similar to that illustrated in Figure 1. The process model in Figure 2 demonstrates the flow through the activity sequence for each work product, and the work products in the warehouse design process model are the proposal, top alternative areas for improvements, and final design. More complete details of the model are discussed in [21].

An important goal of documenting a process model is to ascertain the needs of expert warehouse designers in terms of a computational aid. Currently, the needs for the tool are primarily based on the needs of the designers in the case study. As a result of the limited data, the scope and applicability of this research may be somewhat narrow. However, additional case studies will follow, and each case study will broaden the process model and its domain of applications. The primary targets of this research are methodologies and associated computational tools providing information and serving analysis needs of multiple designers and analysts. The process model presented here supplies guidance toward building such tools. In addition, other existing warehouse design aids are being investigated with the goal of integrating them as appropriate into a full suite of design tools.

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